UNITED STATES DISTRICT COURT
SOUTHERN DISTRICT OF NEW YORK

Metrom Rail, LLC Plaintiff, v. Siemens Mobility, Inc. and Humatics Corp. Defendants.	No. 1:23-cv-03057-MKV **DEMAND FOR JURY TRIAL**

SECOND AMENDED COMPLAINT

Metrom Rail, LLC ("Metrom") alleges the following:

SUBJECT MATTER JURISDICTION

1. This action arises, in part, under the patent laws of the United States, Title 35 of the United States Code. This court has subject matter jurisdiction under 28 U.S.C. §§ 1331, 1332, 1338, and 1367.

PERSONAL JURISDICTION

2. Defendants Siemens Mobility, Inc. ("Siemens") and Humatics Corp. ("Humatics") are Delaware corporations doing substantial business in New York and have also consented to personal jurisdiction in the Southern District of New York by agreeing to transfer to this venue from the District of Delaware.

VENUE

3. Venue is proper under 28 U.S.C. Sections 1391(b)-(d) and 1400(b). Defendants have also agreed to this venue by agreeing to transfer to this district from the District of Delaware.

4. Joinder of the Defendants in this action is proper under 35 U.S.C. § 299 because the claims herein arise from a common nucleus of operative facts related to the same transaction or series of transactions, and joinder is not based soley on allegations that all defendants infringe the same patent.

5. This case is related to Case No. 1:23-cv-02920-DLC, which is co-pending in this district. In that case, Piper Networks, Inc. ("Piper") and Thales Transport & Security, Inc. ("Thales" , also known as "Ground Transport Systems" or "GTS") are accused of infringing some or all of the same patents, including by participating in the same project, as in this case. Piper and Thales were originally joined in the same case but severed by the Delaware court.

BACKGROUND

6. Metrom Rail, LLC ("Metrom") is a pioneer in the area of decentralized train control with Ultra Wide Band ("UWB") technology. Founded in 2010, Metrom is an Illinois Corporation with a headquarters in Lakemoor, Illinois.

7. Railroad equipment is heavy and can travel at speeds over 80 miles per hour while pulling railcars filled with people and/or goods. While generally very safe, accidents do happen. And, because of the sheer size and speed at which trains can travel, the results of an accident can be devastating.

8. Metrom has developed the innovative "AURA" system and other worker and railway equipment protection products using UWB for new and existing rail systems. Metrom's products are designed, built, and tested in Illinois.

9. Historically, railroads have implemented complex and expensive systems to avoid accidents. Despite these systems, accidents still occur, and the traditional suppliers of signal systems have not fielded low cost, reliable train control systems for precisely locating and controlling commuter trains in high traffic, urban rail environments.

10. In 2012, Metrom introduced its first AURA brand product and the first commercially successful application of UWB in the railroad environment, a collision avoidance system for railroad maintenance of way ("MOW") vehicles.

11. Railroad MOW equipment is especially susceptible to collisions because the equipment tends to operate in groups of small but independently powered and operated vehicles in "work trains" with close spacing. Work trains may constitute, for example, a series of machines for performing different kinds of

maintenance on the rail bed, cross ties, and rails. Collisions are surprisingly frequent, since workers are focused on their maintenance work, sightlines on the equipment are poor or obstructed, and the equipment is operated in close proximity with frequent starts and stops.

12. Metrom's collision avoidance technology solved the problem of MOW collisions by equipping each unit with UWB radios that accurately determine the range to the MOW vehicle ahead and automatically warn the operator or brake the MOW equipment if the operator does not act within a margin of safety. Metrom filed for and obtained patents on this system, including U.S. Patent Nos. 8,812,227 and 9,043,131.

13. Since its introduction, Metrom's AURA system has been installed on over 3,000 railroad maintenance vehicles in the U.S. and Canada with overall reductions in incidents of 90% or greater and no collisions between equipped vehicles when the system was properly installed, maintained, and used, avoiding countless injuries and saving millions of dollars in equipment damage.

14. Metrom also pioneered and demonstrated worker safety systems that allow real time alerts to the operators of equipment and MOW workers on the tracks regarding the presence of approaching trains. Metrom has been awarded a series of patents for those innovations including U.S. Patent Nos. 10,179,595 and 10,737,709.

15. In 2013, Metrom began exploring ways to expand its successful collision avoidance system to the mass transit context. Urban mass transit is an environment with some characteristics similar to the MOW environment, with close headways and high numbers of trains. At peak periods, it is desirable for transit agencies to allow trains to run as close together as possible.

16. Traditional signal control for mass transit rail divided train lines into a series of fixed track segments ("blocks"), with complex, cumbersome equipment designed to prevent two trains from entering the same fixed section of track at the same time. Smaller blocks allow for higher volume but each block adds additional signals, controls, and points of failure for maintenance.

17. In the 1980s, systems that allowed for "moving" blocks that allowed a moving buffer region before and after a train were developed. Defendant Siemens, along with Thales, are two of a handful of companies in the world that offer these systems for transit agencies. Their offering in the U.S. is known as "Communications Based Train Control" or CBTC. In order to meet safety requirements, legacy CBTC systems employed complex networks of track side equipment that communicated train status to a central control point, which communicates authority to operate to each train. The technology is subject to large

positional errors, is prone to failure, and while it is an improvement on fixed block systems, is very costly for even small improvements in performance.

18. The problems were especially acute for the New York MTA ("MTA"), which by 2017 attributed 30% of its major incidents to signal issues. At that time, more than 40% of the signaling equipment in the MTA was also more than 50 years old.

19. The MTA and its sub-units, including New York City Transit, are organized as New York public benefit corporations that are not immune from suit under the U.S. Constitution, Amendment XI.

20. An illustration of CBTC complexity and cost is MTA's "Flushing" line. The MTA budget for converting Flushing to CBTC was $588 million, and the project took 9 years to complete 10.5 miles of track from June of 2010 to March of 2019. The project was finally completed at least 5 years late and $157 million over budget.

21. Responding to increasingly severe quality of service issues, in 2017 the MTA solicited "genius" applications from the public for solutions to its ageing, outmoded, and inefficient centralized CBTC system and even older "fixed block" signaling infrastructure. Metrom responded to that invitation with Metrom's design for a system using UWB technology that accurately and continuously resolved train position at the vehicle level and supplied that positioning information in vehicle for

immediate application to train control, greatly reducing position errors and communication delay and allowing for higher frequency and more reliable train operation at a lower cost. Metrom referred to its solution as "Positive Train Control System based on Ultra-Wideband for Communications and Location" or PTCS-2, since Metrom's solution provided the high level of automated control and safety in preventing unsafe train operation with decentralized command authority based on the train. Metrom's proposal was selected by the MTA as a "Genius" challenge finalist in December of 2017 and a Genius challenge winner in March of 2018. http://www.mta.info/press-release/mta-headquarters/mta-announces-8-winners-mta-genius-transit-challenge.

22. The success of Metrom's technology with the MTA was a threat to Siemens and Thales existing business with the MTA. At that time, Siemens and Thales were promoting a multi-billion dollar retrofit of the NYCT system using their existing CBTC technology, which was developed in the 1980s and was effectively unchanged since that time. Metrom's solution obsoleted billions of dollars of legacy trackside and in-cab equipment that supports CBTC resulting in no justification for the MTA to purchase that equipment if Metrom's solution was fully implemented. Metrom's PTCS-2 system cost half as much with higher reliability and superior operational performance.

23. Siemens began a campaign to interfere with the technically superior Metrom offering by filing a patent application dated August 8, 2017 claiming a collision avoidance solution using UWB, international application number WO 2019/030018 ("WO '018"), that appears to be an attempt to file on the same collision avoidance technology that Metrom had already patented. Siemens' application has not been allowed in any jurisdiction, and the primary references cited against allowance of that application are Metrom's patents.

24. The WO '018 application is not the only patent application filed by Siemens attempting to claim inventorship for inventions developed and patented by Metrom and disclosed to Siemens by Metrom. Siemens has also filed, naming as inventors two of Siemens' employees who had been working with Metrom, at least three other patent applications that claim inventions previously disclosed to Siemens by Metrom or already disclosed by Metrom's patents and pending applications. Those cases are United States application number 16/516,456 ("Train Control System and Train Control Method Including Virtual Train Stop"); 16/778,529 ("Ultra-Wideband Work Train Protection"); and 16/778,595 ("Ultra-Wideband Based Vital Train Tracking").

25. After Metrom's original Complaint was filed in Delaware, Siemens allowed the 16/516,456 application to issue as a granted U.S. patent.

26. Defendant Humatics filed a provisional application, US No. 62/931,481, on November 6, 2019, directed to train positioning concepts previously invented by Metrom. Humatics allowed that application to publish on May 6, 2021 as Publication No. 2021/0129881.

27. Other companies have filed later in time applications attempting to claim Metrom's inventions as well. Piper Networks, a defendant in the related case, filed application number 17/014,974, "Enhanced Transit Location Systems And Methods", on September 8, 2020, claiming priority to a provisional filed on September 9, 2019, and published on March 11, 2021 as US Publication No. 2021/0070332. That application includes descriptive text referencing the MTA. A reasonable opportunity for discovery is likely to show other examples as well.

28. Defendants' declarations and course of prosecution in their patent applications, filed with knowledge of Metrom's patent position, are admissions by their agents that Metrom's earlier patents directed to the same inventions are not obvious or anticipated in view of art that Defendants were aware of when they later filed their own applications.

29. Metrom's initial "Proof of Concept" demonstrations of Metrom's technology to the MTA in 2017 and 2018 were compelling. Metrom's solutions were awarded "Genius" prizes by the MTA, and were so compelling that Metrom's

technology and architecture was the basis for the MTA's first large scale pilot demonstration RFP in 2019 for upgrading the decaying MTA signal infrastructure.

30. Metrom's general equipment arrangement is shown below, including power, operator interface, dual redundant controllers, vehicle host interface, vehicle interface, and UWB radio modules:



31. Metrom's advanced train control solutions are the subject of a number of Metrom patent applications, including pending and issued patents.

32. Thales, historically the second source for MTA train control equipment, engaged with Metrom on a proof of concept demonstration using UWB in 2018 after Metrom was selected as a "Genius" winner by the MTA.

33. Siemens did not do a Proof of Concept demonstration using UWB, but did convince Metrom to join with Siemens in an unsolicited joint proposal to the MTA for a train control system for the MTA "Lexington" line, using Metrom's technology.

34. Late in 2018, the MTA asked Metrom to submit its own proposal based on Metrom's Proof of Concept demonstrations, for the next "pilot demonstration phase."

35. The MTA's pilot demonstration RFP then issued with a series of amendments between January 15 and February 7, 2019, also referred to herein as the "Pilot RFP" or "NYCT RFP." The RFP, No. W-81199, was based on Metrom's pioneering system design.

36. Because the MTA requested a bid from Metrom as the prime contractor, Metrom responded to the RFP with Hitachi as a subcontractor. Siemens and Thales submitted as prime contractors but lacked any significant experience with UWB signaling as contemplated by Metrom's winning architecture and partnered with UWB radio suppliers as subcontractors. Siemens partnered with Defendant Humatics, and Thales partnered with Piper to submit bids. Siemens/Humatics, Thales/Piper, and Metrom were the only three bidders for the Pilot RFP. Of the three bidders, Siemens had done no proof of concept demonstrations using UWB, only Metrom had actually demonstrated the solution called for by the RFP, and Thales had previously done a proof of concept with Metrom.

37. In February of 2018, Defendant Humatics acquired a company known as "5D", which had in turn acquired a company known as "Time Domain". Time

Domain was a long-time manufacturer of UWB radios, was Metrom's supplier for UWB radios for at least the prior five years, and was accordingly familiar with Metrom's unique requirements and specifications for the railroad environment.

38. Despite Metrom's pioneering patent position and first mover technical leadership, however, the MTA awarded the Pilot RFP to its entrenched incumbent signal equipment suppliers, Siemens and Thales. While the final award removed some aspects of Metrom's Proof of Concept system to make it easier for Siemens and Thales to comply with the bid requirements, the MTA retained features developed, proven, demonstrated, and patented by Metrom.

39. Siemens has a history of using improper means to secure business. In 2008, Siemens was fined $800,000,000 by the SEC for violations of US law in connection with the payment of bribes to foreign officials, and ultimately eight Siemens executives and agents were charged with violations of the Foreign Corrupt Practices Act ("FCPA"). https://www.justice.gov/opa/pr/eight-former-senior-executives-and-agents-siemens-charged-alleged-100-million-foreign-bribe.

40. A reasonable opportunity for discovery is likely to show that Siemens evades MTA rules on lobbying and doing business with the MTA by former employees, by having former MTA or Siemens employees establish themselves as

consultants, funding their businesses with agreements with Siemens, and then using them to lobby the MTA on issues of interest to Siemens.

41. Siemens is motivated to maintain the status quo and exclude a disruptive supplier. Siemens or its affiliates have 2,500 employees in New York, with a large number of them dedicated to supporting an enormous installed base of unreliable, obsolete, and expensive legacy signal equipment for the MTA.

42. A reasonable opportunity for discovery is likely to show that one or more Defendants conspired with the RFP authors to alter the RFP and issue an RFP "addendum" favorable to Siemens, which was intentionally withheld from Metrom so that Metrom had no opportunity to timely amend Metrom's proposal.

43. A reasonable opportunity for discovery is likely to show that Siemens has acquired dominance in the market for signaling equipment for the MTA; and its practices in writing equipment specifications and RFPs for the MTA, contracting with former employees of the MTA, and appropriating the technology of disruptive competitors has stifled competition in that market.

44. Siemens and Thales have worked together in the past to supply compatible and inter-operable equipment to the MTA for train control.

45. Siemens and Thales conspired with their partners Humatics and Piper to mimic Metrom's technology and take the MTA UWB signaling business.

46. Metrom promptly protested the award of the Pilot Project on various grounds, including the facts that Metrom had an exclusive IP position in the system that the RFP requested bids for, Defendants had no demonstrated history or experience in fielding UWB based controls for a rail system, and Defendant Siemens had not participated in any UWB proof of concept system for the MTA or any other customer at any time. Metrom's protest was not successful.

47. A reasonable opportunity for discovery is likely to show that Metrom was not the high bidder, and also that during the bidding process, Siemens obtained information at least about Metrom's bid amount.

48. A reasonable opportunity for discovery is likely to show that as Defendants gained experience with UWB implementation, Defendants have offered more features covered by Metrom's patents, and that as the MTA builds out its new signaling infrastructure, Defendants will supply or intend to supply those features, or are promising to supply them in order to keep the entirety of the MTA signal business for themselves. Unless enjoined, the total value of those contracts over time is expected to reach over seven billion dollars.

49. A reasonable opportunity for discovery is likely to show that Defendants are preparing to bid on the first complete signal replacement of one or more of New York's 15 subway lines, at an estimated cost on the order of $200-400 million per line.

50. Future complete signal replacement RFPs will be a continuation of the Pilot Project, with the winning bidder required to implement Metrom's proprietary, patented technology, as demonstrated by the Pilot Project, to deliver all of the features sought by the MTA as the MTA eventually replaces all of the signaling on all of its New York City Transit lines with systems covered by Metrom's patent claims.

51. A reasonable opportunity for discovery is likely to show that the systems Defendants are offering will be capable of implementing additional features covered by Metrom's patents, and that the future capability to implement those features are offered for sale by Defendants and are a material aspect of Defendants' bids and the MTA's selection.

52. The MTA accounts for 60% of the dollars spent on transit infrastructure in the United States each year and has plans to spend over 7 billion dollars in the next few years on new signaling and train control systems. Without an injunction against the Defendants, Defendants will have permanently displaced Metrom and all

other competitors from the single largest market for Metrom's technology, depriving Metrom of not just the initial sales of signal equipment but ongoing maintenance and support, as well as a reference installation that is an invaluable sales tool for convincing other transit agencies to adopt Metrom's technology.

53. Because the New York MTA alone comprises more than half the market in the U.S. for signaling equipment for dedicated rail transit systems, MTA suppliers acquire an immediate advantage over competitors in scale and first mover advantage, since other metro rail systems look to the MTA for reference designs.

54. Defendant Siemens is already a dominant participant for signal equipment for the MTA, with Thales consistently taking a minority share to satisfy "dual source" requirements. A reasonable opportunity for discovery is likely to show that Siemens has consistently taken 60-70% of the MTA's train control business annually, with Thales accounting for the balance, and as a practical matter because Siemens and Thales control the specifications for train control opportunities, it is very difficult for a small innovator to bid on subsequent follow-on orders for those systems.

55. Nationally, Siemens is by far the largest market participant for signaling equipment sold to transit agencies for heavy rail. Siemens' patent infringement has allowed Siemens to maintain its duopoly for MTA signal equipment, and raises a

dangerous probability that Siemens will obtain a monopoly position in the balance of the U.S. transit agency heavy rail market for advanced signaling systems. Defendants' actions have suppressed the technical pioneer for UWB train control from the U.S. railway mass transit market, raised prices for advanced signaling systems, and slowed the adoption of a disruptive technology.

56. The Pilot and the MTA's future signal replacement program based on the Pilot are exemplary of Defendants infringement but not exclusive. Defendants are offering the accused systems, or equivalent systems, to other municipal agencies and operators.

57. The monetary and business damage to Metrom, absent an injunction, is enormous, potentially threatening Metrom's survival as a company and is irreparable if allowed to continue. A preliminary injunction is necessary to preserve the status quo and allow Metrom to compete for the delivery of the very systems that Metrom pioneered.

58. Defendants, and their customer the MTA, have actual notice of Metrom's patent rights, including at least by correspondence from Metrom dated June 24, 2019. That letter explicitly identified the '227, '131, and '738 patents, and additional pending applications. A reasonable opportunity for discovery is likely to show that Defendants have monitored Metrom's patent activity, submitted art

anonymously in pending patent applications, and agreed to indemnification agreements specifically concerning Metrom's patent rights. A reasonable opportunity for discovery is also likely to show that Metrom's patents have been cited at least against Siemens' attempts to apply for "me to" patents based on Metrom's demonstrations to the MTA of novel control solutions, and that one or more Defendants has monitored Plaintiff's website that lists Metrom's patents at https://metrom-rail.com/patents. A reasonable opportunity for discovery is likely to show that Defendants were aware of Metrom's bid protest and Metrom's position with the MTA that compliance with the MTA's RFP would require infringing Metrom's IP rights. Defendants have attempted to conceal their infringement by frustrating Metrom's FOIL requests for their responses to the Pilot RFP, and continuing to refuse to provide those responses after the Metrom brought this action.

59. Despite their knowledge of Metrom's patent rights, Defendants did, and a reasonable opportunity for discovery is likely to show will, continue with the acts complained of, knowing and with the intent to have the MTA purchase systems that infringe or would be used by the MTA to infringe Metrom's patent rights.

60. Exhibit D is a true and correct copy of New York City Transit RFP Solicitation No. W-81199, issued January 14, 2019.

61. Exhibit E is a true and correct copy of a Piper press release taken from Piper's web site.

62. Exhibit F is a true and correct copy of a Humatics brochure taken from Humatic's website.

63. Exhibit G is a true and correct copy of a Humatics sales sheet taken from Humatic's website.

NATURE OF THE DEFENDANTS' INFRINGEMENT

64. Defendant Siemens is a direct infringer under 35 U.S.C. § 271(a) by offering for sale, and then selling, the Pilot project systems to the MTA. Siemens obtained contracts for Pilot demonstration projects in response to a single RFP by the MTA that set out the requirements for a system. (MTA contract number W-81199-1 and -2).

65. In July of 2021, the MTA awarded contracts to Siemens/Humatics and Thales/Piper to further integrate their respective offerings and ensure the interoperability, if not the outright exchangeability, of the components of their supply. The MTA and Defendants combine Defendants' systems to operate an MTA system including the systems of all Defendants ("MTA System").

66. All Defendants are contributory infringers under 35 U.S.C. §271(c). Humatics provides onboard and wayside UWB radios and on vehicle controllers especially adapted to infringe, as described further herein. Siemens in turn, integrates that equipment for the MTA, as well as supplies additional equipment that is customized for the MTA in order to infringe. For example, Siemens and Thales have been awarded contracts totalling over 22 million dollars for Humatics to redesign its UWB radios to use Piper's "Qorvo" chip set and for Humatics and Piper to provide common interfaces to ensure the interoperability of Thales/Piper equipped trains with Siemens/Humatics wayside equipment and vice versa. The UWB radio and command interfaces will be interchangeable between Siemens/Humatics and Thales/Piper, and are not staple articles or commodities with a substantial noninfringing use.

67. A reasonable opportunity for discovery is likely to show that all Defendants are direct infringers under 35 U.S.C. § 271(a) by offering for sale systems claimed by the patents in Counts I-III to others in the United States, including the MTA.

68. All Defendants are inducers under 35 U.S.C. §271(b) because the MTA's use of the Pilot systems is known to be infringing both by virtue of the original complaint and for all the reasons that Defendants' infringement is also

willful. To the extent that any limitation from the asserted claims is not supplied by a single Defendant, the Defendants act in concert to induce the MTA to use the infringing combination, knowing that the MTA's use infringes Metrom's patents.

69. In the claim charts that follow, Metrom identifies a response in the Defendants' systems for each limitation of each identified claim, and each row is an allegation under Fed. R. Civ. P. 8(b)(1)(B) that must be admitted or denied.

COUNT I – PATENT INFRINGEMENT, U.S. PATENT NO. 9,731,738, 35 U.S.C. § 271 – ALL DEFENDANTS

70. The allegations in the preceding paragraphs are incorporated herein.

71. This claim is brought under 35 U.S.C. § 271 and the court has original and exclusive jurisdiction under 35 U.S.C. § 1338.

72. Metrom is the owner of duly issued U.S. Patent No. 9,731,738 ("'738 patent") (Exhibit A) titled "Methods And Systems For Decentralized Rail Signaling And Positive Train Control" and has been the owner at all times material to this claim.

73. Defendant Siemens is coordinating the installation and maintenance of a rail signaling system using UWB to enable positive train control and other features for the MTA, with their UWB partner Defendant Humatics. The ongoing offer and sale of that system includes the "Pilot" project described by the NYCT RFP (Exhibit

D), ongoing collaboration between the defendants to coordinate their offerings with each other, Thales, and Piper, and the MTA's requirements, and a planned series of contracts for full scale implementation scheduled to be awarded from 2022 forward are referred to herein as "Defendants' system" or "MTA UWB System".

74. The technical details of the Defendants' current supply for the MTA Pilot are not publicly available, other than the initial bid solicitation from the MTA. Metrom requested details of Siemens and Thales bid responses on the Pilot project under New York's Freedom of Information Law (FOIL), but both companies objected to those requests. Both companies also declined to provide their bid responses after Metrom requested them prior to filing the First Amended Complaint. However, both Siemens-Humatics and Thales-Piper supplied systems for the Pilot that met the common specification provided by the MTA, and the MTA has a requirement that the solutions provided by Siemens-Humatics and Thales-Piper be interoperable, so that trains equipped by Siemens-Humatics can run on tracks equipped by Thales-Piper and vice-versa.

75. A minimum requirement of the MTA Pilot and subsequent projects is to provide a UWB based train control system, which offers Automatic Train Operation (ATO) and Automatic Train Protection (ATP) while utilizing UWB as the primary source for speed and position determination.

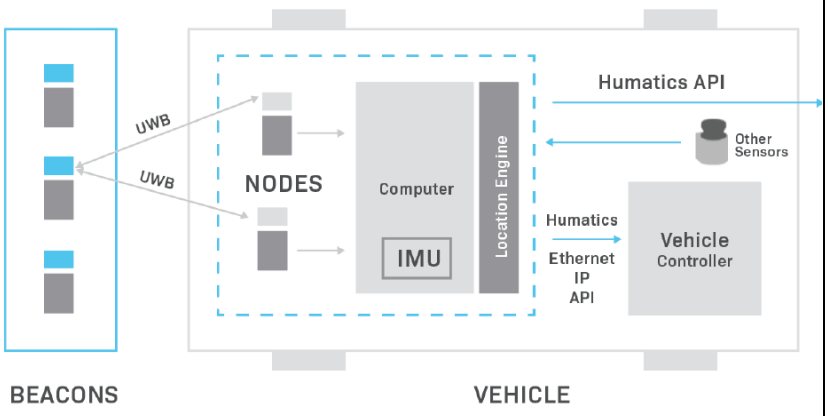
76. Siemens and Thales, as the system integrators and lead contractors on the Pilot and on any subsequent signal replacement projects, are the seller of the Pilot system, and are offering to sell the follow on line replacement MTA UWB Systems. Humatics and Piper are offering to sell infringing systems to the MTA in partnership with Siemens and Thales, and to agencies and operators other than the MTA, and a reasonable opportunity for discovery is likely to show that Siemens and Thales are as well.

77. Where implemented on the MTA, the MTA UWB System will infringe at least one claim of the '738 patent, either literally or by equivalence, either alone or as installed in the MTA System. The following table[1] recites each limitation of at least one claim and the corresponding response in the Defendants' system but is not exhaustive and a reasonable opportunity for discovery is likely to show that additional claims are infringed:

Claims 1-2, 6-18 of the '738 Patent	**Defendants' System**
1. A system for evaluating vehicle operation compliance, wherein the system comprises:	The NYCT RFP (Exhibit D) required a system that evaluates vehicle operation compliance in an "Ultra-Wideband-based Train Control System (TCS)". ATP | Automatic Train Protection

[1] The documents from which the figures and quotes are taken are attached as Exhibits D-G.

Claims 1-2, 6-18 of the '738 Patent	Defendants' System
	d. Train Operations: 1. Train Operations shall be in accordance with the functional requirements of Section 4. 2. Specifically, ATP functions shall be implemented without unnecessarily constraining the minimum station to station run times and operating headways and shall provide for improved run-time and headway performance compared to current performance on the line. Automatic Train Protection is a system for evaluating vehicle operation compliance. Siemens, with Humatics, has offered, sold, and installed pilot demonstration systems on the MTA. NYCT RFP at 31, 37-38, 116
a. a control signal interface subsystem;	The NYCT RFP requires interfaces to the trackside control signals: 3.4.2 Timing and Sizing Document (TSAD) a. The Contractor shall provide a Timing and Sizing Document, including calculations and supporting data and assumptions for review and approval by NYCT. The report shall demonstrate that the Contractor's Train Control System solution will achieve the performance requirements and how the requirements will be achieved by the Contractor's system architecture. The TSAD Document shall provide the timing and sizing analysis of the TCS System and its associated subsystem/devices for operational scenarios: Signal reaction time is included in the timing analysis, and signal status is tracked by the system. NYCT RFP p.37-38, 134. The Control signal interface subsystem includes UWB "anchors", trackside signals, and wayside zone controllers and data radios.
b. and a vehicle-mounted subsystem configured to: communicate with the control signal interface subsystem to receive information	The NYCT RFP requires a vehicle mounted system that communicates with the control signal interface subsystem to receive information corresponding to control signal status. Id., See also "Humatics Rail Nav Datasheet," found on the Humatics website at https://www.humatics.com/wp-content/uploads/2020/07/Humatics_RailNav_Datasheet_0720.pdf ("Humatics Datasheet") (Exhibit F)

Claims 1-2, 6-18 of the '738 Patent	Defendants' System
corresponding to a status of a control signal;	 A reasonable opportunity for discovery is likely to show that signal status information is communicated to the vehicle on board system from the control signal interface subsystem.
c. determine a rule for behavior of a vehicle according to the information corresponding to the status of the control signal;	Overspeed protection, brake assurance, and automatic speed regulation based on signal status, are among the behavior rules that are determined at least in part, according to the status of the control signal. See generally, NYCT RFP p.40-52 of project completion. The proposed system shall provide Automatic Train Protection (ATP) and Automatic Train Operation (ATO) functions as defined in the Technical Specification. The NYCT RFP p.7. b. UWB-based Train Control System is defined as a Train Control System which offers so form of ATO and ATP while utilizing UWB as the primary source for Speed and Posit determination, at a minimum. NYCT RFP p.22. d. The Train Control System shall include the capability for providing ATP, ATO, and A functions. e. ATP functions shall provide fail-safe protection against collisions, excessive speed, other hazardous conditions. f. ATP functions shall have precedence over both the ATO and ATS functions. g. ATO functions shall control basic operations that would otherwise be performed by a tr operator and shall do so within the protection limits imposed by ATP. NYCT RFP p.40.

Claims 1-2, 6-18 of the '738 Patent	Defendants' System
d. and observe operation of the vehicle to evaluate compliance with the rule;	The vehicle mounted system observes the vehicle to determine whether the vehicle is in compliance with the rule. It is a requirement of the RFP that the system react when the vehicle is out of compliance with various rules. 6. Signal indication status to train(s)-train reaction NYCT RFP p.38. b. The safe braking model shall, as a minimum, include consideration of the following factors: 1. Location uncertainty of lead train (including rollback tolerance). 2. Location uncertainty of following train. 3. Allowable overspeed permitted by the Train Control System. 4. Maximum speed measurement error of the Train Control System. 5. Train Control System reaction times and latencies. NYCT RFP p.38. Overspeed protection includes protection against exceeding the speed that would allow the train to stop before exceeding its authority – which includes authority that is defined by signals, such as stop signals. a. Overspeed protection shall be a required ATP function for the Train Control System. 1. In establishing, supervising, and enforcing the ATP profile, as governed by the safe braking model, the Train Control System shall ensure that under no circumstances, including failures, will the train's actual speed exceed its safe speed. 2. The safe speed shall be derived by considering the most restrictive of the following: i. The permanent speed limits on sections of track within the ATP profile. ii. Any temporary speed restrictions on sections of track within the ATP profile. iii. The speed limit associated with a Work Zone. iv. Any permanent speed restriction applicable to the particular class or configuration of train. v. Any speed restrictions enforced on the train because of train-borne failure conditions. vi. The maximum speed that would allow the train to stop safely prior to the limit of the train's movement authority or to slow down sufficiently to meet appropriate permanent or temporary speed restrictions upon entering that section of track. NYCT RFP p.43.
e. wherein: the control signal interface subsystem comprises an ultra-wideband	The NYCT RFP requires the use of a UWB communications component between the control signal wayside equipment and the vehicle mounted subsystem.

Claims 1-2, 6-18 of the '738 Patent	Defendants' System
(UWB) communications component;	**Ultra-Wideband (UWB)-based Train Control System Pilot Program** NYCT RFP p.1 **1 INTRODUCTION, OVERVIEW, AND PROCUREMENT PROCEDURES** New York City Transit (NYCT) is seeking Competitive Proposals from qualified Contractors for the for the provisioning, design, fabrication, construction, and complete testing of an Ultra-Wideband (UWB) -based Train Control System (sometimes referred to herein as "Train Control System") as a pilot program ("Pilot") on NYCT Subways. This work shall include testing of the Wayside, Communications, Vehicle, Solid State Interlocking (SSI), and Automatic Train Supervision (ATS) systems including all hardware and software sub-systems and components. The Contractor shall provide a fully functional UWB-based Train Control System (or equivalent) which meets the functional and operation needs of NYCT. It shall be implied by submitting a Competitive Proposal: NYCT RFP p.7 The primary objective of the Pilot is to demonstrate a UWB-based Train Control System (or equivalent) operating in Shadow Mode for comparison against a Revenue Service Communications Based Train Control (CBTC) System. For the purposes of this RFP, NYCT is defining a UWB-based Train Control System as a system that utilizes UWB technology for speed and position determination, at a minimum. The output of the Pilot is determining whether the proposed system is safety certifiable for consideration in a revenue deployment on NYCT. NYCT RFP p.7 b. UWB-based Train Control System is defined as a Train Control System which offers some form of ATO and ATP while utilizing UWB as the primary source for Speed and Position determination, at a minimum. NYCT RFP p.22.
f. the vehicle-mounted subsystem comprises an ultra-wideband (UWB) communications component;	The accused system has an UWB component. a. UWB – CBTC Speed and Position Comparison Report NYCT RFP p.36, See also supra. See also Humatics Data Sheets, Exhibits F and G
g. and the vehicle-mounted subsystem and the control signal	The Defendants' solution includes UWB signals that have data pertinent to evaluating vehicle operation compliance, see limitation "h" below.

Claims 1-2, 6-18 of the '738 Patent	Defendants' System
interface subsystem are further configured to communicate UWB signals carrying data pertinent to evaluating vehicle operation compliance,	
h. the data comprising at least one of: a unique ID associated with the vehicle-mounted subsystem, a signal indication, a track number, a track direction, speed, and direction of travel.	The Defendants' system provides at least a train ID in the signal from each UWB vehicle mounted subsytem. **4.4.3 Train Identification and Train Tracking** a. Each UWB-equipped train operating within UWB territory shall be assigned a tr identification. This train identification shall indicate the type of train and other pertin information about the train. b. An ATS system shall have the capability to automatically track, maintain records of, a display on the ATS user interface the locations, identities, train schedule, and oth pertinent data for all UWB-equipped trains operating in the UWB territory. NYCT RFP p.50 The Defendants' system must provide signal indications, track occupancy, direction of travel, and speed information by UWB. **1.1 Scope** The primary objective of the Pilot is to demonstrate a UWB-based Train Control System (or equivalent) operating in Shadow Mode for comparison against a Revenue Service Communications Based Train Control (CBTC) System. For the purposes of this RFP, NYCT is defining a UWB-based Train Control System as a system that utilizes UWB technology for speed and position determination, at a minimum. The output of the Pilot is determining whether the proposed system is safety certifiable for consideration in a revenue deployment on NYCT. NYCT RFP p.7. 6. Signal indication status to train(s)-train reaction 7. Track occupancy status to trains/train reaction NYCT RFP p.38.

<table>
<tr><th>Claims 1-2, 6-18 of the ’738 Patent</th><th>Defendants’ System</th></tr>
<tr><td></td><td>
vi. Signal indication status to train(s)-train reaction
vii. Track occupancy status to trains/train reaction

NYCT RFP p.139.

<table>
<tr><td>Potential Cause</td><td>System fails to correctly register track occupancy</td></tr>
</table>

<table>
<tr><td>Control Measures</td><td>1: The TCS system shall provide correct track occupancy status.
2: The interface between TCS and the Signaling system shall be vitally designed and implemented.
3: All vehicles shall be maintained to ensure proper TCS inputs.</td></tr>
</table>

NYCT RFP p.134.

4.2.6 End-of-Track Protection
a. End-of-track protection shall be a required ATP function for the Train Control System configuration that permits the operation of trains up to, or in close proximity to, an end-of-track terminus.
1. End-of-track protection shall be incorporated into, or function in conjunction with, overspeed protection to prevent trains from over-traveling the end-of-track or, if buffers are specified, to prevent trains from exceeding the design limits for impact with an end-of-track buffer.
2. End-of-track protection design shall be based on the Safe Braking Model.

NYCT RFP p.44.

e. The safe braking model shall also include consideration of operational-related requirements such as:
1. The ability to berth at a station platform with a red home signal at the exit from the station platform.

NYCT RFP p.38-39.
</td></tr>
<tr><td>2. The system of claim 1, wherein the rule corresponds to the status of the control signal being</td><td>A reasonable opportunity for discovery is likely to show that Defendants are using this feature for signal overrun protection or speed protection, or offering this feature for sale.</td></tr>
</table>

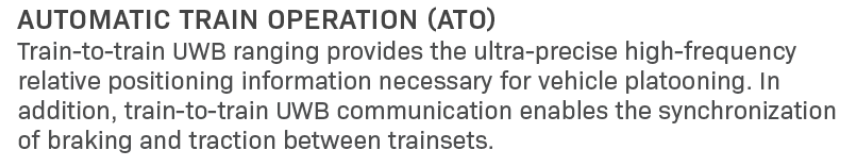
Claims 1-2, 6-18 of the '738 Patent	Defendants' System
at least one of red, double red, yellow, or double yellow.	
6. The system of claim 1, wherein the vehicle-mounted subsystem is configured to:	
a. interface with a braking system of the vehicle;	The Defendants' system on board vehicle controller interfaces with the braking system.
b. communicate with the UWB communications component of the control signal interface subsystem via the UWB communications component of the vehicle-mounted subsystem;	The Defendants' UWB communications components on board and trackside communicate with each other.
c. and determine a distance between the vehicle-mounted subsystem and the control signal interface subsystem based on a time-of-flight of at least one communication between the UWB communications component of the	The Defendant's UWB communication components use time-of-flight to determine the distance between the vehicle mounted subsystem and the control signal interface subsystem.

Claims 1-2, 6-18 of the '738 Patent	Defendants' System
control signal interface subsystem and the UWB communications component of the vehicle-mounted subsystem.	
7. The system of claim 1, wherein the vehicle-mounted subsystem is further configured to generate an alert if a distance between the vehicle-mounted subsystem and the control signal interface subsystem is less than a threshold.	The Defendants' system generates a warning if separation criteria are exceeded.
8. The system of claim 1, wherein the vehicle-mounted subsystem is further configured to cause a braking system of the vehicle to activate if a distance between the vehicle-mounted subsystem and the control signal interface subsystem is less than a threshold.	The Defendants' system is configured to alow a braking system to activate if a threshold distance is violated.
9. The system of claim 1, wherein the vehicle-mounted	

Claims 1-2, 6-18 of the '738 Patent	Defendants' System
subsystem further comprises	
a. a radio-frequency identification (RFID) subsystem configured to scan at least one RFID tag external to the vehicle to retrieve information stored on the at least one RFID tag.	The Defendants system scans RFID tags embedded along the track, that include embedded tag identity information.
10. The system of claim 9, wherein:	
a. the vehicle-mounted subsystem is further configured to substantially continuously receive information relating to speed of the vehicle;	The Defendants vehicle mounted subsystem receives vehicle speed information substantially continuously.
b. and the vehicle-mounted subsystem determines a changing distance between the vehicle-mounted subsystem and the control signal interface subsystem based on the information stored on the at	The Defendants' system integrates position information from RFID tags and speed information from UWB ranging to determine the changing distance between the vehicle and the control signal interface subsystem.

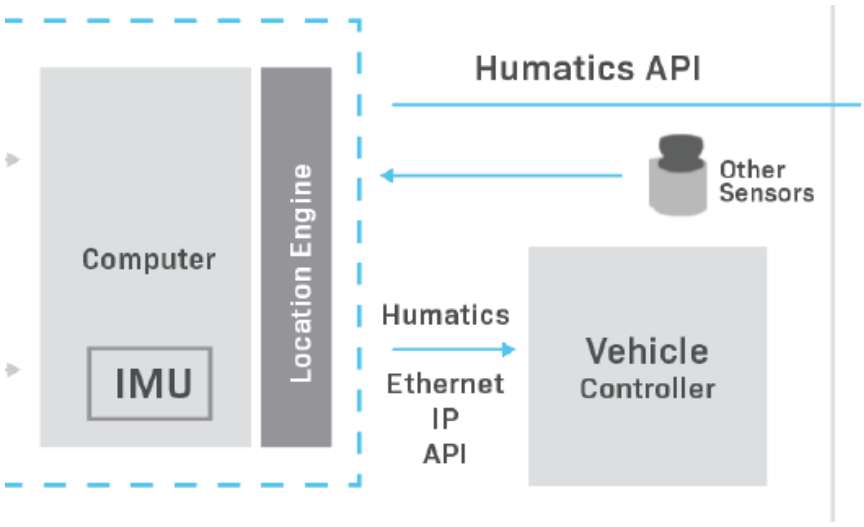
Claims 1-2, 6-18 of the '738 Patent	Defendants' System
least one RFID tag and the information relating to speed of the vehicle.	
11. The system of claim 9, wherein the vehicle-mounted subsystem is further configured to determine a distance between the vehicle-mounted subsystem and the control signal interface subsystem based on the information stored on the at least one RFID tag.	The Defendants' system determines the distance between the vehicle and the control signal interface subsystem based at least in part, on an RFID tag information.
12. The system of claim 1, further comprising:	
a. an access point external to the vehicle; and wherein the vehicle-mounted subsystem is further configured to:	The NYCT RFP specified wayside access points for communication with the vehicle. NYCT RFP Part 5, p.53-56.
b. store data relating to prior behavior of the vehicle; and communicate the data relating to prior behavior of	A reasonable opportunity for discovery is likely to show that the accused system communicates historical data to the wayside access point.

Claims 1-2, 6-18 of the '738 Patent	Defendants' System
the vehicle with the access point.	
13. The system of claim 1, further comprising:	
a. a second vehicle-mounted subsystem including a UWB communications component, wherein the second vehicle-mounted subsystem is configured to be mounted on another vehicle; and	The NYCT pilot project equipped multiple trainsets for the project.
b. wherein the vehicle-mounted subsystem is configured to:	
c. communicate with the UWB communications component of the control signal interface subsystem via the UWB communications component of the vehicle-mounted subsystem;	See claim limitation 6.b, *supra*.
d. communicate with the UWB	The UWB communications components on each trainset communicate with each other.

Claims 1-2, 6-18 of the '738 Patent	Defendants' System
communications component of the second vehicle-mounted subsystem via the UWB communications component of the vehicle-mounted subsystem;	 Exhibit G
e. determine a distance between the vehicle-mounted subsystem and the control signal interface subsystem based on a time-of-flight of at least one communication between the UWB communications component of the control signal interface subsystem and the UWB communications component of the vehicle-mounted subsystem; and	See *supra*, 6.c.
f. determine a distance between the vehicle-mounted subsystem and the	See *supra*,Exhibit G, "Train-to-train UWB ranging."

Claims 1-2, 6-18 of the '738 Patent	Defendants' System
second vehicle-mounted subsystem based on a time-of-flight of at least one communication between the UWB communications component of the second vehicle-mounted subsystem and the UWB communications component of the vehicle-mounted subsystem.	
14. The system of claim 13, wherein the vehicle-mounted subsystem is further configured to:	
a. generate an alert if the distance between the vehicle-mounted subsystem and the control signal interface subsystem is less than a first threshold; and	The Defendants' system includes an operator interface that generates alerts when a distance threshold is reached.
15. The system of claim 13, wherein the vehicle-mounted subsystem is further configured to:	

Claims 1-2, 6-18 of the '738 Patent	Defendants' System
a. cause a braking system of the vehicle to activate if the distance between the vehicle-mounted subsystem and the control signal interface subsystem is less than a first threshold; and	The Defendants' system will activate the braking system when the distance between the vehicle and a control signal interface subsystem is less than a threshold.
b. cause the braking system of the vehicle to activate if the distance between the vehicle-mounted subsystem and the second vehicle-mounted subsystem is less than a second threshold.	The Defendants' system will activate the braking system when the distance between the vehicle and another trainset is less than a threshold.
16. The system of claim 13, wherein the vehicle-mounted subsystem further comprises:	
a. a radio-frequency identification (RFID) subsystem configured to scan at least one RFID tag external to the vehicle to retrieve information stored	The Pilot Project equipped trains include RFID tag readers.

Claims 1-2, 6-18 of the '738 Patent	Defendants' System
on the at least one RFID tag; and	
b. wherein the vehicle-mounted subsystem is further configured to determine a distance between the vehicle-mounted subsystem and the control signal interface subsystem based on the information stored on the at least one RFID tag.	RFID tag information is integrated into the location determinations made by the Humatics Location Engine. 
17. The system of claim 16, wherein:	
c. the vehicle-mounted subsystem is further configured to substantially continuously receive information relating to speed of the vehicle; and	Speed determinations in the Defendants' system is done substantially continuously.
d. the vehicle-mounted subsystem determines a changing distance between the vehicle-mounted	The Defendants' Location Engine determines the changing distance based on RFID tag information in addition to velocity information.

Claims 1-2, 6-18 of the '738 Patent	Defendants' System
subsystem and the control signal interface subsystem based on the information stored on the at least one RFID tag and the information relating to speed of the vehicle.	
18. The system of claim 13, further comprising:	
a. an access point external to the vehicle; and	The Defendants' system includes wayside access points.
b. wherein the vehicle-mounted subsystem is further configured to: store data relating to prior behavior of the vehicle; and	The Defendants' system stores data related to the prior behavior of the vehicle, including speed and location;
c. communicate the data relating to prior behavior of the vehicle with the access point.	A reasonable opportunity for discovery is likely to show that the prior behavior information is communicated to the access point.

78. Both Defendants indirectly infringe, and Defendant Siemens directly infringes, by offering and selling their UWB systems and related components to the MTA, and aiding and abetting the MTA in the operation of the MTA UWB System.

79. A reasonable opportunity for discovery is likely to show that Defendants are offering their infringing system for sale to other transit agencies and using the Pilot project installations as a reference.

80. Defendants are also contributory infringers, because the components sold by Defendants for installation in the MTA System are customized for the MTA's unique requirements and have no substantial non-infringing use.

81. Metrom is entitled to damages adequate to compensate Metrom for Defendants' infringement, as provided by 35 U.S.C. § 284 and in no event less than a reasonable royalty.

COUNT II – PATENT INFRINGEMENT, U.S. PATENT NO. 8,812,227, 35 U.S.C. § 271 – ALL DEFENDANTS

82. The allegations in the preceding paragraphs are incorporated herein.

83. This claim is brought under 35 U.S.C. § 271 and the court has original and exclusive jurisdiction under 35 U.S.C. § 1338.

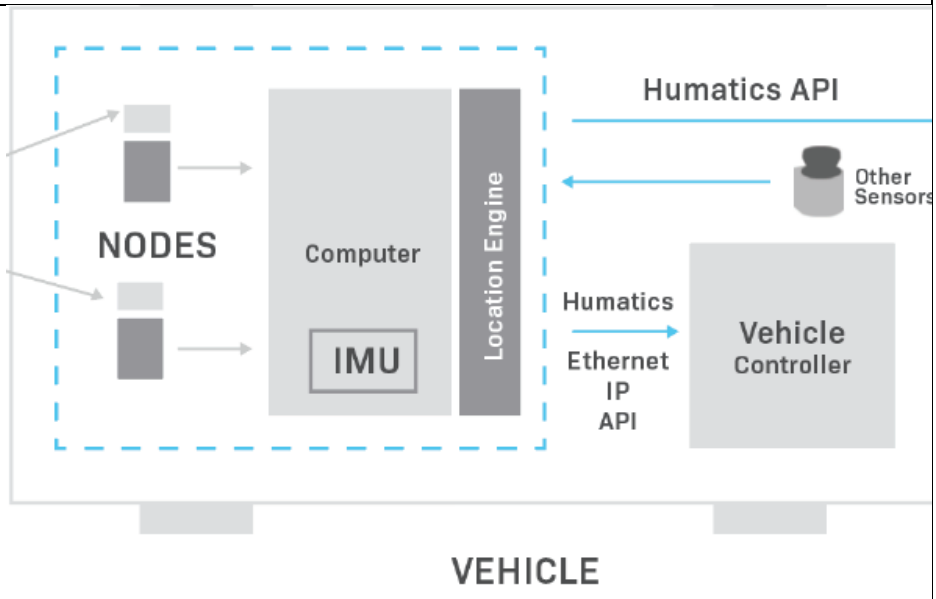
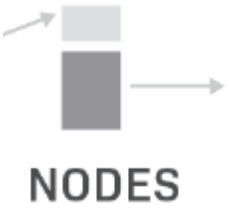
84. Metrom is the owner of duly issued U.S. Patent No.8,812,227 ('227 patent) (Exhibit B) titled "Collision Avoidance System for Rail Line Vehicles" and has been the owner at all times material to this claim.

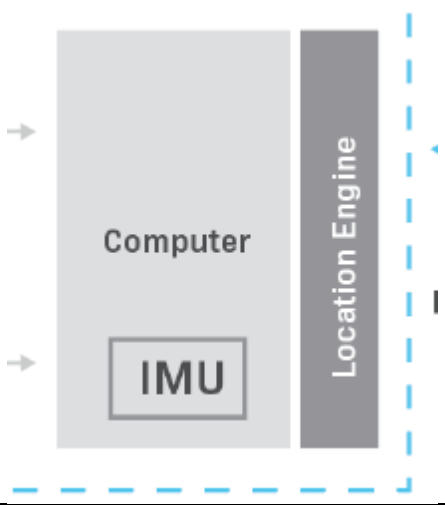
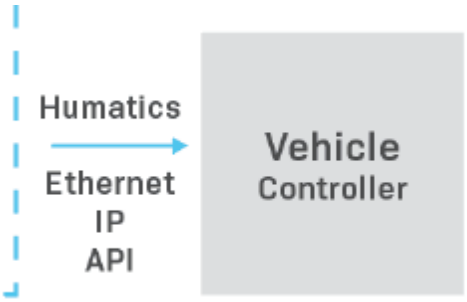
85. Defendants are including in their offers and solicitations to the MTA and others, collision avoidance features that will warn and prevent train operators from colliding with other trains, using UWB technology pioneered by Metrom, with a significantly higher degree of precision than was possible with prior systems.

86. Collision avoidance is of great interest to the MTA, and a reasonable opportunity for discovery is likely to show that the future availability of this feature with no or minimal hardware changes to the Defendants' legacy systems is a factor in awarding contracts to the Defendants.

87. Metrom's '227 patent covers the collision avoidance features that Defendants have offered for sale, will sell, and operate in a UWB system for the MTA, as shown in the following table, either literally or by equivalence, either alone or as installed in the MTA System:

Claims 1-2, 7-10, 12-13, 17-18, 21-27 of the '227 Patent	**Defendants' System**
1. A collision avoidance system comprising:	The MTA UWB system is a collision avoidance system. Both Siemens (with Humatics) and Thales (with Piper) have installed pilot demonstration systems on the MTA, and a reasonable opportunity for discovery is likely to show that the Thales-Piper combination is equivalent to the Siemens-Humatics installation. Piper press release, January 29, 2020 (Exhibit E).

Claims 1-2, 7-10, 12-13, 17-18, 21-27 of the '227 Patent	Defendants' System
a. one or more vehicle mounted modules, each vehicle mounted module mountable on a rail vehicle, each vehicle mounted module comprising:	
b. a transponder sensor module operable to send and receive data wirelessly, the transponder module comprising a first ultra wideband unit and a first antenna;	

Claims 1-2, 7-10, 12-13, 17-18, 21-27 of the '227 Patent	Defendants' System
c. a control electronics module comprising a processor in communica-tion with at least the transponder sensor module unit; and	
d. a user interface module including a user interface, the user interface being operable to provide rail vehicle information to a vehicle operator and to receive input from the vehicle operator; and	The Defendants' system includes a user interface module mounted on the vehicle, that provides information to an operator and can also receive control information from the operator.  DRIVER ASSISTANCE SYSTEMS Integrate with the onboard Train Control & Management System (TCMS) and Driver Machine Interface (DMI) to provide situational awareness and enable precision stops at platforms. Provide zero-speed signal and train type information to SIL-4 door controllers.
e. wherein each vehicle mounted module is operable to	The vehicle mounted modules will communicate with and range to any other vehicle mounted module that is within range.

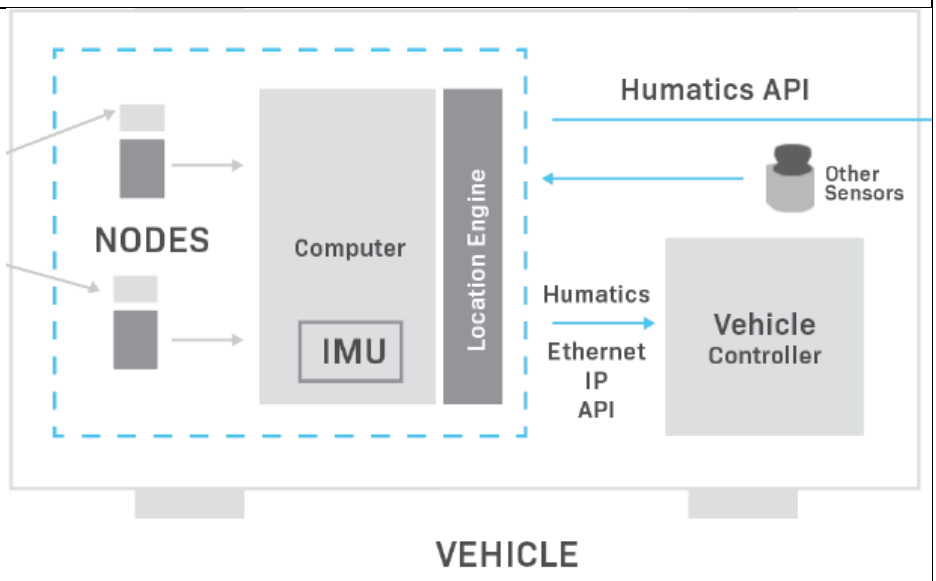
Claims 1-2, 7-10, 12-13, 17-18, 21-27 of the '227 Patent	Defendants' System
communicate with at least one other vehicle mounted module mounted on at least one other rail vehicle, and	
f. wherein each vehicle mounted module is operable to apply a time of flight technique to determine a separation distance between the rail vehicles.	Defendants' system determines this distance, based on a time of flight technique between UWB radios.
2. The collision avoidance system of claim 1, further comprising a central tracking unit in communication with the first vehicle mounted module and the second vehicle mounted module,	The Defendants' system also tracks train location centrally, using an external communications system. 

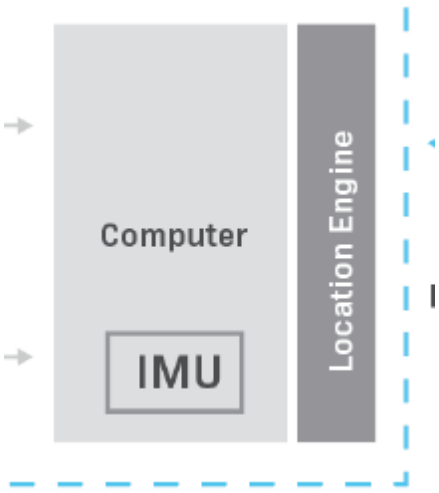
Claims 1-2, 7-10, 12-13, 17-18, 21-27 of the '227 Patent	Defendants' System
wherein the central tracking unit is operable to track the location of at least the first vehicle mounted module and the second vehicle mounted module.	
7. The collision avoidance system of claim 1, wherein the first vehicle mounted module further comprises a global positioning system unit, the global positioning system unit operable to receive information from one or more satellites to determine an absolute position of the rail vehicle, wherein the global positioning system unit is in communication with the control electronics module.	The Defendants' system includes an "other sensor" that is a GNSS/GPS position input. a constellation of UWB beacons. Given this architecture, UWB ranging is especially well-suited to augment GNSS positioning on sections of track with poor or no signal reception such as urban canyons and tunnels.

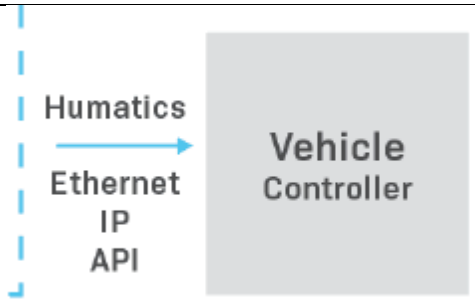
Claims 1-2, 7-10, 12-13, 17-18, 21-27 of the '227 Patent	Defendants' System
8. The collision avoidance system of claim 7, wherein the first vehicle mounted module receives information generated by the global positioning system unit and the first ultra wideband unit to determine whether one or more vehicle separation criteria are violated, and generates a warning signal when one or more vehicle separation criteria are violated.	The Defendants' system includes an "other sensor" that is a GNSS/GPS position input. a constellation of UWB beacons. Given this architecture, UWB ranging is especially well-suited to augment GNSS positioning on sections of track with poor or no signal reception such as urban canyons and tunnels. The Defendants' system will use GNSS data to supplement position information to avoid a collision.
9. The collision avoidance system of claim 1, wherein the first vehicle mounted module is operable to execute a progressive warning signal if one or more vehicle separation	A reasonable opportunity for discovery is likely to show that the in vehicle operator warnings are progressive.

Claims 1-2, 7-10, 12-13, 17-18, 21-27 of the '227 Patent	Defendants' System
criteria are violated, and	
a. wherein the progressive warning signal increases in at least one of signal rate, signal frequency, signal prominence, signal volume, or signal severity as the violation of the vehicle separation criteria approaches or extends beyond a vehicle separation threshold.	A reasonable opportunity for discovery is likely to show that the progressive warning is based on one of these properties (rate, frequency, volume, severity) as separation approaches or exceeds a threshold.
10. The collision avoidance system of claim 9, wherein the first vehicle mounted module executes an adaptive threshold feature that modifies one or more vehicle	A reasonable opportunity for discovery is likely to show that the threshold is adaptive, based at least in part on the speed of the vehicles.

Claims 1-2, 7-10, 12-13, 17-18, 21-27 of the '227 Patent	Defendants' System
separation thresholds based on the speed of the first rail vehicle and the speed of the second rail vehicle.	
12. The collision avoidance system of claim 1, further comprising an inertial measurement unit in communication with at least the control electronics module, the inertial measurement unit being operable to detect changes in the speed of the first rail vehicle.	The Defendants' system includes an inertial measurement unit (IMU). 
13. The collision avoidance system of claim 12, wherein the inertial measurement unit comprises at least one of an accelerometer or a gyroscope.	A reasonable opportunity for discovery is likely to show that the IMU includes at least an accelerometer.

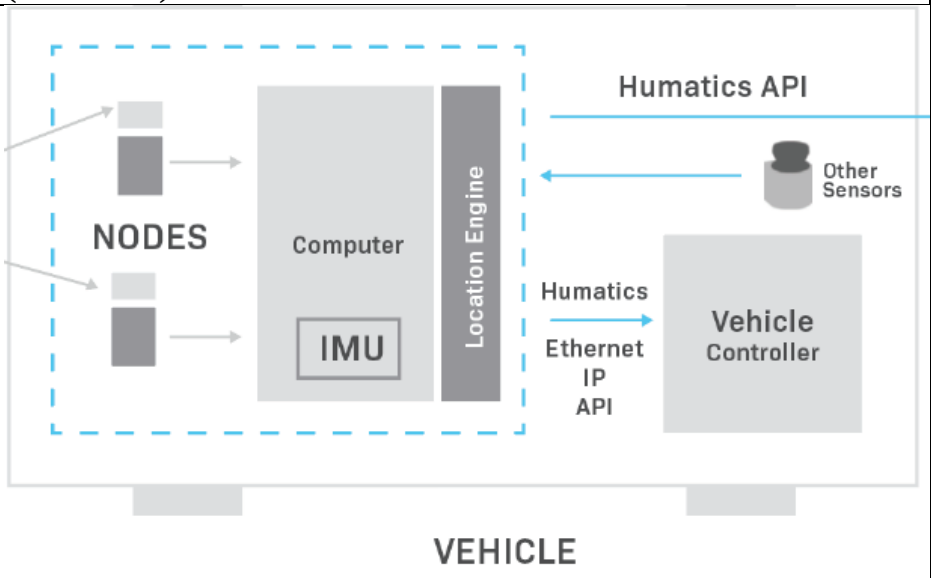
Claims 1-2, 7-10, 12-13, 17-18, 21-27 of the '227 Patent	Defendants' System
17. A rail vehicle module mountable on a rail vehicle, the module comprising:	
a. a transponder sensor module comprising:	The "nodes' are the transponder sensor module.
b. a radio communication unit operable to employ time of flight techniques to detect a distance between the rail vehicle and at least one other vehicle;	The nodes include an UWB, time of flight radio that detects distance to any neighboring nodes, including nodes on vehicles.
c. a wireless communications antenna operable to send and	The module includes a radio for communicating with a central system, including an over the air antenna.

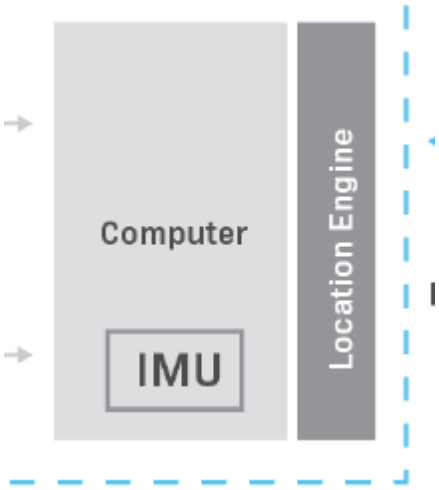
Claims 1-2, 7-10, 12-13, 17-18, 21-27 of the '227 Patent	Defendants' System
receive data over the air; and	
d. a global positioning system unit operable to receive information from one or more satellites to determine an absolute position of the rail vehicle;	The Defendants' system includes an "other sensor" that is a GNSS/GPS position input. a constellation of UWB beacons. Given this architecture, UWB ranging is especially well-suited to augment GNSS positioning on sections of track with poor or no signal reception such as urban canyons and tunnels. The Defendants' system will use GNSS data to supplement position information to avoid a collision.
e. a control electronics module comprising a processor in communication with at least the first transponder sensor module; and	
f. a user interface module including a user interface operable to provide rail vehicle information to	The Defendants' system includes a user interface module mounted on the vehicle, that provides information to an operator and can also receive control information from the operator.

Claims 1-2, 7-10, 12-13, 17-18, 21-27 of the '227 Patent	Defendants' System
a vehicle operator and to receive input from the vehicle operator; wherein the rail vehicle module communicates with at least one other module mounted on at least one other vehicle to detect a separation distance between the rail vehicle and the at least one other vehicle.	 DRIVER ASSISTANCE SYSTEMS Integrate with the onboard Train Control & Management System (TCMS) and Driver Machine Interface (DMI) to provide situational awareness and enable precision stops at platforms. Provide zero-speed signal and train type information to SIL-4 door controllers.
18. The rail vehicle module of claim 17, wherein the radio communication unit comprises an ultra wideband unit configured to send and receive ultra wideband signals.	The "Nodes" are UWB units.

Claims 1-2, 7-10, 12-13, 17-18, 21-27 of the '227 Patent	Defendants' System
21. The rail vehicle module of claim 17, wherein the rail vehicle module is operable to utilize information generated by the radio communication unit and the global positioning system unit to determine whether one or more vehicle separation criteria are violated, and generate a progressive warning signal if one or more vehicle separation criteria are violated, wherein the progressive warning signal increases in at least one of signal rate, signal frequency, signal prominence, signal volume, or signal severity as the violation of	A reasonable opportunity for discovery is likely to show that the in vehicle warnings are progressive relative to a separation threshold.

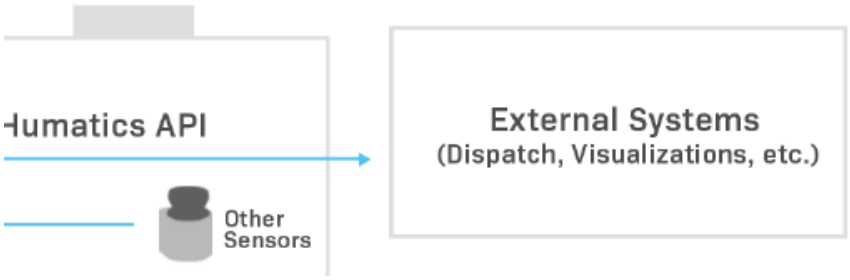
Claims 1-2, 7-10, 12-13, 17-18, 21-27 of the '227 Patent	Defendants' System
the vehicle separation criteria approaches or extends beyond a vehicle separation threshold.	
22. The rail vehicle module of claim 17, further comprising a central tracking unit component, wherein the central tracking unit component is in communication with a central tracking unit component mounted on the at least one other vehicle.	The Defendants' system also tracks train location centrally, using an external communications system. 
23. The collision avoidance system of claim 16, further comprising an inertial measurement unit in communication with at least the control electronics module, the inertial measurement unit	The Defendants' system includes an inertial measurement unit (IMU).  The IMU includes an accelerometer, which detects changes in speed.

Claims 1-2, 7-10, 12-13, 17-18, 21-27 of the '227 Patent	Defendants' System
being operable to detect changes in the speed of the first rail vehicle.	
24. A collision avoidance system comprising	The MTA UWB system is a collision avoidance system. Both Siemens (with Humatics) and Thales (with Piper) have installed pilot demonstration systems on the MTA, and a reasonable opportunity for discovery is likely to show that the Thales-Piper combination is equivalent to the Siemens-Humatics installation. Piper press release, January 29, 2020 (Exhibit E).
a. one or more vehicle mounted modules, each vehicle mounted module mountable on a rail vehicle, each vehicle mounted module comprising:	
b. a transponder sensor module comprising:	The "Nodes" include a transponder sensor module.
c. a radio communication unit operable to employ time of flight techniques to detect a	Each node includes an UWB time of flight radio that measures distance to other UWB radios, including nodes mounted on other vehicles.

Claims 1-2, 7-10, 12-13, 17-18, 21-27 of the '227 Patent	Defendants' System
distance between rail vehicles; and	
d. a global positioning system unit operable to receive information from one or more satellites to determine an absolute position of the rail line vehicle;	The Defendants' system includes a GNSS receiver. a constellation of UWB beacons. Given this architecture, UWB ranging is especially well-suited to augment GNSS positioning on sections of track with poor or no signal reception such as urban canyons and tunnels. The Defendants' system will use GNSS data to supplement position information to avoid a collision.
e. a control electronics module comprising a processor, the control electronics module being in communication with at least the transponder sensor module; and	
f. a user interface operable to provide rail vehicle	The Defendants' system includes a user interface module mounted on the vehicle, that provides information to an operator and can also receive control information from the operator.

Claims 1-2, 7-10, 12-13, 17-18, 21-27 of the '227 Patent	Defendants' System
information to a vehicle operator and to receive input from the vehicle operator;	
g. wherein each of the two or more rail vehicle modules communicate to determine a separation distance between each rail vehicle, and wherein each rail vehicle module is operable to use information provided by the radio communicatio n unit and the	The Defendants' system combines data from neighboring nodes, including nodes on other vehicles, with GNSS data to determine separation and generate a warning if separation criteria are exceeded.

Claims 1-2, 7-10, 12-13, 17-18, 21-27 of the '227 Patent	Defendants' System
global positioning system unit to determine whether one or more vehicle separation criteria are violated, and to generate a warning signal if one or more vehicle separation criteria are violated.	
25. The collision avoidance system of claim 24, wherein each radio communication unit comprises an ultra wideband unit.	The Nodes include UWB radios.
26. The collision avoidance system of claim 24, wherein the progressive warning signal increases in at least one of signal rate, signal frequency, signal	A reasonable opportunity for discovery is likely to show that the user warnings are progressive.

Claims 1-2, 7-10, 12-13, 17-18, 21-27 of the '227 Patent	Defendants' System
prominence, signal volume, or signal severity as the violation of the vehicle separation criteria approaches or extends beyond a vehicle separation threshold.	
27. The collision avoidance system of claim 24, further comprising a central tracking unit in communication with each rail vehicle module, the central tracking unit operable to track the location of each rail vehicle module.	The Defendants' system includes a central tracking unit, that monitors the location of multiple vehicles equipped with vehicle modules. 

88. Both Defendants indirectly infringe, and Defendant Siemens directly infringes, by offering and selling their UWB systems and related components to the MTA, and aiding and abetting the MTA in the operation of the MTA UWB System.

89. A reasonable opportunity for discovery is likely to show that Defendants are offering infringing systems for sale to other transit agencies and using the Pilot project installations as a reference.

90. Defendants are also contributory infringers, because the components sold by Defendants for installation in the MTA UWB System are customized for the MTA's unique requirements and have no substantial non-infringing use.

91. Metrom is entitled to damages adequate to compensate Metrom for Defendants' infringement, as provided by 35 U.S.C. § 284 and in no event less than a reasonable royalty.

COUNT III – PATENT INFRINGEMENT, U.S. PATENT NO. 9,043,131, 35 U.S.C. § 271 – ALL DEFENDANTS

92. The allegations in the preceding paragraphs are incorporated herein.

93. This claim is brought under 35 U.S.C. § 271 and the court has original and exclusive jurisdiction under 35 U.S.C. § 1338.

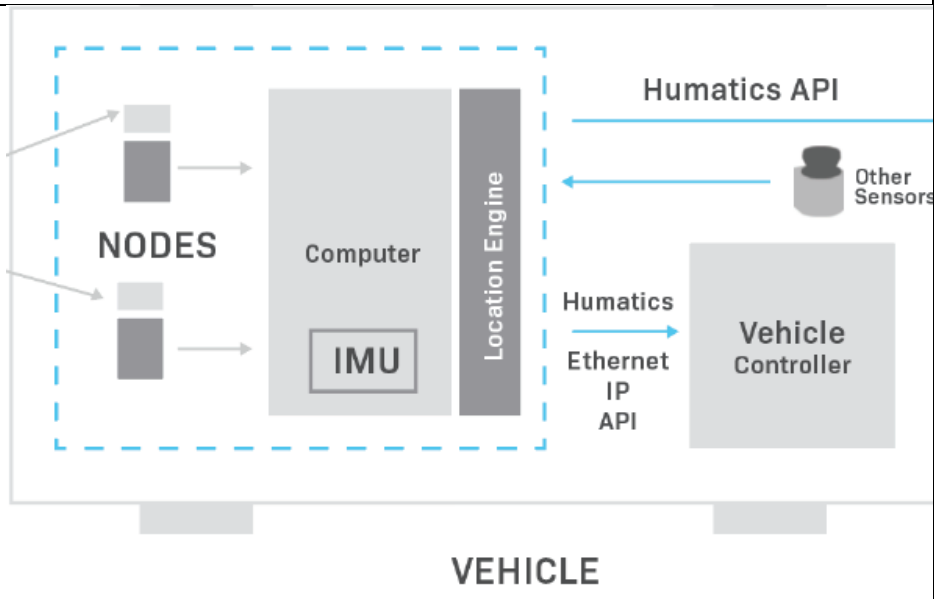
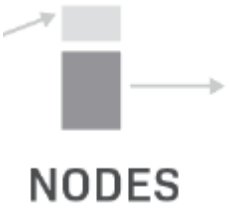
94. Metrom is the owner of duly issued U.S. Patent No. 9,043,131 ("'131 patent") (Exhibit C) titled "Collision Avoidance System for Rail Line Vehicles" and has been the owner at all times material to this claim.

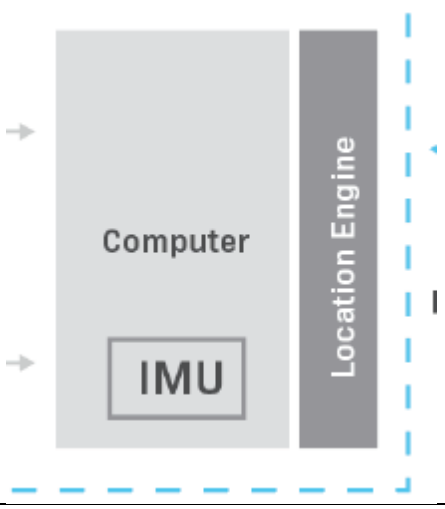
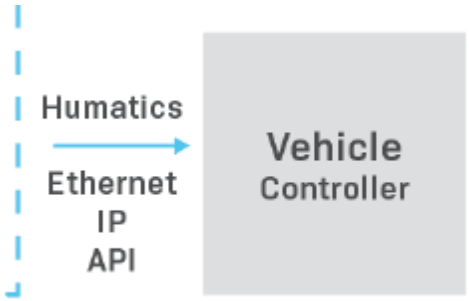
95. Defendants are including, in their offers and solicitations to the MTA and others, collision avoidance features that will warn and prevent train operators from colliding with other trains, using UWB technology pioneered by Metrom, with a significantly higher degree of precision than was possible with prior systems.

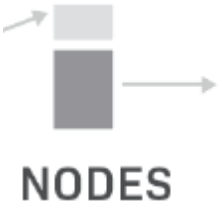
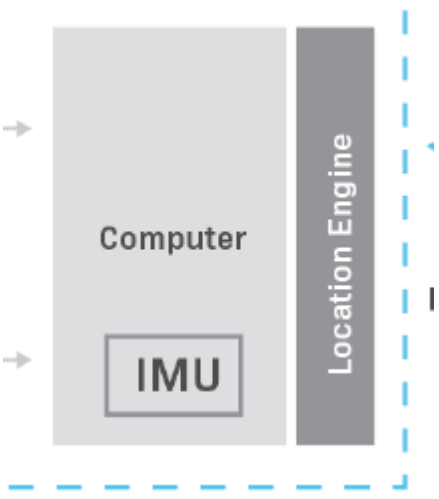
96. Collision avoidance is of great interest to the MTA, and a reasonable opportunity for discovery is likely to show that the future availability of this feature with no or minimal hardware changes to the Defendants' installed systems is a factor in awarding contracts to the Defendants.

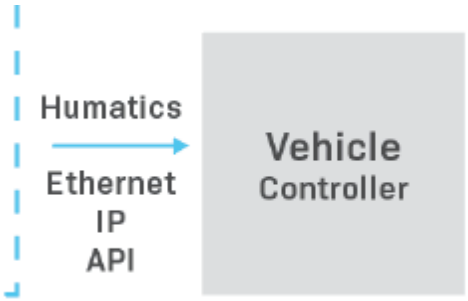
97. Metrom's '131 patent covers the collision avoidance features that Defendants have offered to sell, and will sell and operate, in the MTA UWB System, as shown in the following table, either literally or by equivalence, either alone or as installed in the MTA System:

Claims 1-2, 7-10, 12-14, 17, and 19 of the '131 patent	**Defendants' System**
1. A collision avoidance system comprising:	The MTA UWB system is a collision avoidance system. Both Siemens (with Humatics) and Thales (with Piper) have installed pilot demonstration systems on the MTA, and a reasonable opportunity for discovery is likely to show that the Thales-Piper combination is equivalent to the Siemens-Humatics installation. Piper press release, January 29, 2020 (Exhibit E).

Claims 1-2, 7-10, 12-14, 17, and 19 of the '131 patent	Defendants' System
a. a first vehicle mounted module mounted on a first rail vehicle, the first vehicle mounted module comprising:	
b. a first transponder sensor module operable to send and receive data wirelessly, the first transponder sensor module comprising a first radio communica-tion unit and a first antenna;	

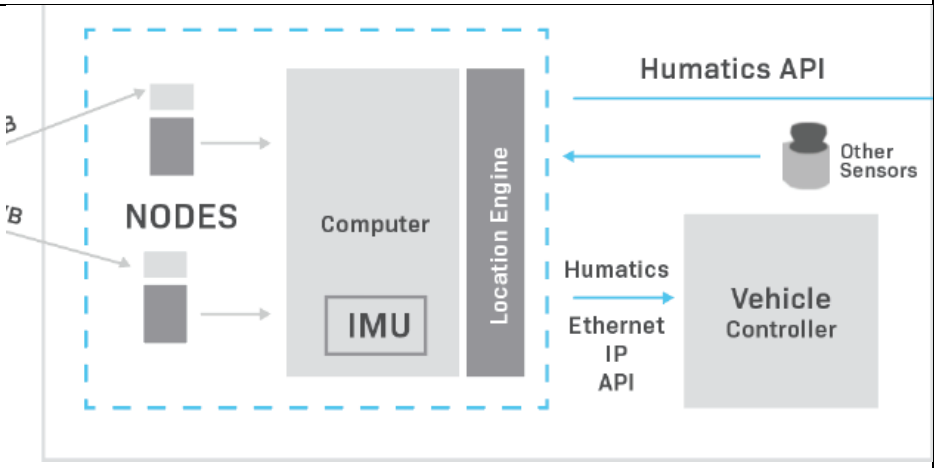
Claims 1-2, 7-10, 12-14, 17, and 19 of the '131 patent	Defendants' System
c. a first control electronics module comprising a first processor in communication with at least the first transponder sensor module; and	
d. a first user interface module including a first user interface, the first user interface operable to provide rail vehicle information to a vehicle operator and to receive input from the vehicle operator;	The Defendants' system includes a vehicle mounted user interface module that provides information to an operator and can also receive control information from the operator.  DRIVER ASSISTANCE SYSTEMS Integrate with the onboard Train Control & Management System (TCMS) and Driver Machine Interface (DMI) to provide situational awareness and enable precision stops at platforms. Provide zero-speed signal and train type information to SIL-4 door controllers.
e. a second vehicle mounted module mounted on a	The Defendants' are providing multiple vehicle modules for use on multiple vehicles in the MTA System.

Claims 1-2, 7-10, 12-14, 17, and 19 of the '131 patent	Defendants' System
second rail vehicle, the second vehicle mounted module comprising:	
f. a second transponder sensor module operable to send and receive data wirelessly, the second transponder sensor module comprising a second radio communicatio n unit and a second antenna;	
h. a second control electronics module comprising a second processor in communica-tion with at least the second transponder	

Claims 1-2, 7-10, 12-14, 17, and 19 of the '131 patent	Defendants' System
sensor module; and	
g. a second user interface module including a second user interface, the second user interface operable to provide rail vehicle information to the vehicle operator and to receive input from the vehicle operator;	The Defendants' system includes a vehicle mounted user interface module that provides information to an operator and can also receive control information from the operator.  DRIVER ASSISTANCE SYSTEMS Integrate with the onboard Train Control & Management System (TCMS) and Driver Machine Interface (DMI) to provide situational awareness and enable precision stops at platforms. Provide zero-speed signal and train type information to SIL-4 door controllers.
h. wherein: the first vehicle mounted module is operable to communicate with the second vehicle mounted module mounted on the second rail vehicle; and	A reasonable opportunity for discovery will show that the accused system was at least offered for sale with this feature, if the feature has not already be enabled. AUTOMATIC TRAIN OPERATION (ATO) Train-to-train UWB ranging provides the ultra-precise high-frequency relative positioning information necessary for vehicle platooning. In addition, train-to-train UWB communication enables the synchronization of braking and traction between trainsets.
i. the first vehicle	The UWB radios range using a time of flight technique.

Claims 1-2, 7-10, 12-14, 17, and 19 of the '131 patent	Defendants' System
mounted module and the second vehicle mounted module are operable to apply a time of flight technique to determine a separation distance between the first rail vehicle and the second rail vehicle.	
2. The collision avoidance system of claim 1, further comprising: a central tracking unit in communication with the first vehicle mounted module and the second vehicle mounted module, wherein the central tracking unit is operable to track a location of the first vehicle	The Defendants' system also tracks train location centrally, using an external communications system. 

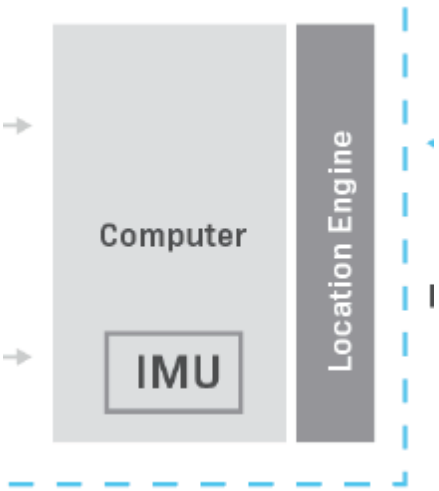
Claims 1-2, 7-10, 12-14, 17, and 19 of the '131 patent	Defendants' System
mounted module and a location of the second vehicle mounted module.	
7. The collision avoidance system of claim 1, wherein: the first vehicle mounted module further comprises a first global positioning system unit, the global positioning system unit operable to receive information from one or more satellites to determine an absolute position of the first rail vehicle; and the first global positioning system unit is in communication with the first control electronics module.	The vehicle mounted modules include GNSS/GPS positioning. a constellation of UWB beacons. Given this architecture, UWB ranging is especially well-suited to augment GNSS positioning on sections of track with poor or no signal reception such as urban canyons and tunnels.
8. The collision avoidance system of claim 7, wherein: the first	The Defendants' location engine combines GPS ("Other Sensors") and UWB positioning information to generate warning signals.

Claims 1-2, 7-10, 12-14, 17, and 19 of the '131 patent	Defendants' System
vehicle mounted module receives information generated by the first global positioning system unit and the first radio communication unit to determine whether one or more vehicle separation criteria are violated; and the first vehicle mounted module generates a warning signal when one or more vehicle separation criteria are violated.	
9. The collision avoidance system of claim 1, wherein: the first vehicle mounted module is adapted to execute a progressive warning signal if one or more vehicle separation criteria are violated; and the	A reasonable opportunity for discovery is likely to show that the in cab collision warnings are progressive.

Claims 1-2, 7-10, 12-14, 17, and 19 of the '131 patent	Defendants' System
progressive warning signal increases in at least one of signal rate, signal frequency, single prominence, signal volume, or signal severity as the violation of the vehicle separation criteria approaches or extends beyond a vehicle separation threshold.	
10. The collision avoidance system of claim 1, wherein the first vehicle mounted module executes an adaptive threshold feature that modifies one or more vehicle separation thresholds based on a speed of the first rail vehicle and a speed of the second rail vehicle.	A reasonable opportunity for discovery is likely to show that the warning threshold is adapted based on the rate of change of the distance (speed) between the vehicles.
12. The collision avoidance system	The Defendants' system includes an inertial measurement unit (IMU).

Claims 1-2, 7-10, 12-14, 17, and 19 of the '131 patent	Defendants' System
of claim 1, further comprising: a first inertial measurement unit in communication with at least the first control electronics module, the first inertial measurement unit being operable to detect changes in a speed of the first rail vehicle.	
13. The collision avoidance system of claim 12, wherein the first inertial measurement unit comprises at least one of an accelerometer or a gyroscope.	A reasonable opportunity for discovery is likely to show that the IMU includes either an accelerometer, gyroscope, or equivalent motion sensor.
14. The collision avoidance system of claim 1, wherein the first radio communication unit is operable to transmit and receive signals with varying	A reasonable opportunity for discovery is likely to show that the Defendants are implementing the accused system with a Qorvo chip set that includes the ability to vary the center frequency of the UWB signal.

Claims 1-2, 7-10, 12-14, 17, and 19 of the '131 patent	**Defendants' System**
center frequencies.	
17. A rail vehicle module mountable on a first rail vehicle, the module comprising:	The Defendants' system includes modules mounted on a first rail vehicle.
a. a transponder sensor module comprising:	The Defendants' system includes a transponder sensor module that comprises the following components:
b. a radio communica-tion unit operable to employ time of flight techniques to detect a separation distance between the first rail vehicle and a second vehicle;	The radio communication unit utilizes a time of flight technique for distance measurement that detects a separation distance between the first and second rail vehicles.
c. a first wireless communicatio ns antenna operable to send and receive data representing the separation	The UWB node includes an antenna that sends and receives data used to determine the time of flight.

Claims 1-2, 7-10, 12-14, 17, and 19 of the '131 patent	Defendants' System
distance over the air;	
d. a global positioning system unit operable to receive information from one or more satellites to determine an absolute position of the first rail vehicle;	The Defendants' system includes an "other sensor" that is a GNSS/GPS position input. a constellation of UWB beacons. Given this architecture, UWB ranging is especially well-suited to augment GNSS positioning on sections of track with poor or no signal reception such as urban canyons and tunnels.
e. a control electronics module comprising a processor in communication with the transponder sensor module; and	
f. a user interface module including a user interface operable to provide rail vehicle information to	The Defendants' system includes a user interface for communicating with the driver and control the train. DRIVER ASSISTANCE SYSTEMS Integrate with the onboard Train Control & Management System (TCMS) and Driver Machine Interface (DMI) to provide situational awareness and enable precision stops at platforms. Provide zero-speed signal and train type information to SIL-4 door controllers.

Claims 1-2, 7-10, 12-14, 17, and 19 of the '131 patent	Defendants' System
a vehicle operator and to receive input from the vehicle operator,	
g. wherein the rail vehicle module communicates with a second rail vehicle module mountable on the second vehicle to detect a separation distance between the first rail vehicle and the second vehicle.	Defendants' system is at least capable of this limitation, it is an element of the NYCT RFP, and the Defendants' offer it for sale: AUTOMATIC TRAIN OPERATION (ATO) Train-to-train UWB ranging provides the ultra-precise high-frequency relative positioning information necessary for vehicle platooning. In addition, train-to-train UWB communication enables the synchronization of braking and traction between trainsets.
19. The rail vehicle module mountable on a first rail vehicle of claim 17, wherein:	
a. the rail vehicle module is operable to utilize information	The Defendants' module determines whether at least one minimum distance criteria has been violated.

Claims 1-2, 7-10, 12-14, 17, and 19 of the '131 patent	Defendants' System
generated by the radio communications unit and the global positioning system unit to determine whether one or more vehicle separation criteria are violated, and	
b. the rail vehicle module is further operable to generate a progressive warning signal if one or more vehicle separation criteria are violated; and	A reasonable opportunity for discovery is likely to show that the module generates a progressive warning.
c. the progressive warning signal increases in at least one of signal rate, signal frequency, signal prominence, signal volume,	A reasonable opportunity for discovery is likely to show that the progressive warning includes at least one of rate, frequency, prominence, volume, or severity as the criteria is approached or exceeded.

Claims 1-2, 7-10, 12-14, 17, and 19 of the '131 patent	Defendants' System
or signal severity as the violation of the vehicle separation criteria approaches or extends beyond a vehicle separation threshold.	

98. Both Defendants indirectly infringe, and Defendant Siemens directly infringes, by offering and selling their UWB systems and related components to the MTA, and aiding and abetting the MTA in the operation of the MTA UWB System.

99. A reasonable opportunity for discovery is likely to show that Defendants are offering their infringing system for sale to other transit agencies and using the Pilot project installations as a reference.

100. Defendants are also contributory infringers, because the components sold by Defendants for installation in the MTA System are customized for the MTA's unique requirements and have no substantial non-infringing use.

101. Metrom is entitled to damages adequate to compensate Metrom for Defendants' infringement, as provided by 35 U.S.C. § 284 and in no event less than a reasonable royalty.

COUNT IV – TORTIOUS INTERFERENCE WITH PROSPECTIVE ECONOMIC ADVANTAGE – DEFENDANT SIEMENS

102. The allegations in the preceding paragraphs are incorporated herein.

103. This claim is a common law claim for tortious interference with prospective economic advantage and the court has jurisdiction under 35 U.S.C. § 1367.

104. The Pilot RFP was based on Metrom's prior demonstrations. Metrom had a proven record of success in meeting the requirements set out in the Pilot RFP, which included having been awarded four U.S. patents directed to its innovative technology. Metrom was therefore reasonably certain to win the Pilot Demonstration Project, and with that project in hand, was reasonably certain to be a supplier to the MTA for the complete UWB signaling project for the NYCT system.

105. Defendant Siemens interfered with Metrom's reasonable expectations of success by deliberately infringing Metrom's patents, or submitting proposals to the MTA knowing that they would inevitably infringe Metrom's patent rights in the future.

106. But for submitting proposals that infringed Metrom's intellectual property rights, Defendants would not have won the Pilot Demonstration RFP and would not have been selected as the dual source providers for the MTA UWB system installation.

107. A reasonable opportunity for discovery is also likely to show that Siemens improperly influenced the MTA to reject Metrom's bid, by obtaining Metrom's bid amount and by compensating consultants who lobbied the MTA for Siemens without disclosing their affiliation with Siemens.

108. Metrom was damaged by Defendants' conduct, in the loss of profits from the Pilot Demonstration project, the loss of future profits from the MTA UWB System installation, and the loss of a reference design.

JURY DEMANDED UNDER FED. R. CIV. P. 38

Metrom demands a jury on all issues so triable.

PRAYER FOR RELIEF

Wherefore, Metrom requests the following relief:

1. A judgment that Defendants have infringed one or more claims of the asserted patents;

2. An accounting for Defendants' profits;

3. All compensatory and punitive damages as may be allowed by statute or law;

4. A decree preliminarily and permanently enjoining Defendants, their principals, officers, directors, employees, agents, successors, assigns, and any persons in active concert with them from infringing, directly or indirectly, the asserted patents, including immediately ceasing all marketing, offers for sale, sales, and support of systems covered by the patents, under 35 U.S.C. § 283;

5. A judgment and order requiring Defendants to pay Plaintiff its damages, costs, expenses, and prejudgment and post-judgment interest for Defendants' infringement of the asserted patents;

6. A judgment and order requiring Siemens to pay Plaintiff its damages, costs, expenses, and prejudgment and post-judgment interest for its tortious acts;

7. An award to Plaintiff for enhanced damages resulting from Defendants' deliberate, willful, and bad faith conduct, as provided under 35 U.S.C. § 284;

8. An award to Plaintiff of its reasonable attorney fees, as provided under 35 U.S.C. § 285;

9. An order requiring Defendants to disgorge any profits or unjust enrichment derived from Defendants' tortious conduct to Plaintiff;

10. An order requiring Defendants to notify any United States transit agency to which Defendants submit a bid that includes UWB train control equipment of this Court's order and injunctions, and to file a quarterly report with the Court certifying compliance with the Court's injunction.

Dated: May 26, 2023

Respectfully submitted,

McAndrews, Held & Malloy, Ltd.

/s/ *Gregory C. Schodde*

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Alejandro Menchaca (*pro hac vice*)
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Attorneys for Plaintiff

EXHIBIT A

US009731738B2

(12) **United States Patent**
Carlson et al.

(10) **Patent No.: US 9,731,738 B2**
(45) **Date of Patent: Aug. 15, 2017**

(54) **RAIL VEHICLE SIGNAL ENFORCEMENT AND SEPARATION CONTROL**

(71) Applicant: **Metrom Rail, LLC**, Crystal Lake, IL (US)

(72) Inventors: **Richard C. Carlson**, Village of Lake in the Hills, IL (US); **Kurt A. Gunther**, Round Lake Heights, IL (US); **Marc W. Cygnus**, Mundelein, IL (US)

(73) Assignee: **METROM RAIL, LLC**, Crystal Lake, IL (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **14/809,950**

(22) Filed: **Jul. 27, 2015**

(65) **Prior Publication Data**

US 2015/0329130 A1 Nov. 19, 2015

Related U.S. Application Data

(63) Continuation of application No. 14/476,338, filed on Sep. 3, 2014.
(Continued)

(51) **Int. Cl.**
B61L 27/04 (2006.01)
B61L 27/00 (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC ***B61L 27/0077*** (2013.01); ***B60T 8/1705*** (2013.01); ***B61L 3/125*** (2013.01);
(Continued)

(58) **Field of Classification Search**
CPC B61L 3/18; B61L 3/22; B61L 3/221; B61L 3/24; B61L 15/0072; B61L 23/00;
(Continued)

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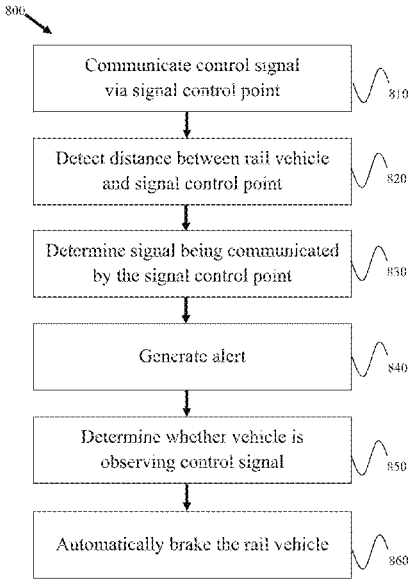
PCT, Notification of Transmittal of the International Search Report and the Written Opinion of the International Searching Authority, or the Declaration, in International application No. PCT/US2014/053900, dated Feb. 18, 2015 (21 pages).

Primary Examiner — Zachary Kuhfuss
(74) *Attorney, Agent, or Firm* — McAndrews, Held & Malloy, Ltd.

(57) **ABSTRACT**

A system for vehicle management includes a control signal interface subsystem and a vehicle-mounted subsystem. Each of these subsystems includes an ultra-wideband (UWB) communications component. The subsystems communicate with each other through the UWB components. The vehicle mounted subsystem interfaces with a braking system of the vehicle. The vehicle mounted subsystem determines the distance between it and the control signal interface subsystem based on the time-of-flight of at least one communication between the subsystems. The vehicle-mounted subsystem can cause the braking system of the vehicle to activate if the distance between the vehicle-mounted subsystem and the control signal interface subsystem is less than a threshold.

18 Claims, 10 Drawing Sheets



Related U.S. Application Data

(60) Provisional application No. 61/959,729, filed on Sep. 3, 2013.

(51) **Int. Cl.**

B60T 8/17	(2006.01)
B61L 3/12	(2006.01)
B61L 25/02	(2006.01)

(52) **U.S. Cl.**

CPC ***B61L 25/021*** (2013.01); ***B61L 25/025*** (2013.01); ***B61L 27/0038*** (2013.01)

(58) **Field of Classification Search**

CPC B61L 23/18; B61L 25/025; B61L 25/026; B61L 25/06; B61L 27/04; B61L 27/0038; B61L 27/0077

See application file for complete search history.

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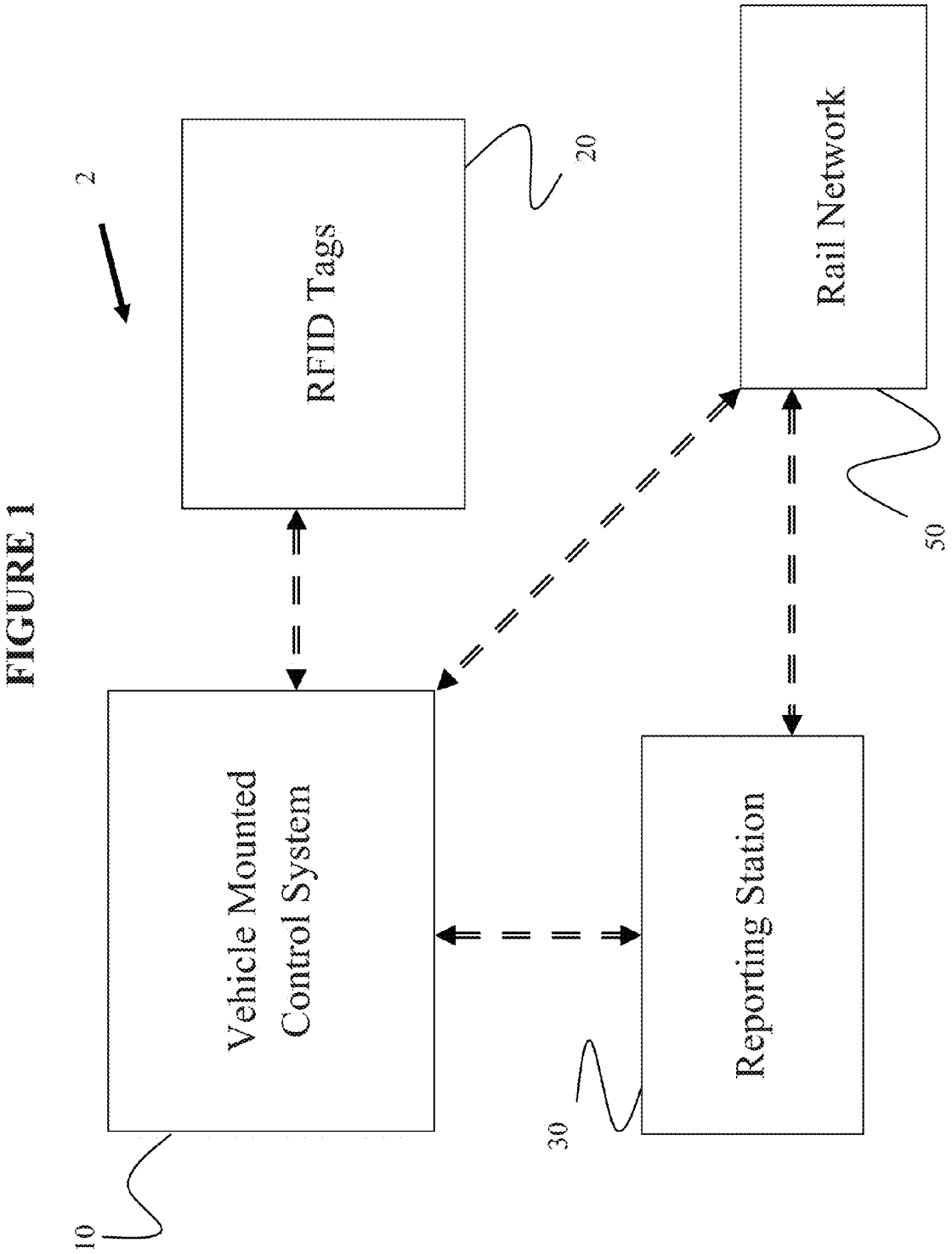

2
RFID Tags
20
Rail Network
50
Vehicle Mounted Control System
10
Reporting Station
30

FIGURE 1

FIGURE 2

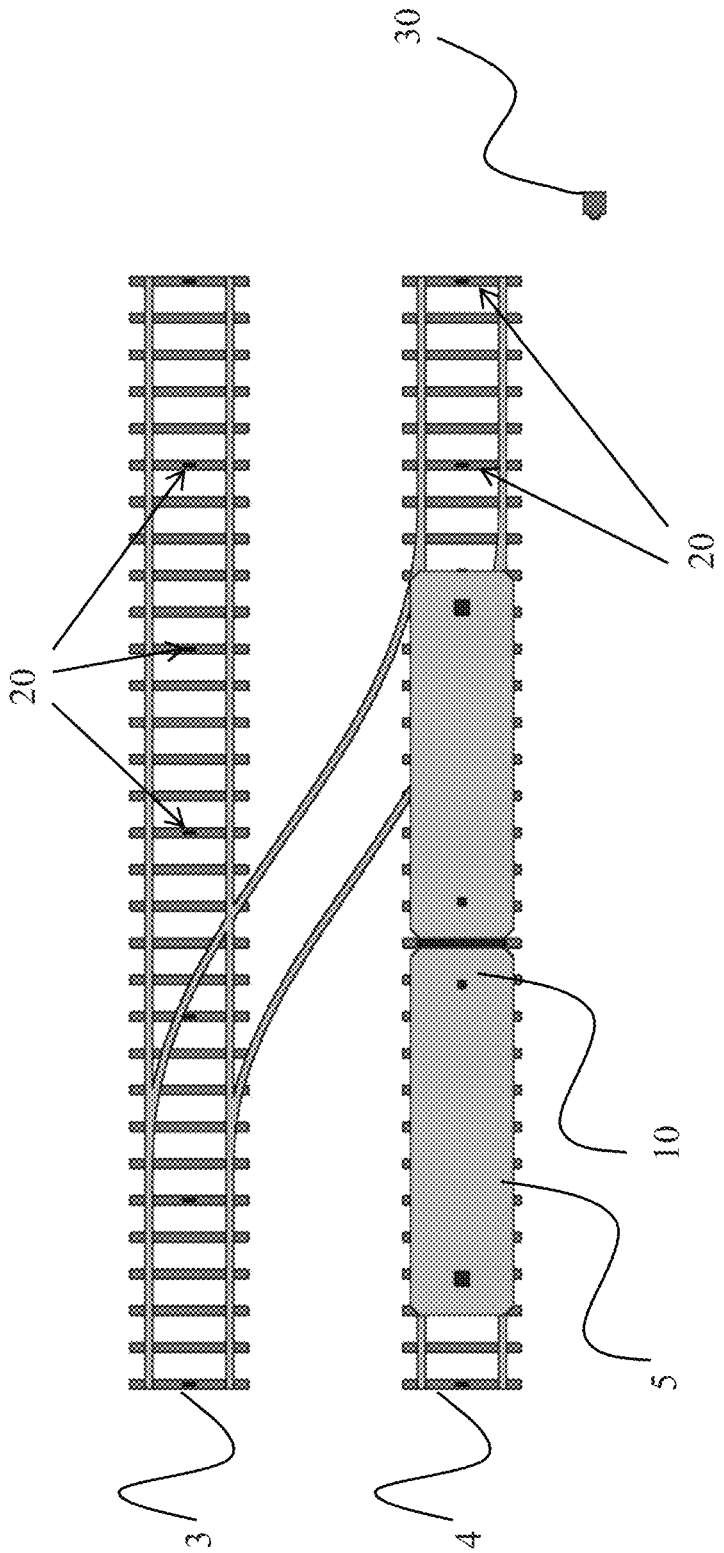
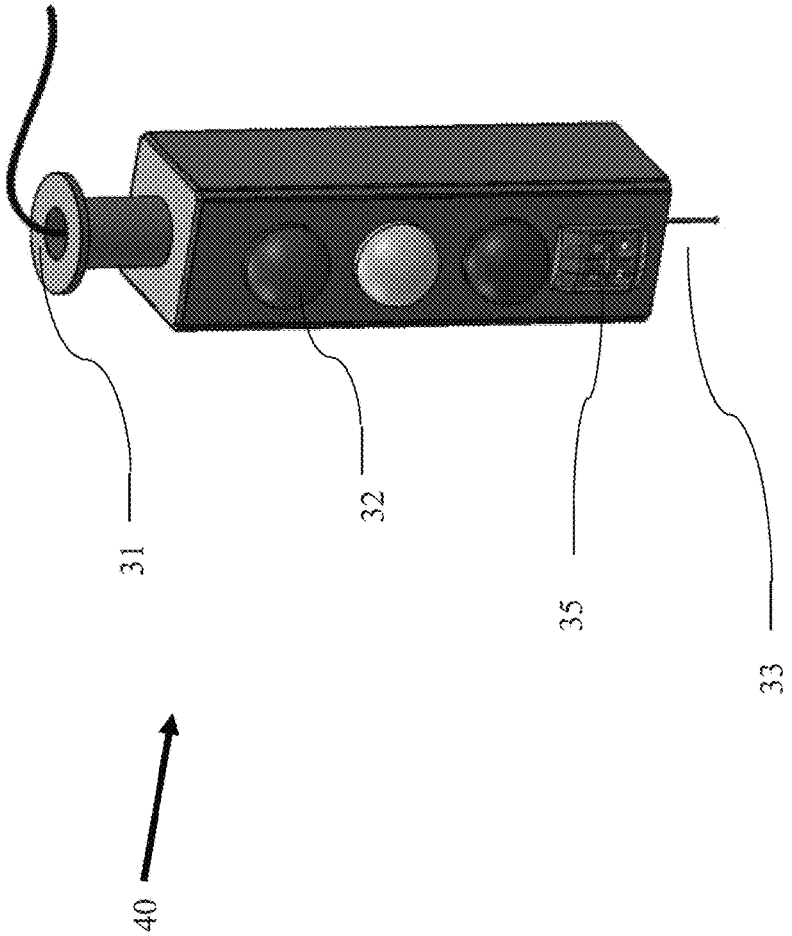


FIGURE 3



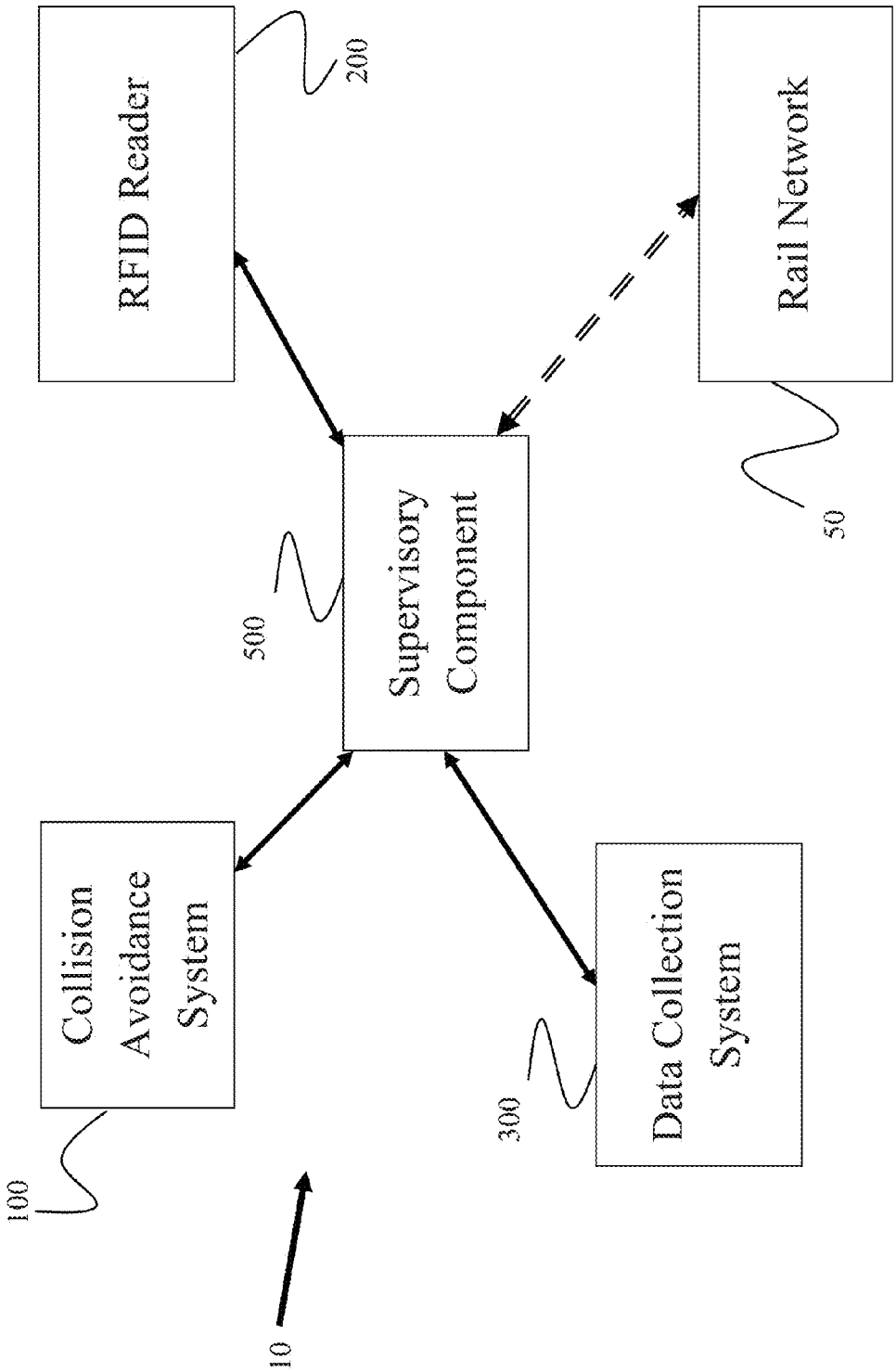
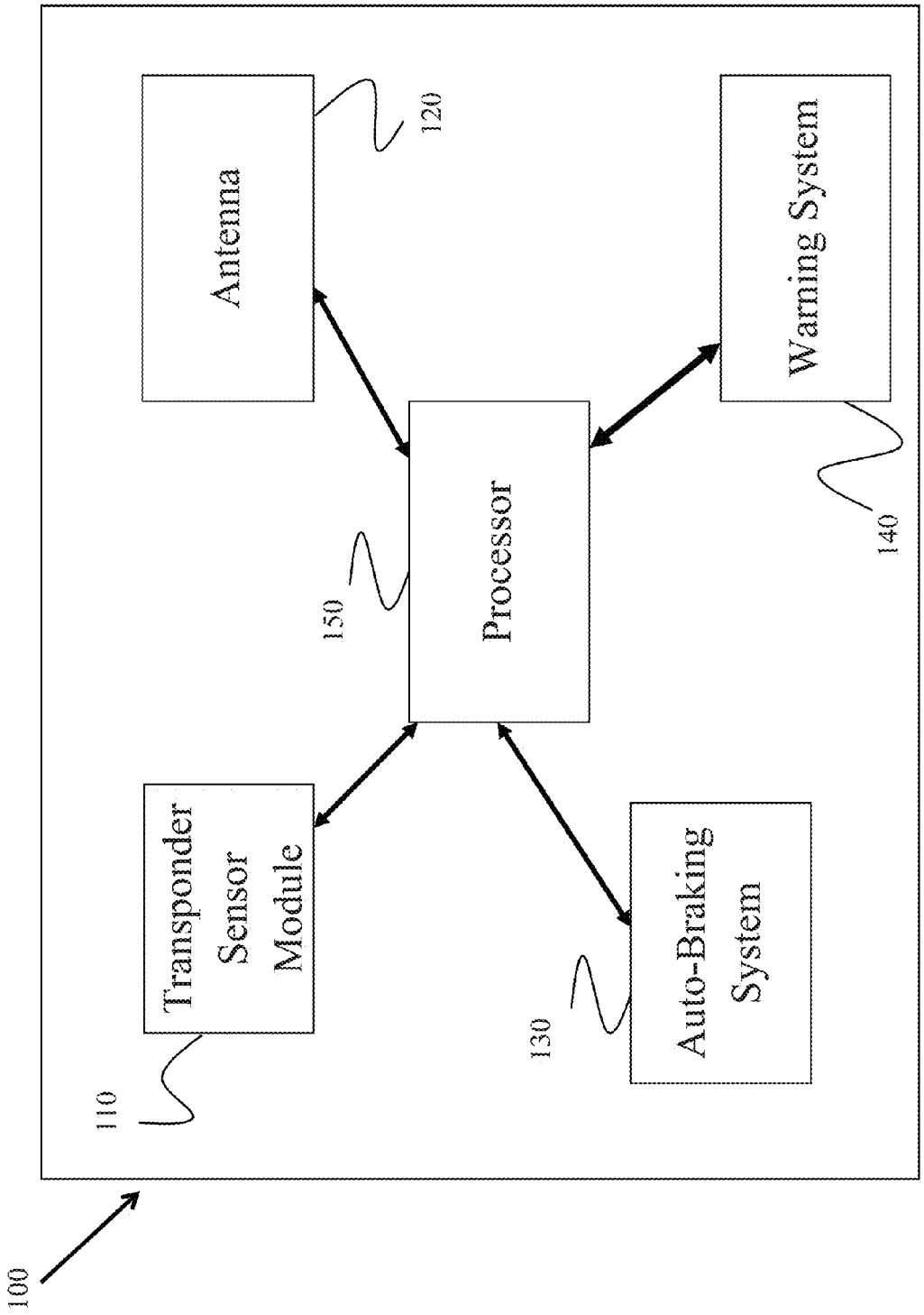

RFID Reader
200
Rail Network
50
Supervisory Component
500
Collision Avoidance System
100
Data Collection System
300
10

FIGURE 4

FIGURE 5


Antenna
120
Warning System
Processor
150
140
Transponder Sensor Module
Auto-Braking System
130
110
100

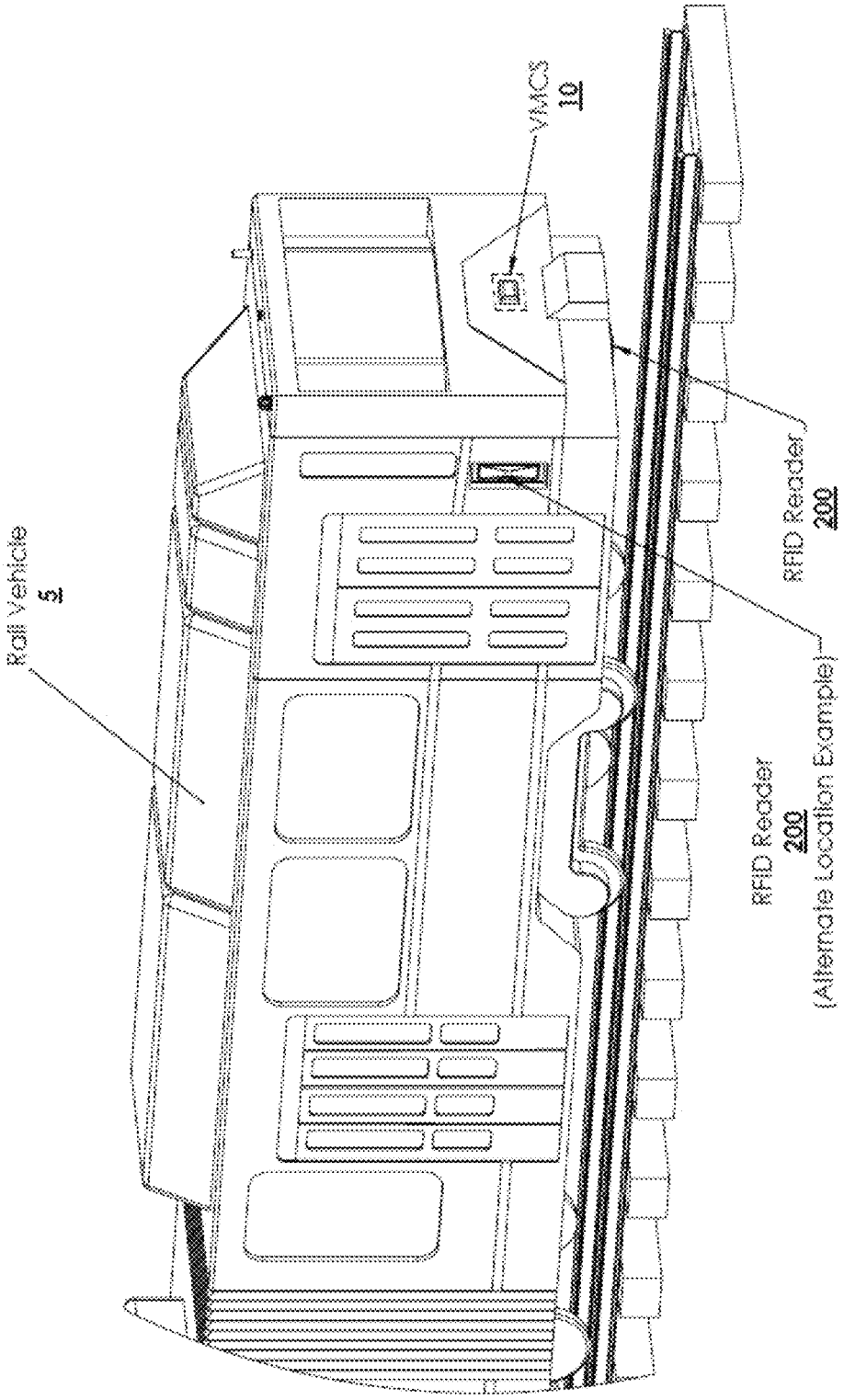

VMC3
10
Rail Vehicle
5
RFID Reader
200
RFID Reader
200
(Alternate Location Example)

FIG. 6

FIGURE 7

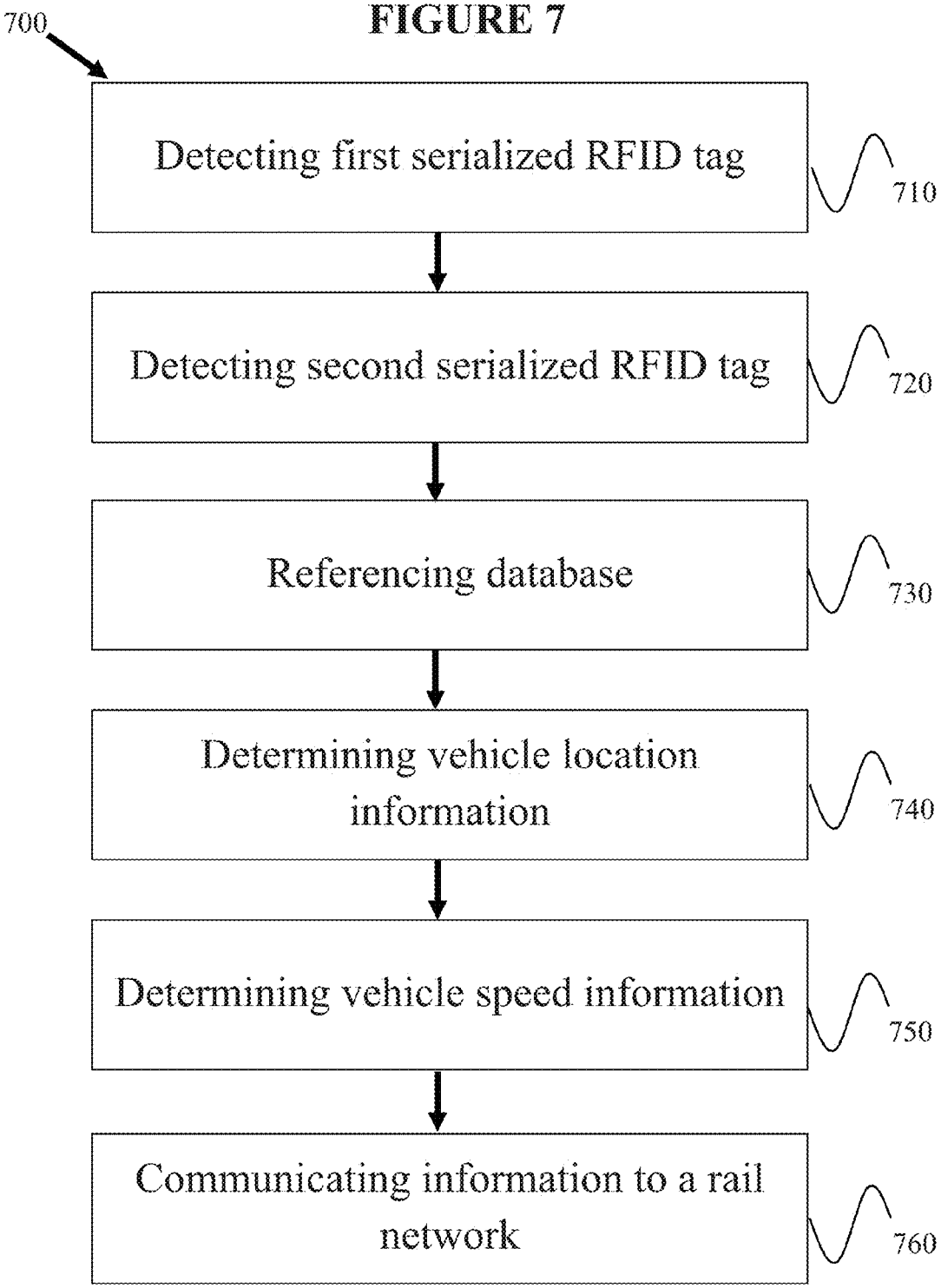
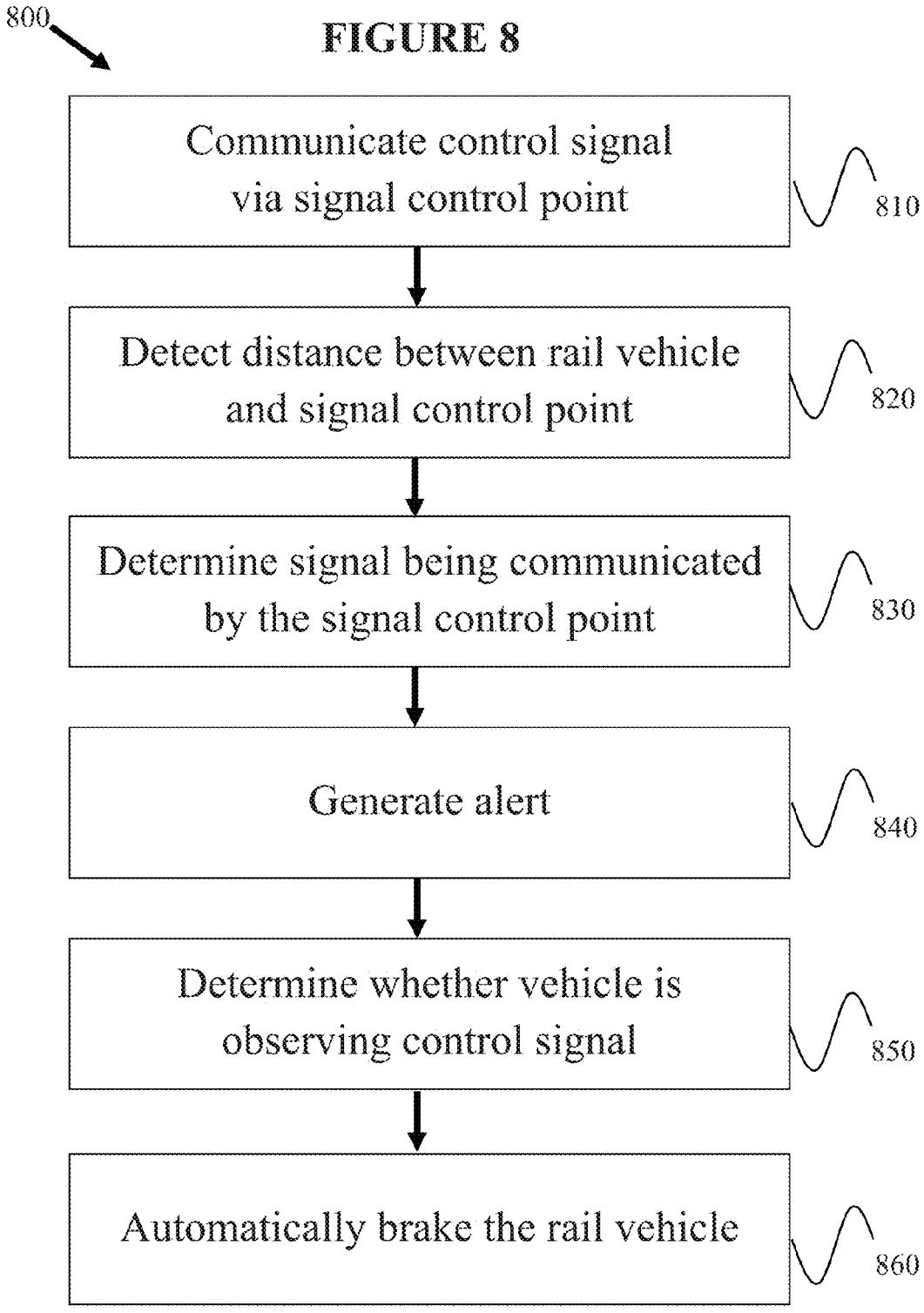

700
Detecting first serialized RFID tag
710
Detecting second serialized RFID tag
720
Referencing database
730
Determining vehicle location information
740
Determining vehicle speed information
750
Communicating information to a rail network
760

FIGURE 8


800
Communicate control signal via signal control point
810
Detect distance between rail vehicle and signal control point
820
Determine signal being communicated by the signal control point
830
Generate alert
840
Determine whether vehicle is observing control signal
850
Automatically brake the rail vehicle
860

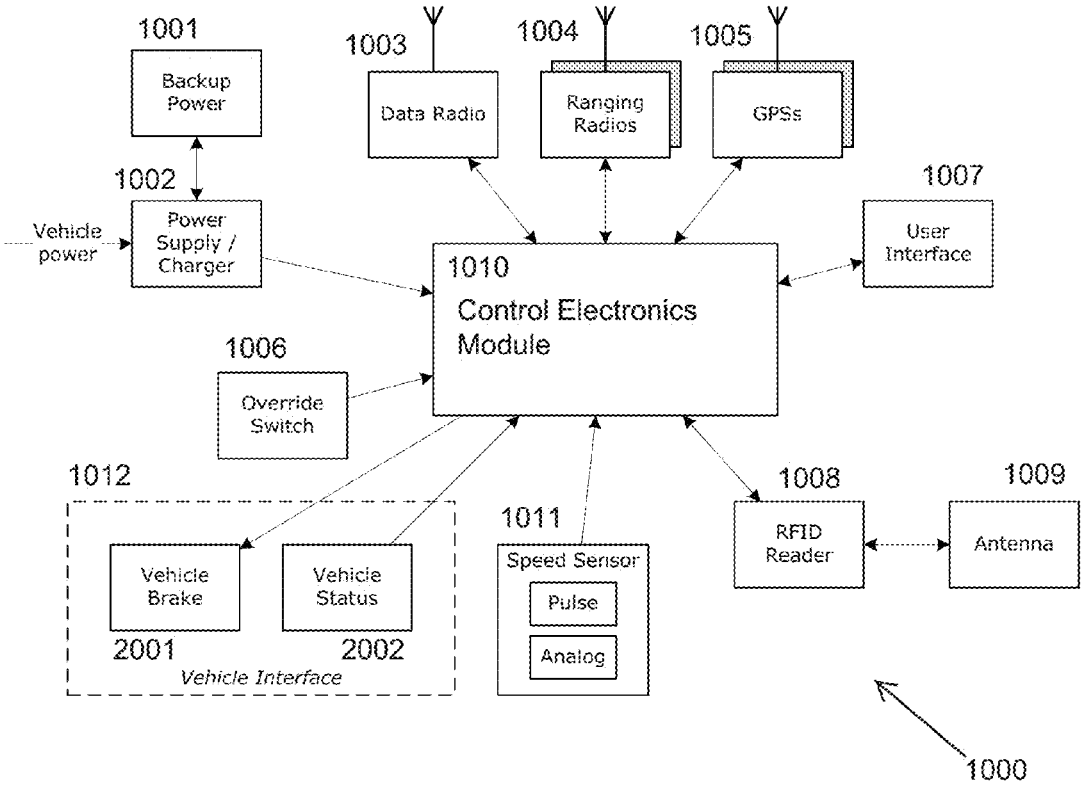

1001
Backup Power
1002
Power Supply / Charger
Vehicle power
1003
Data Radio
1004
Ranging Radios
1005
GPSs
1007
User Interface
1010
Control Electronics Module
1006
Override Switch
1012
Vehicle Brake
Vehicle Status
2001
2002
Vehicle Interface
1011
Speed Sensor
Pulse
Analog
1008
RFID Reader
1009
Antenna
1000

FIG. 9

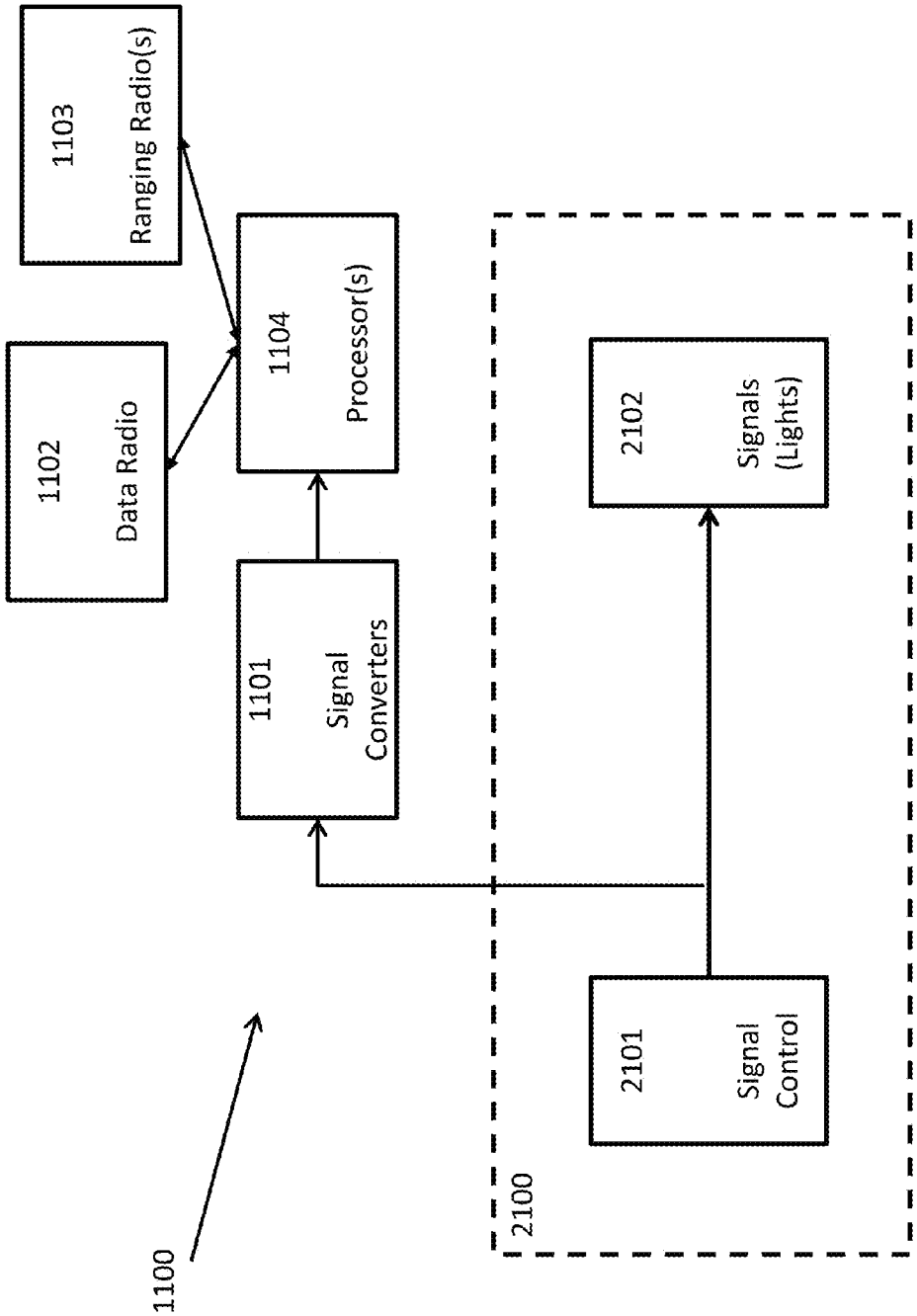

1103
Ranging Radio(s)
1102
Data Radio
1104
Processor(s)
1101
Signal Converters
2102
Signals (Lights)
2101
Signal Control
2100
1100

FIG. 10

RAIL VEHICLE SIGNAL ENFORCEMENT AND SEPARATION CONTROL

CROSS REFERENCE TO RELATED APPLICATIONS

This application is a continuation of U.S. patent application Ser. No. 14/476,338, filed Sep. 3, 2014, and claims priority to U.S. Provisional Patent Application No. 61/959,729, entitled "Light Rail Control System," filed on Sep. 3, 2013, each of which is incorporated by reference in its entirety herein.

FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

[Not Applicable]

JOINT RESEARCH AGREEMENT

[Not Applicable]

SEQUENCE LISTING

[Not Applicable]

BACKGROUND

Railroads have had several severe collisions and other accidents, some resulting in fatalities, when adequate spacing has not been maintained between rail vehicles. A major issue causing rail collisions involves vehicle operators failing to respond to a control point signal, such as a stop signal. For example, vehicle operators may fail to notice a control point signal due to visibility issues, equipment errors, operator maladies, or negligence. In such a situation, rail vehicles may continue to travel along a track not safe for travel, potentially resulting in disastrous collisions and/or accidents.

The Federal Railroad Administration established a system of rail regulations called positive train control ("PTC"). PTC is a system of functional regulations for monitoring and controlling train movements to provide increased safety. PTC, however, is an expensive system that is difficult to implement, particularly in light of the technology presently available. For public transit systems, PTC will generally increase travel time, passenger wait time, and decreased throughput.

Moreover, problems can also occur on railroads when sufficient spacing between rail vehicles is not properly maintained. Rail vehicle spacing can be monitored and maintained using various equipment and sensors installed on rail vehicles. For example, spacing between vehicles may be monitored by use of a global positioning system ("GPS") that tracks and follows the location of rail vehicles on a rail track.

However, present methods and systems for controlling and enforcing rail vehicle separation can be insufficient, particularly under certain circumstances. For example, in subterranean tunnels, or subways, rail vehicles may not have a clear view of the sky, and therefore, may not be traceable by GPS methods. It can therefore be difficult for the operator of such a rail vehicle, to know the location, speed, and position of the rail vehicle relative to other vehicles on the train track with the accuracy necessary to operate safely and efficiently. Moreover, it can be difficult for a rail vehicle control system to properly enforce separation among rail vehicles on a railroad track if the precise location of each rail vehicle is not accurately known. For example, PTC can "dead-reckon" using the odometer in non-GPS areas, but there may be degradation in accuracy. This degradation may be acute in commuter rail applications where train spacing is less than with freight rail.

SUMMARY

Certain embodiments of the present technology provide a rail vehicle control system installable on a rail vehicle. The rail vehicle control system can include a collision avoidance system including a transponder sensor module. In some embodiments, the transponder sensor module is operable to communicate with one or more transponder sensor modules installed on one or more proximate rail vehicles, and/or one or more signal control points to detect a distance between the rail vehicle and the proximate vehicle and/or the signal control point. For example, in certain aspects of the present technology, the collision avoidance system can detect a distance between the rail vehicle and the proximate rail vehicle or signal control point based at least in part on the time it takes a signal to travel between the transponder sensor modules. The control system can also include a radio frequency identification ("RFID") reader adapted to detect serialized RFID tags mounted at locations along a railroad. In certain aspects, the vehicle separation control system includes a data collection system operable to obtain rail vehicle information from the collision avoidance system and the RFID reader. The data collection system can include, for example, a data storage device. In some embodiments, the rail vehicle control system includes a supervisory component in communication with the collision avoidance system, the RFID reader, and the data collection system. The supervisory component can be operable, for example, to communicate rail vehicle information to a rail network.

Certain embodiments of the present technology provide a railroad control system operable to manage rail vehicle separation on a railroad track. The railroad control system can include a rail network that maintains information relating to the location and speed of rail vehicles on the railroad track. In some embodiments, the railroad control system includes multiple serialized RFID tags mounted at locations along the railroad track. The railroad control system can also include at least one signal control point located along the railroad track. Each signal control point can be operable to display signals viewable by a rail vehicle operator. In some embodiments, the signal control points comprise a station transponder sensor module operable to send and receive wireless signals. Each signal control point can also be operable to communicate with the rail network. Some embodiments also include a vehicle mounted system installable on a rail vehicle. The vehicle mounted system can include a vehicle transponder sensor module operable to communicate with a station transponder sensor modules installed in a signal control point to detect a distance between the rail vehicle and the signal control point. The vehicle mounted system can also include a RFID reader adapted to detect the serialized RFID tags mounted along the railroad track. In certain embodiments, the vehicle mounted system also includes data collection system in communication with the vehicle transponder sensor module and the RFID reader. The data collection system can also include a data storage device. In some aspects, the vehicle mounted system also includes a supervisory component operable to communicate with the rail network. In some embodiments of the present technology, the vehicle mounted system

obtains vehicle information relating to the railroad track that the rail vehicle is traveling upon, the rail vehicle location, and the rail vehicle speed based on the serialized RFID tags detected by the RFID reader. In some embodiments, the vehicle mounted system can also communicate the vehicle information to the rail network.

The present disclosure also provides a method for determining the speed and location of a rail vehicle traveling on a railroad track. The method can include the step of detecting a first serialized RFID tag installed along a railroad track with an RFID reader installed on the rail vehicle, where the first serialized RFID tag is detected at a first time (e.g., time t**1**). The method can also include the step of detecting a second serialized RFID tag installed along the railroad track with the RFID reader, where the second serialized RFID tag is detected at a second time (e.g., an earlier or later time t**2**). The method can also include the step of referencing a database to obtain information relating to the location of the first and second serialized RFID tags. In some embodiments, the method includes determining vehicle location information based at least in part on the information relating to the location of the first and second serialized RFID tags. Some embodiments of the method can also include determining vehicle speed information based at least in part on the location of the first RFID tag and the first time, and the location of the second RFID tag and the second time. The method can also include the step of communicating the vehicle location information and the vehicle speed information to a rail network, for example, communicating the information to a rail network via a reporting station installed along a railroad track.

Certain embodiments of the present technology also provide a method for enforcing rail vehicle adherence to control signals. The method can comprise the step of communicating a control signal via a signal control point. In some aspects, the method includes the step of detecting a distance between a rail vehicle and the signal control point using a collision avoidance system. In some embodiments, the step of determining a distance can be based at least in part on the time it takes a signal to travel between the transponder sensor modules on the rail vehicle and signal control point, for example. The collision avoidance system can comprise, for example, one or more transponder sensor modules installed on each of the rail vehicle and the signal control point. In certain embodiments, the method includes the step of generating a warning signal on the rail vehicle via a warning system when the collision avoidance system detects that the rail vehicle is approaching a signal control point that is communicating a stop signal. In some embodiments, the method can also include the step of automatically braking the rail vehicle when the collision avoidance system detects that the rail vehicle is not observing a stop signal communicated by the signal control point.

Certain embodiments of the present technology provide for a system for vehicle management. The system includes a control signal interface subsystem including an ultra-wideband (UWB) communications component. The system also includes a vehicle-mounted subsystem including a UWB communications component. The vehicle-mounted subsystem is configured to: interface with a braking system of the vehicle; communicate with the UWB communications component of the control signal interface subsystem via the UWB communications component of the vehicle-mounted subsystem; and determine a distance between the vehicle-mounted subsystem and the control signal interface subsystem based on a time-of-flight of at least one communication between the UWB communications component of the control signal interface subsystem and the UWB communications component of the vehicle-mounted subsystem.

According to a technique, the vehicle-mounted subsystem is further configured to generate an alert if the distance between the vehicle-mounted subsystem and the control signal interface is less than a threshold. According to another technique, the vehicle-mounted subsystem is further configured to cause the braking system of the vehicle to activate if the distance between the vehicle-mounted subsystem and the control signal interface is less than a threshold. According to another technique, the vehicle-mounted subsystem further includes: a radio-frequency identification (RFID) subsystem configured to scan at least one RFID tag external to the vehicle to retrieve information stored on the at least one RFID tag. In this technique, the vehicle-mounted subsystem is further configured to determine a distance between the vehicle-mounted subsystem and the control signal interface subsystem based on the information stored on the at least one RFID tag. According to another technique, the vehicle-mounted subsystem is further configured to substantially continuously receive information relating to speed of the vehicle. The vehicle-mounted subsystem determines a changing distance between the vehicle-mounted subsystem and the control signal interface subsystem based on the information stored on the at least one RFID tag and the information relating to speed of the vehicle. According to another technique, the system further includes an access point external to the vehicle. In this technique, the vehicle-mounted subsystem is further configured to: store data relating to prior behavior of the vehicle; and communicate the data relating to prior behavior of the vehicle with the access point.

Certain embodiments of the present technology provide for a system for vehicle management that includes: a control signal interface subsystem including an ultra-wideband (UWB) communications component; a first vehicle-mounted subsystem including a UWB communications component, wherein the first vehicle-mounted subsystem is configured to interface with a braking system of the vehicle; and a second vehicle-mounted subsystem including a UWB communications component, wherein the second vehicle-mounted subsystem is configured to be mounted on another vehicle. The first vehicle-mounted subsystem is configured to: communicate with the UWB communications component of the control signal interface subsystem via the UWB communications component of the first vehicle-mounted subsystem; communicate with the UWB communications component of the second vehicle-mounted subsystem via the UWB communications component of the first vehicle-mounted subsystem; determine a distance between the first vehicle-mounted subsystem and the control signal interface subsystem based on a time-of-flight of at least one communication between the UWB communications component of the control signal interface subsystem and the UWB communications component of the first vehicle-mounted subsystem; and determine a distance between the first vehicle-mounted subsystem and the second vehicle-mounted subsystem based on a time-of-flight of at least one communication between the UWB communications component of the second vehicle-mounted subsystem and the UWB communications component of the first vehicle-mounted subsystem.

According to one technique, the first vehicle-mounted subsystem is further configured to: generate an alert if the distance between the first vehicle-mounted subsystem and the control signal interface is less than a first threshold; and generate an alert if the distance between the first vehicle-

mounted subsystem and the second vehicle-mounted subsystem is less than a second threshold. According to another technique, the first vehicle-mounted subsystem is further configured to: cause the braking system of the vehicle to activate if the distance between the first vehicle-mounted subsystem and the control signal interface is less than a first threshold; and cause the braking system of the vehicle to activate if the distance between the first vehicle-mounted subsystem and the second vehicle-mounted subsystem is less than a second threshold. According to a technique, the first vehicle-mounted subsystem further comprises: a radio-frequency identification (RFID) subsystem configured to scan at least one RFID tag external to the vehicle to retrieve information stored on the at least one RFID tag; and wherein the first vehicle-mounted subsystem is further configured to determine a distance between the first vehicle-mounted subsystem and the control signal interface subsystem based on the information stored on the at least one RFID tag. The first vehicle-mounted subsystem may be configured to substantially continuously receive information relating to speed of the first vehicle; and the first vehicle-mounted subsystem may determine a changing distance between the first vehicle-mounted subsystem and the control signal interface subsystem based on the information stored on the at least one RFID tag and the information relating to speed of the first vehicle. According to one technique, the system includes an access point external to the vehicle. The first vehicle-mounted subsystem is further configured to: store data relating to prior behavior of the vehicle; and communicate the data relating to prior behavior of the vehicle with the access point.

Certain embodiments of the present technology provide for a vehicle-mounted system for interfacing with a brake loop of a vehicle, wherein the vehicle-mounted system comprises: a switch including a first contact configured to connect to a first side of the brake loop and a second contact configured to connect to a second side of the brake loop; and at least one processor in electrical communication with the switch. The at least one processor is configured to: automatically determine a braking event without receiving information about a status of an operator-controlled actuator; open the switch upon an occurrence of the braking event, thereby electrically disconnecting the first contact from the second contact; and close the switch upon an expiration of the braking event, thereby electrically connecting the first contact with the second contact. According to one technique, the at least one processor is further configured to cause an alert to be generated upon occurrence of the braking event. According to another technique, the at least one processor is configured to determine the expiration of the braking event based on a change in status of an operator-controlled input.

Certain embodiments of the present technology provide for a system for vehicle speed management, wherein the system comprises: a control signal interface subsystem; and a vehicle-mounted subsystem. The vehicle-mounted subsystem is configured to: communicate with the control signal interface subsystem to receive information corresponding to a status of the control signal; determine a rule for behavior of the vehicle according to the information corresponding to the status of the control signal; and observe operation of the vehicle to evaluate compliance with the rule. According to one technique, the rule corresponds to the status of the control signal being at least one of red, double red, yellow, or double yellow. According to another technique, the rule specifies a stop-time duration for the vehicle. The rule may specify a speed for the vehicle. The rule may specify a maximum speed for the vehicle after an expiration of the stop-time.

BRIEF DESCRIPTION OF SEVERAL VIEWS OF THE DRAWINGS

FIG. **1** is a block diagram of a rail control system for enforcing separation of rail vehicles on a railroad track in accordance with at least one embodiment of the present technology.

FIG. **2** shows an overhead view of a rail vehicle on a rail line equipped with a separation control system in accordance with at least one embodiment of the present technology.

FIG. **3** shows an example of an integrated signal control point used in accordance with at least one embodiment of the present technology.

FIG. **4** is a block diagram of a vehicle mounted control system used in accordance with at least one embodiment of the present technology.

FIG. **5** is a block diagram of a collision avoidance system used in accordance with at least one embodiment of the present technology.

FIG. **6** shows a rail vehicle traveling on a rail line, the vehicle equipped with a control system in accordance with at least on embodiment of the present technology.

FIG. **7** is a flow diagram of a method for determining the speed and location of a rail vehicle on a railroad track in accordance with at least one embodiment of the present technology.

FIG. **8** is a flow diagram of a method for enforcing rail vehicle adherence to control signals in accordance with at least one embodiment of the present technology.

FIG. **9** illustrates a block diagram of a vehicle mounted control system used in accordance with at least one embodiment of the present technology.

FIG. **10** illustrates a block diagram of a control signal interface subsystem in accordance with at least one embodiment of the present technology.

The foregoing summary, as well as the following detailed description of certain techniques of the present application, will be better understood when read in conjunction with the appended drawings. For the purposes of illustration, certain techniques are shown in the drawings. It should be understood, however, that the claims are not limited to the arrangements and instrumentality shown in the attached drawings.

DETAILED DESCRIPTION

The present disclosure generally relates to rail vehicle control systems and methods. More specifically, the present disclosure describes systems and methods for enforcing observance to rail signals, for enforcing rail speed limits, for controlling and enforcing rail vehicle separation on railroad lines, or for temporary speed restriction enforcement for railway workers or degraded rail conditions, for example, on light rail lines.

The present disclosure relates to systems and methods that control rail lines. The present disclosure also provides technology that provides information about the location and traveling speed of trains on a railroad track. For example, the present technology provides systems and methods for alerting a vehicle operator when the rail vehicle is approaching a control signal at an unsuitable rate, and for automatically braking such vehicles. The present disclosure can be used, for example, in connection with public transit (e.g., light rail

lines or commuter lines). The present disclosure, however, is by no means limited to public transit, and may be adapted for use with any combination of vehicles and/or control signals. The present disclosure also provides systems and methods for enforcing rail speed limits (whether temporary or permanent) and for alerting a vehicle operator when the rail vehicle is exceeding a rail speed limit.

Light rail systems typically employ rail vehicles that are manually controlled by operators located in the control cabs. Railroads can achieve safe separation between these rail vehicles can by providing visual cues, for example, visual signals observable by a rail vehicle operator. For example, signal control points and/or reporting stations located about a railroad track (e.g., alongside a railroad track) can provide the visual signals used to control the rail vehicle operation and separation. The signal control points can generate signals, for example, by producing lights of varying colors or audible sounds. For example, a signal control point can provide red, yellow, and green lights that signal a train operator whether it is safe to proceed to the next signal, whether the train operator should stop (e.g., by displaying a red light), or whether the train operator should proceed with caution or at a slower speed (e.g., by displaying a yellow light).

Unfortunately, human error, equipment error, and/or faulty signaling issues, can result in occasional failure to properly communicate and follow important signals. For example, operators may fail to respond in a timely manner to a signal, or a signal change on the rail track. Additionally, visibility conditions may cause a vehicle operator to misread, or fail to read a signal along the rail track. Such misread signals can result in collisions and other accidents that can have catastrophic effects. Because rail vehicles are massive objects that operate at high speeds, even the slightest impacts and collisions can cause significant damage to people and property, both on the railroad track and vehicles, and in the nearby areas. This is particularly so in high areas of high population, for example, in urban areas that employ mass-transit systems in close proximity to pedestrian areas and other buildings.

To address these and other issues, the present technology introduces protective systems and features that provide safeguards against these potential accidents. For example, the present technology provides systems, methods, and features that can detect when a rail vehicle is approaching or passing a signal control point that is indicating for the vehicle to stop, slow down, or proceed with caution. The present technology also provides systems that can automatically brake or reduce the speed of such vehicles.

The present disclosure also describes systems and methods that detect the presence of a rail vehicle on the same rail track and the distance between the vehicles. In this manner, the technology can effectively warn the operator or even automatically brake the vehicle when the distance between vehicles has broached an acceptably safe value. The safe separation distance may be variable according to, for example, the speed of each vehicle and the relative closing speed of the vehicles.

The present disclosure also describes systems and methods that determine whether the rail vehicle is operating in excess of the rail speed limit. In this manner, the technology can effectively warn the operator, automatically brake the rail vehicle, or otherwise control the rail vehicle so that it operates within the rail speed limit.

The present technology also provides systems and methods that allow a rail vehicle (or a rail vehicle operator) to determine the location, operating track, and speed of a rail vehicle, and to communicate that information to a rail network. In particular, the present technology provides systems and methods that allow for the determination of rail vehicle location and speed without the use of GPS technology. This feature can be effective, for example, in subterranean subway tunnels where trains do not have an ability to communicate with satellites transmitting GPS signals.

The present technology utilizes a variety of functionalities and technologies to monitor, control, and enforce separation between rail vehicles on a rail track. For example, in some embodiments, the present technology combines ranging technology such as ultra-wideband ("UWB") ranging, RFID tags and detectors, an ad hoc wireless network between vehicles and control signal control portions, and a wireless or wired data collection system.

In some embodiments, the present technology can utilize a collision avoidance system, such as that disclosed by U.S. patent application Ser. Nos. 13/474,428 and 14/252,987. U.S. patent application Ser. Nos. 13/474,428 and 14/252,987, which are incorporated by reference, describe a system that allows rail vehicles to communicate to determine the separation distance between vehicles.

The present technology can provide a transponder sensor module and/or an UWB system mounted on one or more trains or rail vehicles and can also be integrated into signal control points and/or reporting stations located along a railroad track (e.g., a signal control point located at the side of the tracks). In this manner, the transponder sensor module can determine a distance between the object upon which the transponder sensor module is mounted and another transponder sensor module mounted on another object (for example, another rail vehicle or signal control point). If the rail vehicles violate a pre-set separation distance, or a continuously calculated distance given the current vehicle speed and/or relative closing speed, as calculated by the transponder sensor module, the present technology can then initiate an auto-brake function to slow the offending vehicle or vehicles in order to maintain a safe distance among rail vehicles on a common railroad track.

The present technology can use time of flight techniques, as described in, for example, U.S. patent application Ser. Nos. 13/474,428 and 14/252,987 to detect a distance between rail vehicles and/or between rail vehicles and other objects, such as signal control points and/or reporting stations. For example, in some embodiments of the present technology, signal and/or reporting stations located along a railroad track can be equipped with collision avoidance systems, transponder sensor modules, UWB systems, and/or other ranging technology or radio network signaling devices. In this manner, the rail vehicles can communicate with the signal control points to alert the vehicle operators when the rail vehicle is approaching a signal control point, and the signal that the station is currently indicating. For example, the present technology can warn the vehicle operator that the rail vehicle is approaching a signal control point indicating a "stop" signal, and that the operator should begin to reduce the speed of the vehicle.

Certain embodiments also provide an RFID system, which can comprise an RFID reader or reader head mounted on the train. The RFID system can also include RFID tags (e.g., active and/or passive RFID tags), which can be mounted at locations on, along, or around the railroad track. For example, the RFID tags can be mounted on the rails or ties of the railroad track, or alternatively, on structures adjacent to the track. The RFID tags can be individually serialized for identification purposes, and available for reference or look-up in a database. In addition, the tags may be

programmed with specific data, such as a speed limit, track number, or distance to an associated signal, for example. In this manner, each RFID tag can be associated with a location, so that when the serialized RFID tag is read by the RFID reader, the system can have knowledge of the location of the rail vehicle upon which the RFID reader is mounted. Moreover, providing multiple RFID tags mounted on the railroad tracks allows the system to calculate the rail speed using the distance and time between successively read RFID tags. The RFID-based technique for calculating speed may be a supplemental, backup speed detection means. Other, potentially primary means of speed determination might be GPS, vehicle-mounted wheel speed sensor, and/or the change in distance and time to fixed ranging transducers.

In some aspects, the RFID system can also identify or determine a specific railroad track that it is operating upon. This feature can be particularly useful when the rail vehicle is traveling on a railroad track that operates in close proximity to a parallel railroad track. For example, if two trains are equipped with the collision avoidance system and approaching each other on parallel tracks, by using the RFID system, a rail vehicle or control system can determine that the two vehicles do not pose a collision threat, and therefore avoid false alarms and unnecessary auto-braking can be avoided. That is, by reading individually serialized or individually programmed RFID tags located on the track itself, the present technology allows for the identification of the specific track or line that the vehicle is traveling on, providing an ability to ignore or bypass unnecessary or invalid collision alerts.

By using the RFID system, the present technology enables a train location to be tracked with an accuracy greater than that allowable using only GPS methods. Conversely GPS technology does not have the resolution or accuracy necessary to determine a particular rail track that a vehicle is traveling upon, particularly when there are several parallel rail tracks located in close proximity to one another. In this manner, the present technology provides a system that can determine and be aware of the particular operating rail track for each vehicle, so that real collision threats can be determined, and other non-threatening situations, like an upcoming vehicle on a parallel rail track, can be ignored.

In some embodiments, the RFID system can also monitor a specific train position when the train is located in areas where conventional GPS positioning navigational aids are inoperative, such as tunnels and subways, for example. By reading each RFID tag's serialization code, or alternatively, a programmed mile-marker value, a specific location of the train can be determined. This information can then be wirelessly transmitted over to a supervisory component, for example, via a wired or wireless communication network, for further processing.

The data collection system can comprise an on-board data storage device capable of periodically sending data via wired or wireless transmission, for example, to or through a supervisory component. In this manner, the data collection system can communicate with a rail network to provide information about the rail vehicle location and speed, and to obtain information pertaining to the location and speed of other vehicles on the rail track. The data collection system can also maintain and transmit information relating to rail vehicle warning (e.g., collision alert) history, maintenance logs, and other related vehicle and track information. For example, the information can be transmitted to a rail network by communicating with communication modules located on reporting stations or signal control points located along the rail line. That is, the rail vehicle can communicate wirelessly with a reporting station to transmit and receive relevant vehicle information as the rail vehicle passes the reporting station on the track. The information can be assimilated into a database on the rail network and/or the rail vehicle data collection system for future analysis. In some embodiments the information can be used as a platform for generating automated alerts which can be sent out over a cell network, or other data stream.

In some embodiments, the present technology functions by independently monitoring the state of track block and switch control signals. For example, if a vehicle is approaching a signal control point indicating a red (i.e., stop) signal, the present technology can notify the operator of the vehicle that the red signal is approaching via an audible tone, a visual indication, and/or continuously provide an updated distance to the red signal to help ensure that the operator is aware of the stop indication. In some embodiments, if the vehicle operator fails to stop the in an appropriate time or distance relative to the red signal, the technology can apply vehicle brakes to slow or stop the vehicle.

The present technology also provides systems and methods that can monitor the separation distance between equipped rail vehicles, and apply safeguards to assure that the vehicle operators are warned of potential collision threats, and/or apply automatic stopping and braking of the vehicles where a collision may be imminent. For example, the acceptable separation distance may be automatically varied by this system in response to vehicle speeds, the grade of the track, and/or track condition directives (a we rail condition, for example, would result in extended stopping distances).

The present technology can accommodate the diverse range of operating, weather, and ambient temperature conditions in a variety of locations and circumstances. For example, the present technology can account for various weather conditions (e.g., ice, rain, extreme temperatures, etc.) and other locations and/or circumstances that add variability to rail travel, such as time-of-day or traffic volume. For example, the present technology can operate with rail vehicles operating on street rails that must take automobile traffic and various nearby fixed obstructions into account. The present technology can also operate with subway vehicles or in subterranean tunnels that have visibility issues and may not have access to GPS technology. The present technology can also operate in rail conditions that include sharp curves, closely spaced parallel tracks and track switches, or multiple rail intersections or crossover switches.

Certain embodiments of the present technology are shown by way of the figures included with the present application. For example, FIG. **1** is a block diagram of a rail vehicle separation control system **2** in accordance with one or more embodiments of the present technology. The rail control system **2** can include a vehicle mounted control system ("VMCS") **10**, which can be, for example, mounted or installed on a rail vehicle such as a train or subway car. In some instances, there may be more than one VMCS **10** mounted on a single vehicle (such as an articulated vehicle, where wiring between control systems is problematic or expensive). In some embodiments, the system **2** can comprise multiple VMCS's **10**, mounted on several rail vehicles. The VMCS's **10** mounted on various rail vehicles can be configured to communicate with one another in order to determine the speed of the vehicles, and the relative distance between the vehicles, for example.

The system **2** can also comprise one or more reporting stations **30** located along a railroad. The reporting stations

30 can be located at or integrated with, for example, signal control points or other objects positioned at fixed positions along a railroad track. The reporting stations 30 can include a communication mechanism that allows the rail vehicles and/or the VMCS 10 installed on the rail vehicles to exchange data and information, and otherwise communicate with the reporting stations 30. For example, the reporting stations 30 can include transceivers that allow the reporting stations to send and receive information via Bluetooth, WiFi, radio signals, cellular signals, UWB, peer-to-peer networks, microwaves, infrared signals, lasers, ultrasonic signals, electromagnetic induction signals, or other modes of wireless communication.

The reporting station 30 can also communicate and exchange information with a rail network 50. For example, the reporting station can be in wireless or wired communication with a rail network 50 that manages and maintains information relating to the speed and location of the rail vehicles connected to the network 50, as well as other information about the rail tracks and present weather conditions, for example. The rail network 50 can manage and control railroads and tracks in several locations or geographical areas. In some embodiments, the rail network 50 can manage and maintain railroad information pertaining to all railroad tracks in a region, a state, a country, a continent, or the world, for example.

Information from the VMCS 10 mounted on the rail vehicles can communicate with the network 50 via the reporting stations 30 such that each vehicle can be aware of the location of other vehicles traveling along the railroad, their speeds, weather conditions, railroad conditions or situations (e.g., steep grades, approaching sharp curves, rail crossings, or stations), and other information that can be useful to ensure safe and efficient rail transportation. In some embodiments, the VMCS 10 can communicate directly with the rail network 50 via a wireless communication mode without the use of a reporting station.

The rail control system 2 can also include one or more RFID tags 20 mounted at locations along a railroad track. For example, the RFID tags 20 can be mounted on the railroad rails or the ties of the railroad. In some embodiments, the RFID tags 20 can be mounted in other locations, for example, on the wall of a tunnel, on the ground, or on poles or stakes located along the railroad track. In this manner, the VMCS (which may include an RFID reader) can read the RFID tags 20 located along the railroad track to obtain information about the location, operating track, track speed limit, and/or speed of the vehicle.

FIG. 2 shows an overhead view of a rail vehicle 5 on a railroad line equipped with a rail vehicle separation control system in accordance with at least one embodiment of the present technology. FIG. 2 depicts two railroad tracks 3 and 4 running parallel to one another, and a rail vehicle 5 traveling along one railroad track 3. Each of the tracks 3 and 4 has a plurality of RFID tags 20 located on the railroad ties of the track. As shown in FIG. 2, the RFID tags 20 are positioned about every six ties; however, in some embodiments, the RFID tags can occur with more or less frequency as necessary for accurately determining the speed, track, and location of the rail vehicles 5. In some embodiments, the RFID tags can be installed more frequently, for example, one RFID tag on every tie, or on every second, third, fourth, or fifth tie. Alternatively, the RFID tags can be installed less frequently, such as one RFID tag on every ten, 20, 30, 50, or 100 railroad ties. As another example, RFID tags could be located at a distance prior to signals that would allow a train at the highest speed to stop before the signal if braking began at the RFID tag (plus some safety margin), as well as on either side of switches to indicate the track segment on which the train is now operating. There may also be redundant tags at those locations.

Where the RFID tags are positioned closer together and occur with greater frequency, the system can detect the location and speed of the rail vehicle 5 with greater accuracy. For example, where the RFID tags are placed close enough together so that a slower moving rail vehicle can detect several RFID tags per second, the separation control system can continually determine and calculate the location and speed of the vehicle with the passing and detection of each RFID tag. However, RFID tags that are too close together may not be distinguishable by a rail vehicle traveling at a high rate of speed, and may therefore result in a less accurate speed determination. Conversely, where the RFID tags are located farther apart, the system may be unaware of the precise location and speed of the rail vehicle 5 in between the RFID tags, but the sufficient separation can assure that each RFID tag is properly readable and distinguishable from the others. Accordingly, in some embodiments, the RFID tags are placed sufficiently close together so as to accurately provide rail vehicle location and speed information, while also being sufficiently spaced to ensure that each RFID tag can be properly detected and distinguished by the VMCS 10 on the rail vehicle 5.

FIG. 2 also shows a reporting station 30 located along the railroad track 4. As shown, the reporting station 30 is located to the side of the railroad tracks in close proximity to the tracks. In this manner, the reporting station can be visible to a vehicle operator on a passing rail vehicle. In some embodiments, the reporting station 30 can transmit and/or receive information from a passing rail vehicle 5 via a VMCS 10, for example. The reporting station 30 can then transmit rail vehicle information and/or other information (e.g., information regarding weather conditions) to the rail network. For example, the reporting station 30 can include a transponder sensor module adapted to communicate with the transponder sensor module installed on the rail vehicle 5.

The reporting station 30 can also be, for example, a signal control point that generates signals viewable by an operator of the rail vehicle 5. For example, the reporting station 30 can provide signals in the form of various colored lights that provide information and/or instructions to an operator of a passing rail vehicle 10. The reporting station 30 may also communicate information (e.g., signal state or other types of information known to the reporting station 30) to the VMCS 10. FIG. 3 shows an example of a reporting station that operates as an integrated signal control point 40 in accordance with the present technology. The signal control point 40 comprises wiring 31 that can connect the signal control point 40 to a power source, a processor, and/or other controlling equipment. The signal control point also comprises one or more signal lights 32, which can be, for example, LED signal lights.

The signal lights can operate as a signal where the illumination of certain lights indicates a certain railroad track status, an instruction, or other information. For example, when a red light is illuminated, the signal control point can be indicating that the operator of the passing rail vehicle 5 should stop the vehicle 5. A green light can indicate that the rail vehicle 5 can proceed to travel along the track at the authorized speed. And a yellow light can indicate, for example, that the rail vehicle operator should proceed with caution, or be prepared to stop at an upcoming signal. In some embodiments, the signal control point can include other signals, for example a double red signal (or a red over

red signal), which can indicate, for example, that the vehicle should stop and stay. In this manner, only an "authorized person," such as an inspector or higher ranking officer can hand flag a car through a double red signal. In some embodiments, the signal control point can also display a double yellow (or a yellow over yellow) signal, indicating that the operator should stop, and then proceed at a restricted speed with caution, for example, because an upcoming station may be occupied by a train.

The signal control point can also comprise a communication link **35**, which allows for communication and/or information exchange with passing rail vehicles and a rail network **50**. The communication link **35** can be, for example, a component of the AURA™ system provided by Metrom Rail, which is described in U.S. patent application Ser. Nos. 13/474,428 and 14/252,987 that are incorporated by reference. The communication link **35** can communicate, for example, with a VMCS **10** mounted on a passing rail vehicle **5**. In this manner, the communication link **35** can be used to execute warning signals as a rail vehicle **5** is approaching the signal control point **40** and/or to execute other functionality, such as automatic braking when the rail vehicle **5** is not heeding the signal control point **40** instructions. In some embodiments, the communication link **35** can be, for example, a transponder sensor module.

Referring again to FIG. **1**, the rail vehicle separation control system **2** comprises a VMCS **10** that is mounted on a rail vehicle, and communicates, either directly or indirectly, with a rail network **50**. The VMCS **10** also senses RFID tags **20** that are located along a railroad track. One embodiment of the VMCS **10** is depicted in greater detail in FIG. **4**.

FIG. **4** is a block diagram of a VMCS **10** that can be used in connection with the rail line vehicle separation control system of the present technology. The VMCS **10** can comprise one or more components that can be mounted, connected, or otherwise installed on a rail vehicle. For example, the VMCS **10** can be a single module comprising one or more components that and installable at a location on a rail vehicle. Additionally and/or alternatively, the VMCS **10** can comprise one or more modules, each module comprising one or more components and being installable at one or more locations on a rail vehicle. In some embodiments, the VMCS **10** is adapted to communicate with one or more VMCS's **10** installed on another rail vehicle operating on the same railroad track.

In certain embodiments, the VMCS **10** comprises a collision avoidance system **100**, an RFID reader **200**, a data collection system **300** and a supervisory component **500**. The VMCS **10** can include, or be in wireless communication with the rail network **50** that manages and maintains information about various rail vehicles and/or other VMCS's installed on vehicles on a railroad track.

The collision avoidance system **100** can be adapted to determine a distance between the rail line vehicle and another rail line vehicle operating on the same railroad track. For example, the collision avoidance system **100** can be adapted to communicate with a nearby or proximate rail vehicle operating on the same track. In some embodiments, the collision avoidance system **100** can communicate with at least the rail vehicle that is directly in front of it, and the rail vehicle that is directly behind it on the same railroad track. In this manner, the collision avoidance system **100** can determine a distance between the rail vehicle and the proximate rail vehicles on the same track. In some embodiments, the collision avoidance system **100** can include or incorporate one or more components of AURA™ system and/or the system described in U.S. patent application Ser. Nos. 13/474,428 and 14/252,987 (which have been incorporated by reference in their entireties).

A more detailed view of a collision avoidance system **100** is provided in FIG. **5**. FIG. **5** is a block diagram of a collision avoidance system **100**, which can include, for example, one or more transponder sensor modules **110**, one or more antennae **120**, an auto-braking system **130**, a warning system **140** and a processor **150**, or central control unit. As disclosed herein, a "processor" may include more than one processors acting together to achieve a given function. According to one technique, the processor **150** includes a main processor and a safety processor to make the system more robust and fail-safe.

One or more transponder sensor modules **110** can be located on the rail vehicle. According to one technique, one transponder sensor module **110** is located on or proximate to the front of the rail vehicle, and another transponder sensor module **110** is located on the back of the vehicle. According to another technique, only one transponder sensor module **110** is located at a known location on the rail vehicle.

In some embodiments, the transponder sensor module **110** is adapted to send out a signal and receive a reflective or responsive signal from a corresponding transponder sensor module installed on another rail vehicle. The transponder sensor module **110** can send signals using a one or more technologies and methods. For example, in some embodiments, the transponder sensor module **110** can be or include a UWB ranging unit configured to send UWB radio waves. Additionally and/or alternatively, the transponder sensor module **110** can comprise a transceiver configured to utilize another communication technology including, but not limited to, radio waves, lasers, ultrasonic waves, RADAR, or light signals (e.g., infrared signals), that can be reflected or re-sent at a determinable speed. The transponder sensor module **110** can be used to communicate with other transponder sensor modules installed on proximate rail vehicles, for example, by sending radio waves/pulses outward via the antenna **120** or other transceivers associated with the transponder sensor module **110**.

In this manner, a distance between the various transponder sensor modules **110** (and thus, the distance between the rail vehicles upon which the transponder sensor modules are installed) can be determined. By measuring how long it takes a wave/pulse or a signal to travel (for example by reflecting and/or bouncing, or a precisely timed response) between two transceivers, the distance between the transponder sensor modules can be accurately determined. That is, the present technology can detect the distance between two rail vehicles and/or the distance between a rail vehicle and signal/reporting station based on the time it takes a signal to travel between the transponder sensor modules. This technique may be referred to as "time of flight." The processor **150** or another processing unit can be used to determine the distance between the vehicles based on the results of the time of flight.

Consider the scenario in which a transponder sensor module **110** is located on the back of a first rail vehicle and another transponder sensor module **110** is located on the front of a second rail vehicle. The first rail vehicle is in front of the second rail vehicle. In this scenario, the time of flight technique can be used to determine the distance between the two transponder sensor modules **110**, and therefore the distance between the first and second rail vehicles.

Consider, alternatively, the scenario in which there is only one transponder sensor module **110** on the first rail vehicle and only one transponder sensor module **110** on the second

rail vehicle. The first rail vehicle is in front of the second rail vehicle. Given the time of flight and the known length of one or more of the first or second rail vehicles, the distance between the vehicles can be determined. For example, if the transponder sensor modules **110** are located on the front of each rail vehicle, the distance between the vehicles would be a function of the distance between the transponder sensor modules **110** and the length of the first rail vehicle. As another example, if the transponder sensor modules **110** are located on the back of each rail vehicle, the distance between the vehicles would be a function of the distance between the transponder sensor modules **110** and the length of the second rail vehicle.

In some embodiments of the present technology, the collision avoidance system **100** also includes a GPS unit that can be used in combination with (or as a component of) the transponder sensor module to determine a position (e.g., an absolute position) of the rail vehicle. In this manner, the present technology can combine GPS functionality with the time of flight technology to determine a separation distance between rail vehicles. The GPS and/or the time of flight technology can serve as redundant systems that assure a separation distance between rail vehicles is known even when one of the systems is not effectively working. For example, the GPS unit can be used to ensure that the time of flight technology is not providing incorrect separation distance information because of reflected signals. Moreover, the time of flight technology can be used to observe separation distance in situations where the GPS unit is incapable of receiving positioning information, for example, due to issues with satellite connectivity. This can be particularly useful, for example, for rail vehicles traveling in subterranean tunnels (e.g., subways), where there is limited or no access to GPS functionality. The GPS operating frequency may be 1.575 GHz. The system may include two GPS receivers, for example, to provide redundancy. GPS information may provide speed data and the vehicle direction of travel. Such data may allow for periodic self-calibration of the on-board vehicle speed measurement system. This can allow for automatic compensation of wheel wear (which can otherwise cause exaggerated speed measurements over time). The VMCS **10** may perform the automatic compensation.

The VMCS **10** may have a speed measurement system which may be distinct from the speedometer of the vehicle (prior to installation of the VMCS **10**). The VMCS **10** may receive information regarding the rate of wheel rotation, and speed may be calculated therefrom. The VMCS **10** may also be capable of determining speed information from GPS information and/or RFID tag scanning rate. It may also be possible to measure speed using the UWB time-of-flight data, since this data provides substantially continuous location information over time.

In some embodiments of the present technology, the collision avoidance system **100** can operate fully, effectively, and safely without GPS technology. This is particularly true for subway rail vehicles, which can often have limited or no use for a GPS feature.

In some embodiments, the collision avoidance system **100** and/or the transponder sensor module **110** can communicate with reporting stations and/or signal control points, such as the signal control point **40** depicted in FIG. **3** (for example, via UWB communications). In this manner, the transponder sensor module **110** may communicate with the communication link **35** or another similar component of the signal control point **40** to determine a distance between the vehicle and the signal control point **40**.

The VMCS **10** may also implement a second or redundant wireless network. Such a network may improve the robustness of the system. Such a network may be of a different type than the first network. For example, the second network may be a spread-spectrum network (for example, one that implements frequency hopping). Such a network may operate at 2.4 GHz. The second network may transmit information similar to what is transmitted by the first network.

When the collision avoidance system **100** determines that the signals provided by the signal control point **40** are not being followed by the rail vehicle operator, the processor **150** can operate one or more other functions of the collision avoidance system **100**. For example, the processor may use the auto-braking system **130** to initiate an auto-braking feature to automatically brake or otherwise reduce the speed of the rail vehicle. In some embodiments, when the collision avoidance system **100** determines that the distance between the rail line vehicle and a proximate rail line vehicle operating on the same railroad track has come within a predetermined limit, the collision avoidance system **100** may initiate the auto-braking feature in order to prevent and/or reduce the likelihood of a collision. The processor can then log the auto-braking action, for example, in the data collection system **300** of the VMCS **10**.

In some embodiments, the auto-braking system **130** can be adapted to automatically brake a rail vehicle based on the distance between the vehicle and a signal control point **40**, depending on the signal indicated by the signal control point **40**. For example, the collision avoidance system **100** can automatically brake the rail vehicle when the collision avoidance system **100** detects that the rail vehicle is not observing a stop signal communicated by the signal control point. In some embodiments, the collision avoidance system **100** may determine that the stop signal is not being observed based on the speed of the rail vehicle and the distance between the rail vehicle and the signal control point. For example, in some embodiments, there can be a safety point located on the railroad tracks relative to the signal control point, the safety point representing the furthest location where rail vehicles can come to rest when a stop signal is indicated in order to ensure safe railroad track operation. In some embodiments, the safety point can be, for example, at or around the location of the signal control point. When the distance between the rail vehicle and the signal control point approaches or exceeds a limit where it is no longer possible to bring the vehicle to a complete stop before the safety point during existing conditions, the auto-braking system **130** can automatically brake the vehicle.

In some aspects of the present technology, the speed and/or distance used to determine whether or not to apply the auto-braking system **130** can vary based on conditions. For example, when the tracks are we or icy, the collision avoidance system **100** may determine that the stop signal is not being observed at a lower rate of speed and/or distance from the signal control point than under normal dry conditions. In certain embodiments, the collision avoidance system **100** may determine that the stop signal is not being observed if the rail vehicle passes the signal control point. In other embodiments, the collision avoidance system **100** may determine that the stop signal is not being observed if the vehicle operator fails to respond to warnings or other commands for a predetermined period of time, for example.

The auto-braking system **130** does not include the vehicle brakes. Instead, the auto-braking system **130** can be configured to work with brakes and associated vehicle componentry. The auto-braking system **130** can provide one or more

outputs that cause existing brakes to be applied (either at 100% of braking force or at some lesser level) or released.

The collision avoidance system **100** can also utilize the warning system **140** to initiate a warning signal as the rail vehicle approaches a signal control point **40** or another rail vehicle. The warning system **140** can be operable to initiate a warning signal indicating that the rail vehicle operator should decrease the speed of the rail vehicle. In some embodiments, the warning system **140** can operate to initiate a warning signal as the rail vehicle approaches or passes a signal control point indicating a stopping signal. Additionally and/or alternatively, the warning system **140** can be operable to initiate a warning signal when the distance between the rail vehicle and a proximate rail vehicle is within a predetermined limit. For example, the predetermined limit can be a value that ensures that the rail vehicle can safely be brought to a complete stop without colliding with the proximate vehicle. The predetermined limit can vary depending on the rail conditions, the weather conditions, and the speed of the rail vehicle and the proximate rail vehicle, for example.

For example, when a rail line vehicle is approaching a signal control point **40** indicating a red light, the warning system **140** can generate an audible and/or visual warning indicating the approaching signal. Further, the warning system **140** can be configured so that the warning signal changes, or increases in intensity as the signal is approaching. In some embodiments, a warning signal, or warning alarm can involve a continuous, alternating audible notification for the vehicle operator, along with an urgent flashing visual indication. In some embodiments, the warning signal can sound continuously until the operator presses an acknowledge button an interface, until the vehicle has come to a stop, or until the condition that caused the alarm has been cleared. In some embodiments, after a warning alarm has been acknowledged, the collision avoidance system **100** can initiate a reminder alert will sound periodically (e.g., every five seconds) until the vehicle has come to a stop, or the condition that originally caused the alarm has been cleared.

In some embodiments, the collision avoidance system **100** may use auto-braking system **130** and the warning system **140** together. For example, when the vehicle passes a red signal without stopping, the collision avoidance system **100** can alert the vehicle operator using the warning system **140**, log the event description, timestamp, signal state, measured distance to the signal, and the vehicle operating conditions when the alarm was sounded. The collision avoidance system **100** can be configured such that the warning signal can be quieted if the vehicle operator presses a confirmation button, but to sound a periodic alert until vehicle is stopped or the signal is no longer red. If the vehicle doesn't begin braking within a predetermined distance or time (e.g., 50 feet or two seconds of passing the signal control point **40**), the collision avoidance system **100** use the auto-braking system **130** to slow or bring the vehicle to a haft.

In some embodiments, the collision avoidance system **100** can record and log information about passing signal control points. For example, when a vehicle is passing a signal control point **40** indicating a green signal, the auto-braking system **130** may not be used. Rather, the event can be logged with an event description, timestamp, signal state, and vehicle operating conditions when the signal was passed. Moreover, when the vehicle passes a signal control point **40** indicating a yellow signal, the collision avoidance system **100** may alert the vehicle operator; log the event description, timestamp, signal state, measured distance to the signal, and the vehicle operating conditions when the alert was sounded.

Referring again to FIG. **4**, the collision avoidance system **100** operates in connection with a supervisory component **500**, which also communicates with an RFID reader **200** and a data collection system **300**. In some embodiments, the RFID reader **200** can be connected to the collision avoidance system **100**. The data collection system **300** can include, for example, a data storage device capable storing data and information that can be accessible via the supervisory component **500**. The data collection system **300** can maintain a log of events, conditions, and rail vehicle information, and transmit that data to the rail network **50**. The data collection system **300** can also comprise a database of information that relates to the rail vehicle, the rail track, and other rail vehicles associated with the rail network **50**. Information obtained by the collision avoidance system **100** and/or the RFID reader **200** can be transmitted to stationary collision avoidance systems (e.g., collision avoidance systems installed on control signal points), which can in turn transmit the information to a rail network **50** (e.g., a wired network).

The RFID reader **200** can be configured to detect the RFID tags **20** that are installed or otherwise located along the railroad track. The RFID reader **200** can be configured to detect active tags, passive tags, or both. The RFID tags **20** can be serialized such that each RFID tag **20** is distinguishable from the other. In this manner, each RFID tag **20** can be associated with information about the location of the RFID tag. RFID tags **20** may also include or convey information relating to specific information about a given RFID tag **20**. Such information includes work zone status, speed limit, grade, subterranean track segment, track reroute, and/or increased stopping distances. Temporary tags **20** may be installed to temporarily provide such information to the VMCS **10**. Such information can be actually stored in a tag **20**, or may be stored in a database. The unique identity of the tag **20** may be used to look up such information in a database. Such a database may be stored in the VMCS **10** or remotely. A VMCS **10** database may be updated via the rail network **50**, for example, through an access point or reporting station **30**.

For example, each serialized RFID tag **20** can be referenced in a database once read by the RFID reader **200**. The database can be, for example, a part of the data collection system **300**. The database can include information pertaining to the location of each RFID tag **20** associated with the rail vehicle separation control system **2**. In this manner, each time the RFID reader **200** detects an RFID tag **20**, the VMCS **10** can consult the database via the data collection system **300** to determine the location of the RFID tag **20**, and thus, the location of the rail vehicle. Location may also be determined by interaction between a signal control point **30** and a map (for example, one stored in the VMCS **10** or remotely). If the signal control point **30** is known and the distance of the VMCS **10** from the signal control point is known, then location can be determined.

In some embodiments, the RFID reader **200** and/or the VMCS **10** can record a specific time at which each RFID tag **20** has been read. Thus, the speed of the rail vehicle can be determined based on the distance between two or more RFID tags **20**, and the time elapsed between the RFID tag **20** detection. In some embodiments, the present technology can include, or can be interfaced with a speed measurements system on the vehicle (e.g., the speedometer). In this manner the present technology and the existing speed measurement system can serve as redundant features to improve the speed calculation of the vehicle. The system may also include a

vehicle wheel speed sensor to independently determine the speed of the vehicle. These other speed determining components (speedometer and/or wheel speed sensor) may be used together with the RFID tag scanning system. Data from the speed determining components may be transmitted to other system components via an ad hoc, decentralized network. As another example, data generated by these other speed sensing components may be communicated to the rail network **50** similar to how the RFID tag scanning data is transmitted.

The RFID system (comprising the RFID reader **200** and the RFID tags **20**) can also be used to determine the specific railroad track that the rail vehicle is traveling on. That is, each serialized RFID tag **20** can be associated with a particular railroad track such that the VMCS **10** and the rail vehicle separation control system **2** can be aware of which track each rail vehicle is traveling. This can be particularly useful if two railroad tracks are located parallel to one another and in close proximity. By reading individually serialized RFID tags located on the track itself, the present technology allows for the identification of the specific track or line that the vehicle is traveling on, providing an ability to ignore or bypass unnecessary collision warnings or auto-braking processes. The RFID tags **20** may operate in a 900 MHz ISM band.

Using the RFID reader **200** and tag **20** system of the present technology, a VMCS **10** can be aware of the vehicle's location and speed at any time regardless of its location. The location and speed information can be determined even when the rail vehicle is not able to access satellites and/or GPS functionality. In this manner, the present technology can be used in subterranean tunnels and/or subways to keep all vehicle operators and rail control systems apprised of the location and speed of each vehicle on the network, regardless of its location or access to GPS functionality.

The VMCS **10** may actually have several ways of determining speed. Such ways include determining speed by: wheel rotation rate; GPS information; RFID tag **20** scanning; and/or distance ranging over time (for example, using the UWB time-of-flight data over time). This may provide redundancy for robustness and also serve to allow the VMCS **10** to periodically recalibrate the estimated wheel size (which is used in conjunction with the wheel rotation rate to determine speed).

The supervisory component **500** can be connected remotely and/or wirelessly to the rail network **50**. For example, the supervisory component can communicate with the rail network **50** via one or more reporting stations **30** that are installed or otherwise located along the railroad track. For example, when the rail vehicle passes a reporting station **30**, the supervisory component **500** and/or the VMCS **10** can communicate information to the reporting station **30**, and thus the rail network **50** wirelessly. For example, the reporting stations **30** and/or the VMCS **10** can include one or more antennae, receivers, transmitter, and/or transceivers that allow the reporting stations to send and receive information via Bluetooth, WiFi, radio signals, cellular signals, microwaves, infrared signals, lasers, ultrasonic signals, electromagnetic induction signals, or other modes of wireless communication. In this manner, the VMCS **10** can communicate information about the rail vehicle location, speed, separation between proximate vehicles, weather conditions, track conditions, and other relevant information to the rail network **50**. The rail network **50** can use this information to manage and maintain an entire railway system to ensure that all rail vehicles on the railway system are operating at safe distances from one another and/or are properly distributed for timely transit operations.

FIG. **6** shows an image of a rail vehicle **5** traveling on a rail line equipped with various components of a VMCS **10** of the present technology. The rail vehicle **5** can have a collision avoidance system **100** installed at a location on the front of the rail vehicle **5**. An RFID reader **200** can also be installed at the front end of the rail vehicle **5**, so that RFID tags located on the rails or ties can be read and detected. Other locations for the RFID reader **200** include the side, rear, or bottom of the vehicle **5**. Placing the RFID reader **200** on the bottom of the vehicle may be particularly effective when RFID tags **20** are located on rail ties. As shown, the VMCS **10** can be installed on a rail vehicle as a module that comprises one or more components separate from one another.

In operation, the present technology can be used to control and enforce separation among rail vehicles. In some embodiments, the present technology provides a system that can detect a distance between the rail vehicle and a proximate rail vehicle on the rail track. In some embodiments, the present technology vehicle separation control system is adapted to detect the location of the rail vehicle, the speed of the rail vehicle, and the distance between the rail vehicle and the proximate rail vehicle when the rail vehicle is located in a subterranean tunnel. The present technology can include systems that have an auto-braking system **130** that automatically reduces the speed of the rail vehicle when the distance between the rail vehicle and the proximate rail vehicle on the rail track is within a predetermined limit. The predetermined limit can be calculated based at least in part on the speed of the rail vehicle. For example, where a rail vehicle is traveling at a high rate of speed, it will take a greater distance to bring the vehicle to a stop. Accordingly, in such a circumstance, a predetermined distance can be relatively high to ensure that the rail vehicle can come to a complete stop before colliding with another vehicle.

Certain embodiments of the present technology relate to systems mounted or mountable on a rail vehicle. Moreover, some embodiments of the present technology relate to rail vehicle separation control systems that include or incorporate a VMCS **10** in addition to other features, including but not limited to: a rail network **50** maintaining information relating to the location and speed of rail vehicles on the railroad track; one or more of serialized RFID tags **20** mounted at locations along the railroad track; and one or more reporting stations located along the railroad track, the reporting station operable to communicate with the rail network **50**. The VMCS **10** can obtain vehicle information relating to the railroad track that the rail vehicle is traveling upon and the rail vehicle location based on the GPS information and/or serialized RFID tags **20** detected by the RFID reader **200**. Speed may be determined by these subsystems and/or by the wheel rotation rate. The VMCS **10** can then communicate the vehicle information to the rail network **50**. In some embodiments, the reporting station can be a signal control point operable to display signals viewable by an operator of a rail vehicle traveling along the railroad track.

Certain embodiments of the present technology also provide methods of enforcing rail vehicle separation. In some embodiments, the methods involve determining the speed and location of a rail vehicle traveling along railroad track.

FIG. **7** is a flow diagram **700** depicting a method for determining the speed and location of a rail vehicle in accordance with at least one embodiment of the present technology. The method may be performable using the

structures and functions described herein. The steps illustrated in the flow diagram **700** may be performable at least in part by one or more processors, such as the processor(s) in the VMCS. Furthermore, the steps illustrated in the flow diagram **700** may be performable in a different order, or some steps may be omitted according to design and/or preferences. The steps illustrated in the flow diagram **700**, or a portion thereof, may be performable by software, hardware, and/or firmware. The steps illustrated in the flow diagram **700**, or a portion thereof, may also be expressible through a set of instructions stored on one or more computer-readable storage devices, such as RAM, ROM, EPROM, EEPROM, flash memory, optical disk, magnetic disk, magnetic tape, and/or the like.

As shown in FIG. **7**, the flow diagram **700** includes, at step **710**, detecting a first serialized RFID tag located along a railroad track. The first serialized RFID tag can be detected, for example, with an RFID reader mounted on the rail vehicle. The first serialized RFID tag can have a serialized identifier, for example, that corresponds to location information of the RFID tag along the railroad track. In this manner, a VMCS can reference the serialized RFID tag in a database to obtain information about the RFID tag's (and thus the rail vehicle's) location along the railroad track. In some embodiments, at step **710**, the method may include noting a time (e.g., a first time n) that the serialized RFID tag was read.

At step **720**, a second serialized RFID tag is detected using the RFID reader. The second RFID tag can also have a serialized identifier that can be referenced in a database to obtain information about the RFID tag's location along a railroad track. In some embodiments, at step **720**, the method may include noting a time (e.g., a second time t**2**) that the serialized RFID tag was read.

At step **730**, the first and/or second serialized RFID tag are referenced in a database. In this manner, at step **730**, information can be obtained about the location of the rail vehicle at the first time n, and the location of the rail vehicle at the second time t**2**, based on the times that the first and second RFID tags were read by the RFID reader. In some embodiments, the RFID tags may be referenced by a latitude and longitude coordinate system. Additionally and/or alternatively, in some embodiments, each RFID tag may be associated with location information that is referenced with respect to the railroad tracks. For example, the RFID tags can be identified as a certain distance (e.g. 5 miles, 2390.81 feet) from a reference point, such as a rail station, a reporting station, railroad tie, etc.

At step **740**, the flow diagram **700** can include determining vehicle location information. For example, at step **740**, the flow diagram **700** can determine a precise or approximate vehicle location based on the location information associated with the RFID tags recently read by the reader based on the information referenced in the database. In some embodiments, the location information can be based on geographic coordinates (e.g., latitude and longitude coordinates) or a position relative to a reference point, for example. As another example, location information may correspond to a mile-marker value (e.g., 21.3 miles).

At step **750**, the flow diagram **700** determines the vehicle speed information. The vehicle speed information can be based on the locations of the RFID tags read by the RFID reader, the distance between the RFID tags, and the times at which the RFID tags were read. In this manner the method can determine and continually update the speed of the rail vehicle by dividing the distance between two detected RFID tags by the time elapsed between the points when they were detected. In certain embodiments, this can provide a validation, or redundancy for the on-board speed measurement system (e.g., the speedometer). That is, the RFID reader can be used as a cross-check to the on-board speed measurement system. If it is determined that there is a significant disagreement over the course of multiple measurement cycles, the technology may record a fault and notify the rail network. In this way any problems can be diagnosed and repaired.

The rail vehicle location and speed information can be logged, stored, and/or maintained in a database. For example, in some embodiments, the rail vehicle speed and location information can be logged in a data collection system that is a component of the VMCS as rail vehicle information.

In some embodiments the method also involves determining the distance between the rail vehicle and another rail vehicle. For example, in some embodiments, a VMCS can be used to send signals, and receive signals from other VMCS devices mounted on proximate rail vehicles. In this manner, a time of flight technology can be used to determine a separation distance between the rail vehicles. In some embodiments, a GPS unit can be used to determine the separation distance between two or more rail vehicles. And in some embodiments, the method may use a combination of time of flight and GPS technology to more accurately detect and determine a distance between rail vehicles operating on a common rail track. The separation distance information can also be logged, stored, and maintained in a database, for example, a data collection system component of a VMCS as rail vehicle information.

In some embodiments, other information can be obtained and recorded by the VMCS. For example, information about weather conditions, rail track conditions, rail track problems or issues, signal control point conditions, instructions, or issues, and/or passing rail vehicle issues can be detected. This information can also be logged, stored, and maintained in a data collection system component of a VMCS as rail vehicle information.

Logged information may be stored at the VMCS in non-volatile memory. Logging may involve two event categories: incident and activity. Incident logging may record catastrophic events (for example, a collision), whereas activity logging may be used for all other events (for example alarm-generating events or braking events).

At step **760**, the method communicates rail vehicle information to a rail network. The information can be communicated, for example, by transmitting information from a VMCS to a reporting station located along a rail track.

In some embodiments of the present technology, the method can involve generating a signal to alert a vehicle operator of an approaching stopping signal, an approaching vehicle, or of other noteworthy events, in particular, events that could result in a collision or accident such as excessive speed. In some embodiments, the present technology may automatically brake or reduce the speed of a rail vehicle. For example, in some aspects, methods could involve initiating an auto brake feature that automatically applies brakes to reduce the speed and/or stop the rail vehicle.

FIG. **8** is a flow diagram **800** depicting a method for enforcing rail vehicle adherence to rail control signals in accordance with at least one embodiment of the present technology. The method may be performable using the structures and functions described herein. The steps illustrated in the flow diagram **700** may be performable at least in part by one or more processors, such as the processor(s) in the VMCS. Furthermore, the steps illustrated in the flow

diagram **700** may be performable in a different order, or some steps may be omitted according to design and/or preferences. The steps illustrated in the flow diagram **700**, or a portion thereof, may be performable by software, hardware, and/or firmware. The steps illustrated in the flow diagram **700**, or a portion thereof, may also be expressible through a set of instructions stored on one or more computer-readable storage devices, such as RAM, ROM, EPROM, EEPROM, flash memory, optical disk, magnetic disk, magnetic tape, and/or the like.

As shown in FIG. **8**, the flow diagram **800** includes, at step **810**, communicating a control signal via a signal control point. For example, the signal control point can communicate a "stop" signal by presenting a red light, a "proceed" signal by presenting a green light, or a "proceed with caution" signal by presenting a yellow light. In some embodiments, the control signal may include a speed limit for the rail vehicle. The control signal can be communicated to passing rail vehicles, to a rail network, and to other signal control points, for example, via wireless communication devices.

At step **820**, the flow diagram **800** detects a distance between the rail vehicle and the signal control point. For example, the flow diagram **800** can employ a collision avoidance system to detect a distance between the rail vehicle and the signal control point using time of flight techniques. That is, in some embodiments, the step of determining a distance can be based on the time it takes a signal to travel between the transponder sensor modules on the rail vehicle and signal control point, for example. The collision avoidance system can comprise, for example, one or more transponder sensor modules installed on each of the rail vehicle and the signal control point.

In certain embodiments, at the step **830**, the flow diagram **800** can include determining whether the rail vehicle is approaching a signal control point indicating or communicating a control signal. A control signal may be a "stop" signal or a signal communicating a speed limit for the rail vehicle. For example, the flow diagram **800** can use a collision avoidance system to detect a distance between the rail vehicle and a signal control point to determine whether the signal control point is indicating a "stop" or other signal. For example, the rail vehicle can communicate with the signal control point and/or a rail network using a supervisory component to determine the signal that the signal control point is currently indicating. If it is determined at step **830** that the rail vehicle is not approaching a signal, the method can cycle back to step **820**, for example, and continue detecting the distance between the rail vehicle and upcoming signal control points. If it is determined that the upcoming signal control point is indicating a "proceed" signal, then the flow diagram **800** can allow the vehicle to proceed past the signal without any warning or suggestion to slow the vehicle.

If it is determined that the signal control point is indicating a "stop" signal, or any other signal suggesting that the rail vehicle reduce its speed (such as a speed limit signal), then the flow diagram **800** can proceed to step **840** and generate a warning signal. For example, step **840** can involve generating a warning signal via a warning system component of a collision avoidance system on the rail vehicle. In certain embodiments, the warning system can issue a series of beeps or alarms that will continue until the vehicle operator acknowledges the signal, for example, by pressing a button or communicating a signal acknowledgement, or until the vehicle reduces its speed or comes to a stop. In certain embodiments, the warning signal can be a progressive warning signal that increases in volume, duration, repetition rate, and/or frequency as the signal control point draws nearer. In this manner, the warning signal can be used as a failsafe to ensure that the vehicle operator recognizes the signal and thereby take steps to slow and/or stop the vehicle. Warning signal(s) may also be visual.

At step **850**, the flow diagram **800** determines whether the vehicle is observing the control signal. For example, at step **850**, the flow diagram **800** can determine, based on factors such as the vehicle speed, vehicle location relative to the rail signal, and rail track conditions whether it is possible for the vehicle to come to a stop in a safe manner. For example, given the speed of the vehicle, the track conditions, and the distance to the signal control point, an appropriate braking distance or speed reduction distance may be determined. This is a distance that allows for safe braking by the time the vehicle reaches the signal control point. If the vehicle does not begin slowing down at an appropriate rate once the distance is reached, then it can be determined that the vehicle is not observing the control signal.

In some embodiments, step **850** may determine that the vehicle is not observing the stop signal when the vehicle passes the signal control point (or any predetermined point along the rail track) at any speed. If it is determined that the vehicle is indeed observing the stop signal, the flow diagram **800** can cycle back to step **830**, **820**, and/or **810** and depending on the location of the train and the conditions of the signal control points. In some embodiments, step **850** may determine that the vehicle is not observing the speed limit signal when the vehicle passes the signal control point (or any predetermined point along the rail track such as an RFID tag).

According to one technique, a database of trackside RFID tags (each with a unique ID) is maintained. Each RFID tag (or a portion thereof) has an associated speed limit that is stored in the database. As the vehicle reaches an RFID tag, the speed of the vehicle is checked against the appropriate speed indicated by the database for the given RFID tag. If the vehicle speed exceeds the given speed limit for that tag, then it can be determined that the vehicle is not observing the speed limit. The database may store different limits for each RFID tag according to other conditions such as weather, construction, or time-of-day. Alternatively, the database may store one or more limits for each RFID tag that can be adjusted according to such other conditions. For example, if the track is we or there is rain, a speed limit value for an RFID tag may be reduced by a percentage, such as 20%. The database may be stored locally on the vehicle or remotely at a rail control system.

According to another technique, the distance of an approaching vehicle (for example, another vehicle in front of the vehicle) may be determined. The rate of change of the distance may also be determined. Based on the distance, the rate of change of the distance, the speed of the vehicle, the speed of the other vehicle, and/or the track conditions, it may be determined that there is a risk of the vehicles colliding. Accordingly, a warning (an alert may be a type of warning) may be generated.

If a warning is being generated, the failure of the vehicle to observe control points, speed limits, or recognize an approaching vehicle may escalate the level of the warning—e.g., causing a louder warning or a brighter, different colored warning (for example, go from yellow to red). If a warning is not being generated, then failure to observe control points or speed limits may cause a warning signal to be initiated.

If it is determined at step **850** that the rail vehicle is not observing the control signal, speed limit, or approaching

vehicle, then the flow diagram **800**, at step **860**, automatically brakes the vehicle, for example, using an auto-braking system. In some embodiments, the auto-braking feature can be applied until the rail vehicle comes to a complete stop, or until the vehicle speed is below a determined threshold (e.g., below 2 miles per hour or below the speed limit for that portion of the track), depending on the conditions and the situation. In some embodiments, once the vehicle has been brought to a stop or otherwise has been brought into compliance with the control signal, any warning signals currently generated (e.g., by step **840**) may cease or be altered to notify the vehicle operator of the current state of events.

In the event that the VMCS automatically stops the vehicle, the brake can be continually applied until the operator acknowledges that he or she is prepared to again assume control of the vehicle. This acknowledgement can be accomplished by pressing a confirmation button on the user interface. When pressed, the brake can be released and system operation is returned to normal. Note that the braking event and the acknowledgement events and times can be logged.

The VMCS may provide a way for status messaging to be uploaded to the rail network. Access points may be located periodically along the track (for example, vehicle storage yards or turn-around points). At these points, information may be transferred to and from the vehicle and rail network.

The systems and methods disclosed herein can provide additional layer(s) of protection for transit operations by warning the vehicle operator when operating rules are violated. If necessary to restore safe operating margins, the VMCS can cause the vehicle slow or stop using the vehicle's full service brake. The protection provided by these systems and methods can include signal compliance, speed limit compliance, vehicle-to-vehicle collision avoidance, operations and incident recording, work-zone temporary speed limits, vehicle location tracking, and precision station stopping. The techniques described herein can function by independently monitoring operating conditions such as vehicle speed, signal indications, and local speed restrictions on the transit line.

The techniques can operate through the use of multiple sensing and communication technologies which are mounted on the vehicle and at strategic wayside locations. The vehicle-side portion of the system can operate autonomously and make internal operational decisions without requiring a central server. The techniques can adapt to a transit system's existing operating rules and may not require the addition of restrictive block controls or additional vehicle spacing, avoiding adverse impact on existing system throughput. The techniques can operate as an overlay to the existing safety controls in transit systems by interfacing in a non-invasive means with legacy vital signals. This system enhances safety by providing warnings and/or actions which may include automatic braking in the event the transit vehicle operator fails to comply with operating rules and procedures. The techniques may comply with IEC61508 SIL 3.

The techniques may be used as a safety enhancement to supplement existing procedures and safe operating principles that transit vehicle operators are trained to follow. In order to avoid compromising the existing "safety net" already achieved with established operating behaviors, the techniques disclosed herein may to diminish or suppress operator responsibility. For example, instead of notifying the operator when the vehicle is approaching a track signal which is displaying a red (stop) indication, the techniques may not indicate a warning simply because the vehicle is approaching a red signal. Instead, the techniques may wait until the VMCS calculates that the approach speed to the red signal is beyond what has been determined as a reasonably safe operating margin. Only when vehicle operation has exceeded the established safe operating parameters will the techniques indicate a warning. If the safe operating margin continues to deteriorate because the operator fails to immediately slow the vehicle to a stop, the techniques can escalate intervention by automatically causing application of vehicle brakes until the vehicle comes to a stop.

This approach may keep the vehicle operator accustomed to being the primary facilitator of safe operation. In an alternative implementation, the techniques were to warn the operator every time the vehicle was approaching a condition that requires slowing or stopping, the operator may eventually become complacent. In time, under this alternative scenario, the operator may come to depend upon the system to maintain safe operation instead of being vigilant and observant. This alternative approach may compromise the intended safety enhancement intended.

According to one technique, in order to assure that the operator retains operational responsibility, the methods and systems keep a log of the conditions for each event where it intervenes by indicating a warning or by applying vehicle brakes. This log can include the nature of the intervention, the justification for the intervention, the date, time, vehicle ID, vehicle speed, vehicle direction of travel, operating track, location, and, where applicable, the distance to the signal, other vehicle, or the speed limit for the track segment. Audits of logs may highlight if a particular operator is in need of additional training or discipline.

According to a technique, the system may operate using a peer-to-peer data communications network (e.g., an ad-hoc network) between vehicles and signals. As components come into communications range, they enter the network. Such a decentralized approach may allow each vehicle to determine its safe operating envelope using only the necessary local inputs from signals and other vehicles.

FIG. **9** illustrates a vehicle management control system **1000** (or vehicle-mounted subsystem), and may be similar to VMCS **10**. For example, either the VMCS **1000** or VMCS **10** may be adapted to perform the techniques disclosed herein. The VMCS **1000** may include a backup power module **1001**, a power supply/charger **1002**, a data radio **1003**, one or more ranging radios **1004**, a GPS radio **1005**, an override switch **1006**, a user interface **1007**, an RFID reader **1008**, an RFID antenna **1009**, a control electronics module **1010**, a speed sensor **1011**, and/or a vehicle interface **1012**. The control electronics module **1010** may include one or more processors (or, for simplicity, a processor) and one or more memories. The control electronics module **1010** may control the operations of peripheral components and receive data from them as well.

The VMCS **1000** may include a power supply **1002** and/or charger and a backup power source **1001** (e.g., batteries) rechargeable by the charger **1002**. The power supply **1002** may provide suitable electrical power to the remainder of the VMCS **1000**. The power supply **1002** may receive power from the vehicle.

The data radio **1003** may be a peer finder. The data radio **1003** may be capable of detecting other peers, such as another VMCS **1000**, a signal control subsystem, a temporary control subsystem, or an access point, all of which are discussed below. Once peers have been identified, a peer-to-peer network may be created. The peer-to-peer network may operate independently of a central network, such as the rail network discussed above.

The control electronics module **1010** may determine or recognize the presence of peers detected by the data radio **1003**. The data radio **1003** may also serve to transfer data to and from other peers. The data network may be a spread-spectrum network and may employ frequency hopping. Such techniques may improve signal quality and robustness of the network. The data network may share speed and location of the vehicle with the other peers. This may facilitate determining a proper separation distance between the peers (be they other VMCSs or signal control subsystems). The data network may allow wireless data uploads of daily operation logs and fault reports, for example, with an access point. Information may be transmitted to a central network, either through another peer or directly, that includes operating data of the vehicle (e.g., location and speed) or faults that have been detected.

Once another peer is added to the network, the control electronics module **1010** may operate one or more ranging radios **1004** to communicate with the other peers. The radios may be described as "ranging," because they may operate in conjunction with the control electronics module **1010** to determine a distance between the VMCS **1000** and a given peer. Distance may be determined by time-of-flight of the communications with another peer. For example, a signal may be sent to a peer and it may be returned, and the time-of-flight may be calculated, thereby providing information about the distance to the peer.

One particularly useful technology for the ranging radios **1004** is an UWB network. UWB may provide a wide bandwidth distance measurement signal that can be used to measure distance, for example, within inches. UWB may be resistant to multipath distortions. Narrow-band time-of-flight distance measurement systems may suffer from multipath distortion. UWB may be compatible with varying operating environments including ones with buildings and walls (which cause reflections), curved tunnels, and underground. In addition to determining range information, the UWB network may be used to communicate data, such as: the VMCS's unique ID, a signal indication, a track number, a track direction, the vehicle speed, the vehicle direction of travel, or GPS information (position information and/or GPS clock value).

The GPS radio **1005** may be capable of receiving GPS information from satellites. This information may be translatable into a position by the control electronics module **1010**. The GPS operating frequency may be 1.575 GHz (civilian frequency). The GPS information may include absolute location and time/date information. The location information may be used to derive speed of the vehicle. The location and speed information may be used for collision avoidance techniques as discussed herein. The position/speed information may also be communicated to other peers or to a central network. The speed data may be used to automatically compensate for wheel wear when determining speed via the speed sensor **1011** discussed below. The time information may be used for data timestamps as well as local real-time clock calibration to allow accurate logging of event times.

The VMCS **1000** may include an override switch **1006** to override operation of the VMCS **1000**. In the override state, the vehicle may return to its native functioning (i.e., the functioning of the vehicle prior to installation of the VMCS **1000**). The override switch **1006** may be a physical actuator or an electronic signal.

The user interface **1007** may include one or more displays, input devices, or speakers. The user interface may receive inputs through the input device(s) from an operator. System information may be displayed on the display(s). Alerts may also be displayed on the display(s). The speaker (s) may also produce alerting sounds.

The RFID reader **1008** may operate with its antenna **1009** (collectively, RFID subsystem) to scan RFID tags located outside of the vehicle (e.g., trackside). The RFID network may operate in the 900 MHz ISM band. The tags may be passive or active tags. When the RFID reader **1008** approaches a tag, the contents of the tag may be retrieved and processed by the control electronics module **1010**. The RFID tag may contain a unique ID. The control electronics module **1010** may use that unique ID to retrieve additional information about the tag from a database (e.g., a database stored in the memor(ies) of the control electronics module **1010**. Such information (which may also be directly stored on the RFID tag) may include location, speed limit, track direction, distance to a control signal subsystem, or the like. If the speed of the vehicle is greater than the indicated speed limit, then feedback may be provided through the user interface **1007** (for example, alerting the operator visually or through sound that a speed limit has been exceeded).

The RFID subsystem may be employed to allow the VMCS **1000** to determine when the vehicle is a predetermined distance away from an upcoming signal along the direction of travel. This may provide a calibration check of the UWB and GPS subsystems. By locating a particular RFID tag on the track at a consistent distance before a track signal, or at a distance noted in the data stored in the RFID tag, the distance measurement accuracy may be periodically verified. In the event the RFID information indicates that the vehicle is approaching a particular signal but that signal is not being detected (for example, by radios **1003** or **1004**), it may be determined that there is a problem such as a fault in the VMCS **1000** radios or a fault in the radios of the missing peer. Such information may be logged or reported to the operator through the user interface or reported to another network such as a central network.

The speed sensor **1011** may sense the number and/or rate of revolutions of one or more wheels on the vehicle. This component may be added onto an existing vehicle (prior to installation of the VMCS **1000**), or may already be installed on the existing vehicle. The speed sensor may be a magnetic or optical sensor that, for example, measures a given number of pulses per wheel rotation. The speed sensor may also provide information relating to the direction of wheel rotation. The speed sensor may output a digital or analog signal (e.g., voltage with the magnitude being proportional to speed).

The VMCS **1000** may include a vehicle interface **1012** that interfaces with existing vehicle controls and data. The vehicle interface **1012** may interface with the vehicle's existing brake system. The brake system interface may include a switch that interrupts the vehicle's brake loop. The vehicle may include a fail-safe feature that automatically engages the brake when the brake loop is interrupted. The VMCS **1000** can leverage this vehicle feature by opening the brake loop when a braking event is determined by the control electronics module **1010**.

The brake system interface may include a switch. An exemplary switch may be, for example, a relay (solid state or mechanical). The first contact of the switch may connect to a first side of the brake loop and the second contact may be connected to a second side of the brake loop. To install the switch, an installer may find a suitable conductor on the brake loop, cut it, and then install the switch contact to each side of the cut conductor. It may also be possible to install the switch through other techniques. For example, an exist-

ing connector (e.g., terminal) can be removed from a contact on the existing vehicle and then moved to the connector the first contact on the switch. A jumper from the second contact of the switch may be run back to the original contact on the existing vehicle.

The processor of the control electronics module **1010** may cause the switch to open upon a braking event, thereby disconnecting the first contact from the second contact. This will cause the vehicle's braking algorithm and implementation to activate. The control electronics module **1010** may cause an alert to be generated by the user interface **1007** (visual and/or auditory) that there has been an automatic braking event (i.e., not a braking event caused by the operator's direct interaction with a braking actuator).

The control electronics module **1010** may then close the switch after expiration of the braking event. Such expiration may occur after a given period of time (e.g., one minute) and/or upon a change in status of an operator-controlled input. For example, after a suitable period of time, the control electronics module **1010** may receive an input from the user interface **1007** indicating that the braking event should end. This may occur through an operator acknowledging and ending the braking event by interacting with the user interface **1007**.

FIG. **10** illustrates a control signal interface subsystem **1100** that interfaces with a signal control **2100**. FIG. **10** and its functions may be similar to those discussed above in context of the signal control point **40**. The control signal interface subsystem **1100** may be added to an existing signal control **2100**. The signal control **2100** may include signal controls **2101** and signals **2102**. The signal controls **2101** may cause illumination of appropriate signals **2102**. The signal control subsystem **1100** may interface with the signals through one or more signal converters **1101**. This information may be received by one or more processors **1104**. One or more of the signal converters **1101** may also provide power to the processor **1104** (not shown). The signal converters **1101** may also include isolation circuitry, for example, to reduce the risk of a ground fault through the control signal interface subsystem **1100**. The data radio **1102** may operate in a similar fashion to data radio **1003** of the VMCS **1000** discussed above. The ranging radio(s) **1103** may operate in a similar fashion to ranging radio(s) **1104** of the VMCS **1000** discussed above. The signal information may also be communicated to peers through the data radio **1102** and/or ranging radio(s) **1103**.

The VMCS **1000** and control signal interface subsystem **1100** may operate in the following manner. The VMCS **1000** is mounted on a vehicle travelling towards a control signal to which a control signal interface subsystem **1100** is mounted. The VMCS **1000** searches for peers through the data radio **1003** (e.g., spread-spectrum frequency hopping data network). The control electronics module **1010** detects and identifies the control signal interface subsystem **1100** as a peer and adds it to the VMCS **1000** recognized peer list.

The VMCS **1000** then communicates with the control signal interface subsystem **1100** via the ranging radio(s) **1004** and **1103** (e.g., UWB network). The VMCS **1000** receives control signal status information from the control signal interface subsystem **1100** (e.g., what signal light is being displayed) via the ranging radio(s) **1004**, **1103** or the data radios **1003**, **1102**. The VMCS **1000** determines the time-of-flight of one or more communications (e.g., single-segment or round-trip communications). The control electronics module **1010** of the VMCS **1000** then calculates the distance between the VMCS **1000** and the control signal interface subsystem **1100** based on the time-of-flight. The distance may also be calculated (for example, redundantly) based on GPS data. The distance may also be calculated based on RFID tag location data in addition to the known speed of the vehicle. For example, given a known RFID tag location, the distance of a vehicle can be determined by continuously tracking the speed of the vehicle after passing the RFID tag location.

An alert may be generated via the user interface **1007** by the control electronics module **1010** if the distance between the VMCS **1000** and the control signal interface subsystem **1100** is less than a threshold. This distance threshold can vary (e.g., vary in real-time) according to a number of factors, such as: speed of vehicle; rate of change of speed of vehicle (acceleration or deceleration); track speed limit; track conditions (e.g., icy or we tracks); temperature; track grade (e.g., steepness); work zone status; and/or the like. The threshold is exceeded when the VMCS **1000** determines that, given the relevant factors, the distance is becoming too close with the control signal interface subsystem **1100**. Exceeding this threshold, or a different threshold, may cause the VMCS **1000** to cause the vehicle braking system to initiate (e.g., by interrupting the vehicle brake loop). Thresholds for alert and/or an automatic braking event may be the same or different. For example, the VMCS **1000** may only cause an alert when the vehicle operating conditions and position are getting near to a dangerous condition. A braking event may be caused only when the conditions and position actually become dangerous. A different type of alert may be generated when an automatic braking event takes place. According to one technique, alerts can be initiated upon exceeding a first threshold and the alert can continue escalating in severity over time if no corrective action is taking place. The alert can escalate until the situation becomes sufficiently dangerous that the vehicle may not be capable of safely stopping before the control signal (or such lack of capability is sufficiently imminent). The alert can then escalate further or change character once an automatic braking even takes place.

The VMCS **1000** may employ alerts and/or automatic braking events to promote compliance with rules. A rule may have one or multiple components. Such rules may be associated with control signal states. Different control signal states may include red, yellow, green, double red, or double yellow. Each control signal state may have an associated set of behaviors required for vehicles observing such a state. A red signal may mean the following: stop the vehicle; remain stopped for a period of time (e.g., one minute); and proceed after stopping at a restricted speed (e.g., 10 miles per hour or less until the next signal). A yellow signal may mean proceed with caution and be prepared to stop at the next signal. A green signal may mean proceed at an authorized speed. A double red (or red over red) may mean stop and stay only until an authorized person hand flags the vehicle past the signal. A double yellow (or yellow over yellow) may mean stop and then proceed at a restricted speed with caution (because, for example, a station ahead is occupied by a train).

Besides color coded signals, other signals may report system problems. For example, an "imperfect display" signal may indicate if one or more lights on the control signal are malfunctioning. For example, a control signal generally has only one signal illuminated—no more, no less. If no signal is illuminated, or if more than one signal is illuminated simultaneously, then there may be an imperfect display. Proper response to such a signal may depend on which type of light is defective. An "imperfect display at an interlocking" may indicate that the vehicle must stop and

should not proceed unless authorized by an authorized person. An "imperfect display at an automatic block signal" may indicate that the vehicle should stop, wait for a duration of time (e.g., one minute), and then proceed at a restricted speed (e.g., not greater than 10 miles per hour).

The VMCS **1000** may promote compliance with such signals by monitoring a vehicle's behavior as compared to a rule. If one or more components of a rule are violated, then the VMCS **1000** may cause an alert and/or braking event. For example, if a signal is red, then a rule may include the following components: (1) come to a safe stop before reaching the signal; (2) wait for one minute; and (3) proceed after stopping at a speed of 10 miles per hour or less. The VMCS **1000** enforces compliance with each one of these components. As discussed above, the VMCS **1000** can enforce compliance of the first component of coming to a safe stop before reaching the signal. Then, the VMCS **1000** can ensure that the vehicle remains stopped for one minute (other intervals can also be chosen). If the vehicle begins moving prior to the expiration of the one minute timer, then the VMCS **1000** can cause an alert and/or automatic braking event. After stopping for one minute, the VMCS **1000** can then cause an alert and/or automatic braking event if the vehicle does not comply with the third component of the rule—proceeding at a reduced speed of 10 miles per hour or less. Thus, the VMCS **1000** can monitor and enforce complex vehicle behavior for rules that require safe stopping, stopping duration, or reduced vehicle speed. Rules may also involve maintaining safe separation distances from other vehicles. For example, a rule may adjust a safe separation distance.

The VMCS **1000** may also communicate with an access point (e.g., via the data radio **1003** and/or ranging radio(s) **1004**). Data logs including vehicle incidents (e.g., alarm-generating incidents) and speed-limit compliance may be stored in the control electronics module **1010**. This information can be communicated with the access point and then forwarded to a centralized network (e.g., a rail network). The access point may also communicate data to the VMCS **1000**. Such data may include, for example, track conditions, weather, and/or an updated RFID tag database (which may include location, work zone status, speed limit, etc.). In addition to communicating this information wirelessly, it may be communicated with an access point via a physical connector (for example, connected to an access port on the VMCS **1000**).

In addition to communicating with a control signal interface subsystem **1100**, the VMCS **1000** may also communicate with another VMCS on another vehicle. Such VMCS-to-VMCS communications may be implemented as discussed with respect to the VMCS-to-control signal interface subsystem communications. The VMCS-to-VMCS communications may be employed to determine safe vehicle separation distances. Thresholds and automatic braking events may be determined in similar fashion as those determined in the context of the VMCS **1000** interacting with the control signal interface subsystem **1100**. To avoid collisions by maintaining adequate vehicle-to-vehicle separation, braking event thresholds may be determined by accounting for factors of the remote vehicle, such as the remote vehicle's speed, rate of change of speed, direction, or the like. As more peers are added to the network (be they other VMCS's or control signal interface subsystems), new safe operating thresholds can be determined for each new peer.

Other types of peers are also possible. For example, a peer may be a temporarily fixed unit. An example is a maintenance crew's portable unit or a temporary slow-down marker. These types of peers may be constructed and function in a fashion similar to that of the control signal interface subsystem **1100** and may cause the VMCS **1000** to issue alerts and/or cause automatic braking events upon exceeding safe operating thresholds in the manners discussed above.

Aspects of the techniques described herein may be implemented in digital electronic circuitry, computer software, firmware, or hardware, including the structures disclosed herein and their structural equivalents, or in various combinations. Aspects of the techniques described herein may be implemented as one or more computer programs, for example, one or more sets of program instructions residing on or encoded in a computer-readable storage medium for execution by, or to control the operation of, one or more processors. Alternatively or in addition, the instructions may be encoded on an artificially-generated propagated signal, for example, a machine-generated electrical, optical, or electromagnetic signal that may be generated to encode information for transmission to a suitable receiver apparatus for execution by one or more processors. A computer-readable medium may be, or be included in, a computer-readable storage device, a computer-readable storage substrate, a random or serial access memory array or device, various combinations thereof. Moreover, while a computer-readable medium may or may not be a propagated signal, a computer-readable medium may be a source or destination of program instructions encoded in an artificially-generated propagated signal. The computer-readable medium may also be, or be included in, one or more separate physical components or media (for example, CDs, disks, or other storage devices).

Certain techniques described in this specification may be implemented as operations performed by one or more processors on data stored on one or more computer-readable mediums or received from other sources. The term "processor" may encompass various kinds of apparatuses, devices, or machines for processing data, including by way of example a central processing unit, a microprocessor, a microcontroller, a digital-signal processor, programmable processor, a computer, a system on a chip, or various combinations thereof. The processor may include special purpose logic circuitry, for example, a field programmable gate array or an application-specific integrated circuit.

Program instructions (for example, a program, software, software application, script, or code) may be written in various programming languages, including compiled or interpreted languages, declarative or procedural languages, and may be deployed in various forms, for example as a stand-alone program or as a module, component, subroutine, object, or other unit suitable for use in a computing environment. Program instructions may correspond to a file in a file system. Program instructions may be stored in a portion of a file that holds other programs or data (for example, one or more scripts stored in a markup language document), in a dedicated file or in multiple coordinated files (for example, files that store one or more modules, sub-programs, or portions of code). Program instructions may be deployed to be executed on one or more processors located at one site or distributed across multiple sites connected by a network.

The present technology has now been described in such full, clear, concise and exact terms as to enable any person skilled in the art to which it pertains, to practice the same. It is to be understood that the foregoing describes preferred embodiments and examples of the present technology and that modifications may be made therein without departing from the spirit or scope of the invention as set forth in the claims. Moreover, it is also understood that the embodiments

shown in the drawings, if any, and as described above are merely for illustrative purposes and not intended to limit the scope of the invention. As used in this description, the singular forms "a," "an," and "the" include plural reference such as "more than one" unless the context clearly dictates otherwise. Where the term "comprising" appears, it is contemplated that the terms "consisting essentially of" or "consisting of" could be used in its place to describe certain embodiments of the present technology. Further, all references cited herein are incorporated in their entireties.

What is claimed:

1. A system for evaluating vehicle operation compliance, wherein the system comprises:

a control signal interface subsystem; and

a vehicle-mounted subsystem configured to:

communicate with the control signal interface subsystem to receive information corresponding to a status of a control signal;

determine a rule for behavior of a vehicle according to the information corresponding to the status of the control signal; and

observe operation of the vehicle to evaluate compliance with the rule;

wherein:

the control signal interface subsystem comprises an ultra-wideband (UWB) communications component;

the vehicle-mounted subsystem comprises an ultra-wideband (UWB) communications component; and

the vehicle-mounted subsystem and the control signal interface subsystem are further configured to communicate UWB signals carrying data pertinent to evaluating vehicle operation compliance, the data comprising at least one of: a unique ID associated with the vehicle-mounted subsystem, a signal indication, a track number, a track direction, speed, and direction of travel.

2. The system of claim **1**, wherein the rule corresponds to the status of the control signal being at least one of red, double red, yellow, or double yellow.

3. The system of claim **1**, wherein the rule specifies a stop-time duration for the vehicle.

4. The system of claim **3**, wherein the rule specifies a speed for the vehicle.

5. The system of claim **4**, wherein the rule specifies a maximum speed for the vehicle after an expiration of the stop-time.

6. The system of claim **1**, wherein the vehicle-mounted subsystem is configured to:

interface with a braking system of the vehicle;

communicate with the UWB communications component of the control signal interface subsystem via the UWB communications component of the vehicle-mounted subsystem; and

determine a distance between the vehicle-mounted subsystem and the control signal interface subsystem based on a time-of-flight of at least one communication between the UWB communications component of the control signal interface subsystem and the UWB communications component of the vehicle-mounted subsystem.

7. The system of claim **1**, wherein the vehicle-mounted subsystem is further configured to generate an alert if a distance between the vehicle-mounted subsystem and the control signal interface subsystem is less than a threshold.

8. The system of claim **1**, wherein the vehicle-mounted subsystem is further configured to cause a braking system of the vehicle to activate if a distance between the vehicle-mounted subsystem and the control signal interface subsystem is less than a threshold.

9. The system of claim **1**, wherein the vehicle-mounted subsystem further comprises

a radio-frequency identification (RFID) subsystem configured to scan at least one RFID tag external to the vehicle to retrieve information stored on the at least one RFID tag.

10. The system of claim **9**, wherein:

the vehicle-mounted subsystem is further configured to substantially continuously receive information relating to speed of the vehicle; and

the vehicle-mounted subsystem determines a changing distance between the vehicle-mounted subsystem and the control signal interface subsystem based on the information stored on the at least one RFID tag and the information relating to speed of the vehicle.

11. The system of claim **9**, wherein the vehicle-mounted subsystem is further configured to determine a distance between the vehicle-mounted subsystem and the control signal interface subsystem based on the information stored on the at least one RFID tag.

12. The system of claim **1**, further comprising:

an access point external to the vehicle; and

wherein the vehicle-mounted subsystem is further configured to:

store data relating to prior behavior of the vehicle; and

communicate the data relating to prior behavior of the vehicle with the access point.

13. The system of claim **1**, further comprising:

a second vehicle-mounted subsystem including a UWB communications component, wherein the second vehicle-mounted subsystem is configured to be mounted on another vehicle; and

wherein the vehicle-mounted subsystem is configured to:

communicate with the UWB communications component of the control signal interface subsystem via the UWB communications component of the vehicle-mounted subsystem;

communicate with the UWB communications component of the second vehicle-mounted subsystem via the UWB communications component of the vehicle-mounted subsystem;

determine a distance between the vehicle-mounted subsystem and the control signal interface subsystem based on a time-of-flight of at least one communication between the UWB communications component of the control signal interface subsystem and the UWB communications component of the vehicle-mounted subsystem; and

determine a distance between the vehicle-mounted subsystem and the second vehicle-mounted subsystem based on a time-of-flight of at least one communication between the UWB communications component of the second vehicle-mounted subsystem and the UWB communications component of the vehicle-mounted subsystem.

14. The system of claim **13**, wherein the vehicle-mounted subsystem is further configured to:

generate an alert if the distance between the vehicle-mounted subsystem and the control signal interface subsystem is less than a first threshold; and

generate an alert if the distance between the vehicle-mounted subsystem and the second vehicle-mounted subsystem is less than a second threshold.

15. The system of claim 13, wherein the vehicle-mounted subsystem is further configured to:

cause a braking system of the vehicle to activate if the distance between the vehicle-mounted subsystem and the control signal interface subsystem is less than a first threshold; and

cause the braking system of the vehicle to activate if the distance between the vehicle-mounted subsystem and the second vehicle-mounted subsystem is less than a second threshold.

16. The system of claim 13, wherein the vehicle-mounted subsystem further comprises:

a radio-frequency identification (RFID) subsystem configured to scan at least one RFID tag external to the vehicle to retrieve information stored on the at least one RFID tag; and

wherein the vehicle-mounted subsystem is further configured to determine a distance between the vehicle-mounted subsystem and the control signal interface subsystem based on the information stored on the at least one RFID tag.

17. The system of claim 16, wherein:

the vehicle-mounted subsystem is further configured to substantially continuously receive information relating to speed of the vehicle; and

the vehicle-mounted subsystem determines a changing distance between the vehicle-mounted subsystem and the control signal interface subsystem based on the information stored on the at least one RFID tag and the information relating to speed of the vehicle.

18. The system of claim 13, further comprising:

an access point external to the vehicle; and

wherein the vehicle-mounted subsystem is further configured to:

store data relating to prior behavior of the vehicle; and

communicate the data relating to prior behavior of the vehicle with the access point.

* * * * *

EXHIBIT B

US008812227B2

(12) **United States Patent**
Carlson et al.

(10) **Patent No.: US 8,812,227 B2**
(45) **Date of Patent: Aug. 19, 2014**

(54) **COLLISION AVOIDANCE SYSTEM FOR RAIL LINE VEHICLES**

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(73) Assignee: **Metrom Rail, LLC**, Lake Zurich, IL (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **13/474,428**

(22) Filed: **May 17, 2012**

(65) **Prior Publication Data**

US 2012/0296562 A1 Nov. 22, 2012

Related U.S. Application Data

(60) Provisional application No. 61/598,750, filed on Feb. 14, 2012, provisional application No. 61/627,697, filed on Oct. 17, 2011, provisional application No. 61/519,201, filed on May 19, 2011.

(51) **Int. Cl.**

G05D 1/02	(2006.01)
G06F 17/10	(2006.01)
G06G 7/78	(2006.01)
B61L 23/06	(2006.01)
B61L 15/00	(2006.01)
G08G 1/16	(2006.01)
B61L 25/02	(2006.01)
B61L 23/34	(2006.01)

(52) **U.S. Cl.**

CPC ***B61L 15/0027*** (2013.01); ***B61L 23/06*** (2013.01); *B61L 2205/04* (2013.01); ***G08G 1/166*** (2013.01); ***B61L 25/025*** (2013.01); ***G08G 1/161*** (2013.01); ***B61L 23/34*** (2013.01)

USPC **701/301**; 701/300

(58) **Field of Classification Search**

USPC 342/53, 115, 118, 125, 70; 340/905; 701/408, 301, 29.6, 34.3, 36, 19, 13, 701/23, 4, 117, 468, 409, 63, 28, 1, 116, 701/500, 2, 46

See application file for complete search history.

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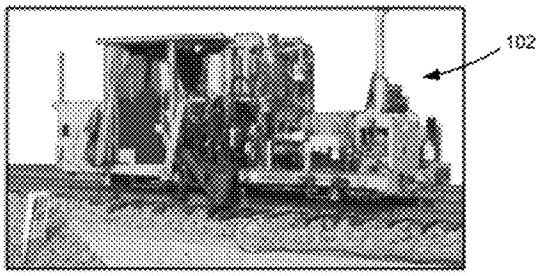
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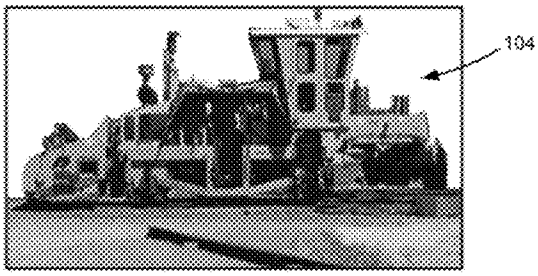
Primary Examiner — Thomas Black
Assistant Examiner — Robert Payne
(74) *Attorney, Agent, or Firm* — McAndrews, Held & Malloy, Ltd.

(57) **ABSTRACT**

A collision avoidance system (CAS) is described that includes one or more sensor technologies, including, for example, an Ultra Wideband (UWB) sensing technology. The collision avoidance system is designed to reliably track the location and speed of vehicles and the distance between vehicles over a wide variety of track and terrain. The collision avoidance system may utilize information from a variety of sensor technologies to determine whether one or more vehicles violate speed and/or separation criteria, and may generate a warning.

28 Claims, 15 Drawing Sheets





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Fig. 1A

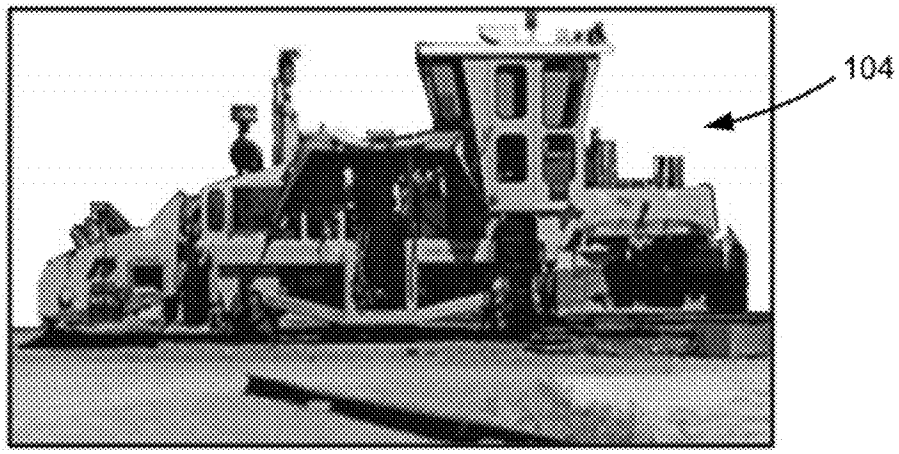


Fig. 1B

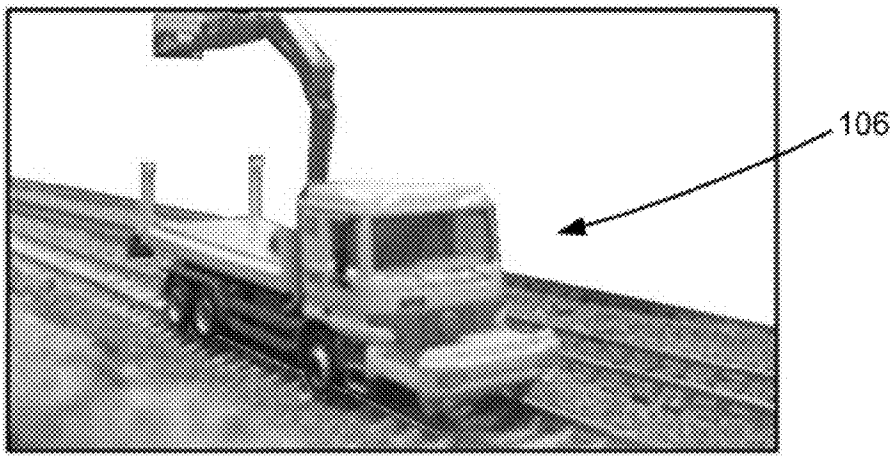


Fig. 1C

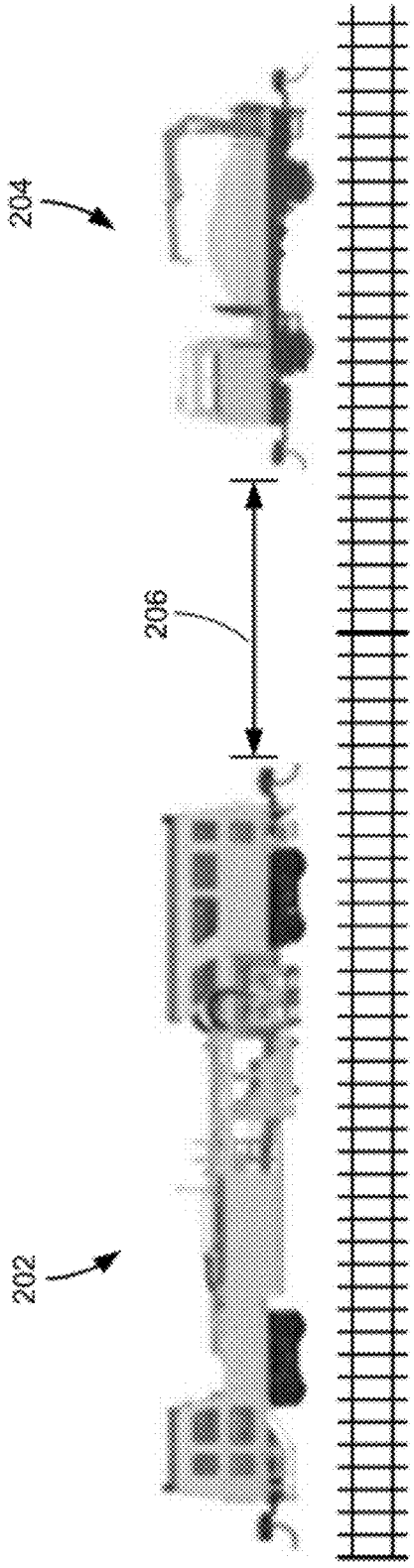


Fig. 2

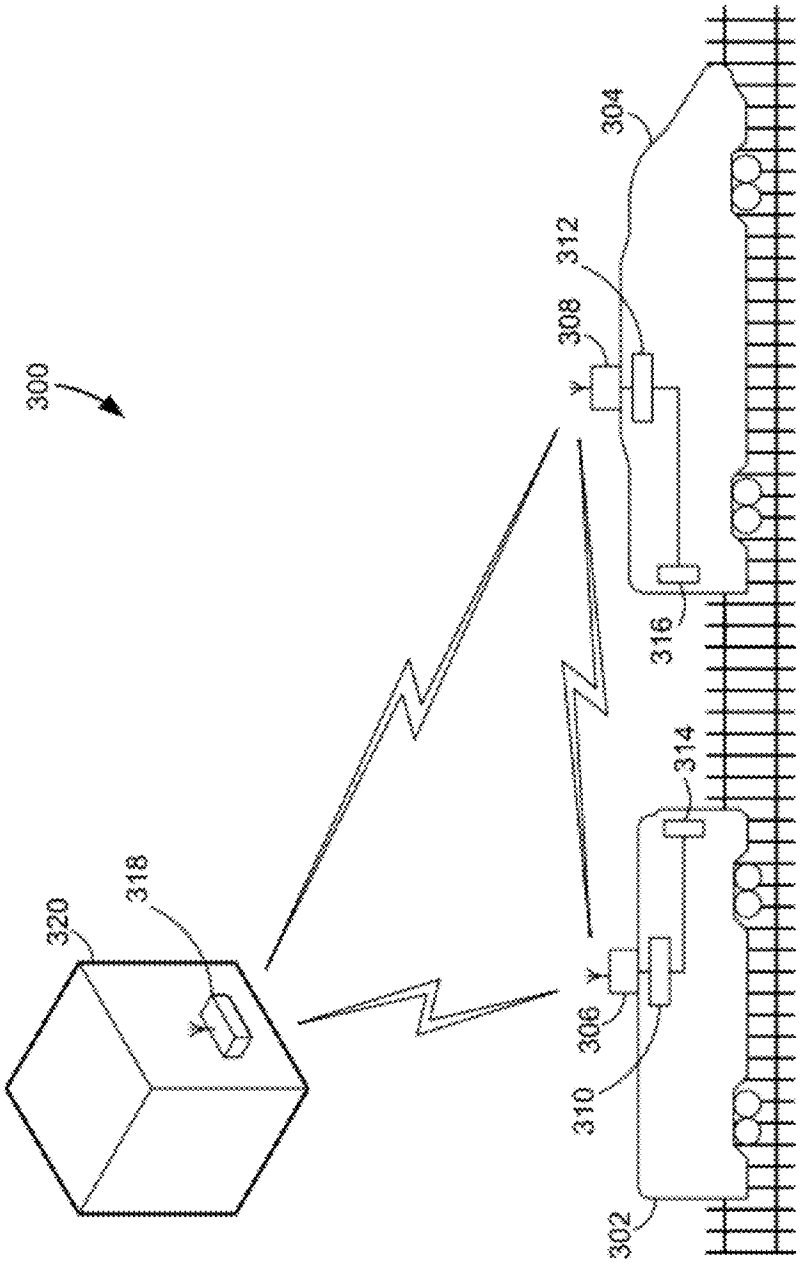


Fig. 3

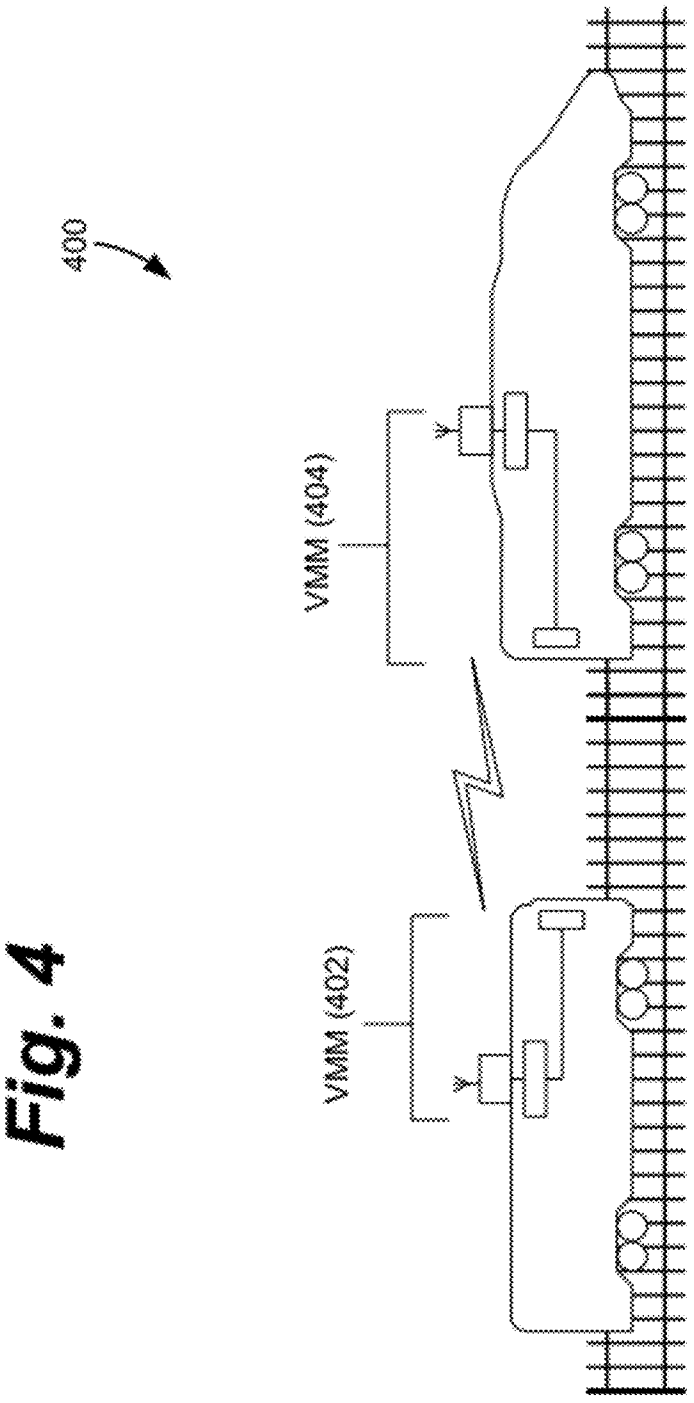
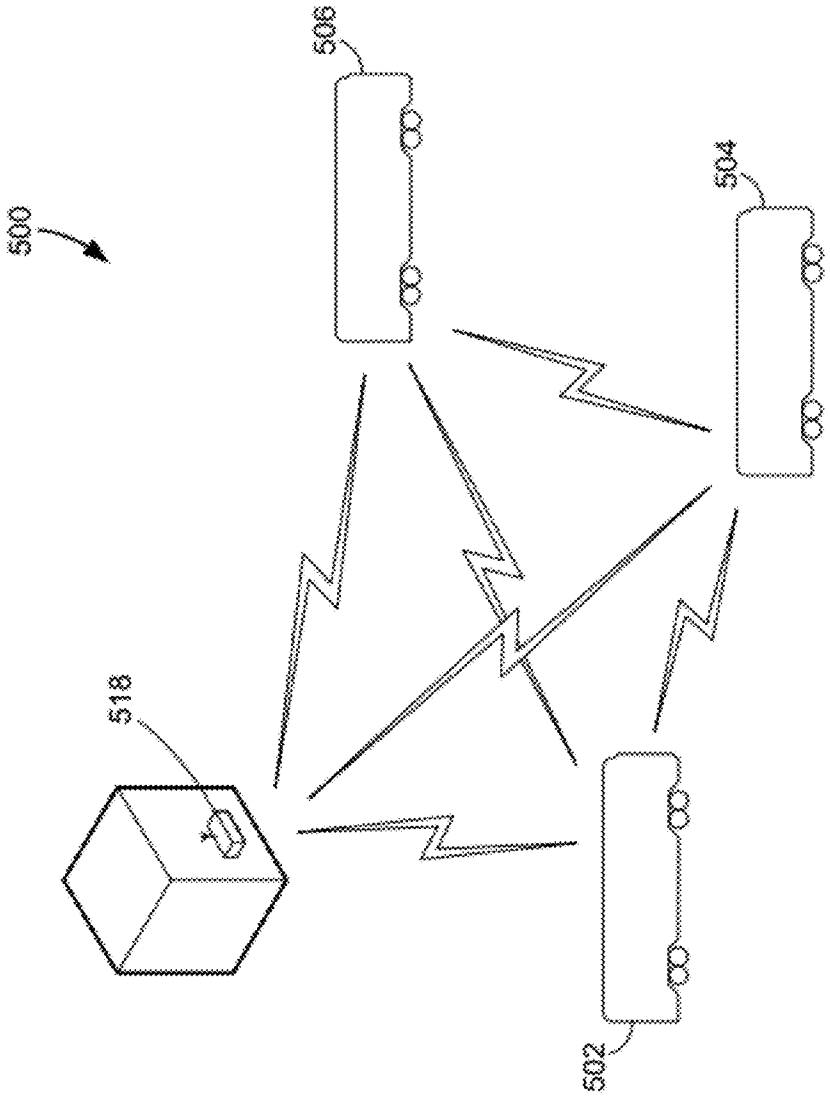


Fig. 4

Fig. 5



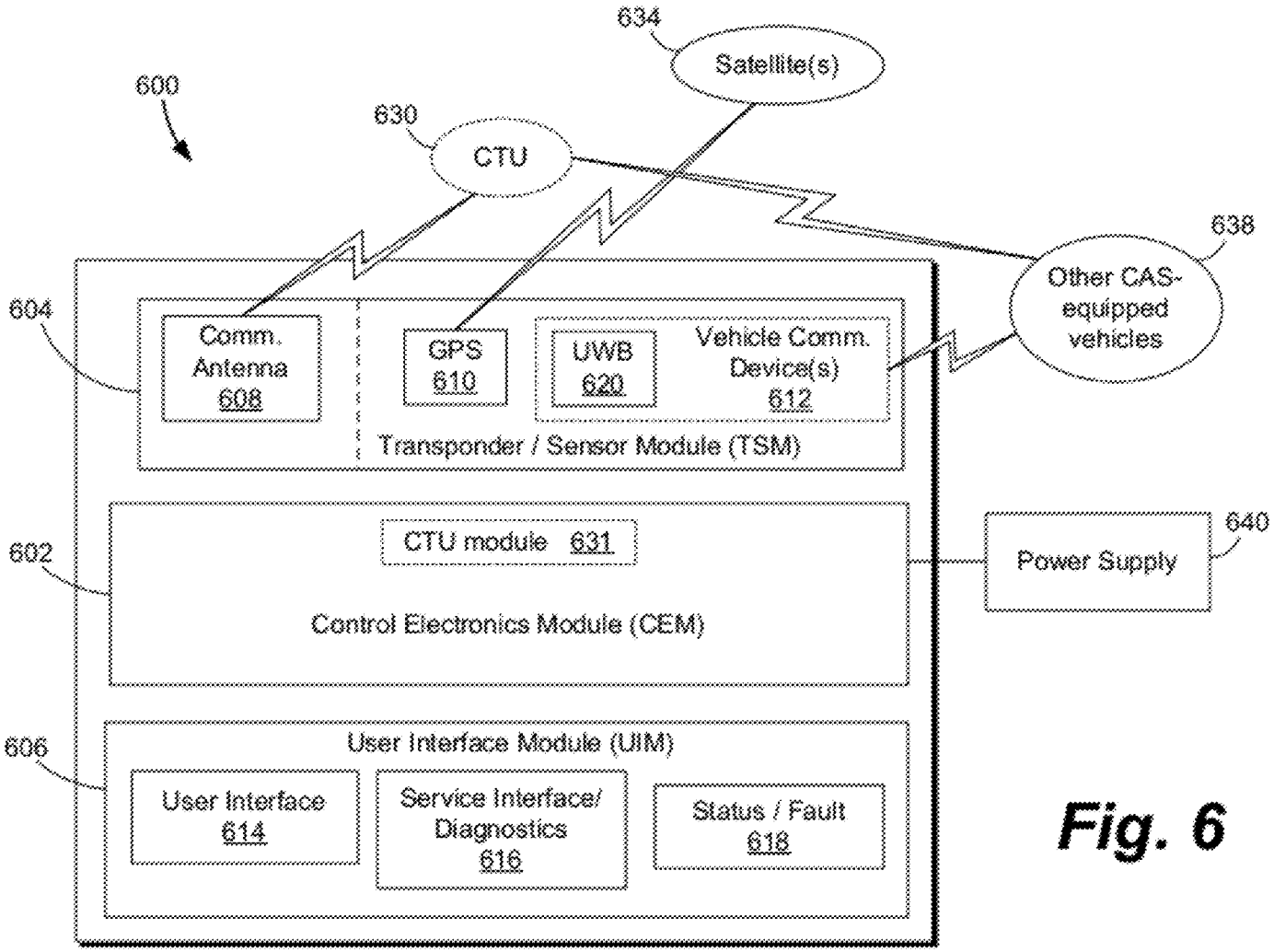

634
Satellite(s)
600
630
CTU
638
Other CAS-equipped vehicles
604
Comm. Antenna 608
GPS 610
UWB 620
Vehicle Comm. Device(s) 612
Transponder / Sensor Module (TSM)
602
CTU module 631
Control Electronics Module (CEM)
640
Power Supply
606
User Interface Module (UIM)
User Interface 614
Service Interface/ Diagnostics 616
Status / Fault 618

Fig. 6

Fig. 7

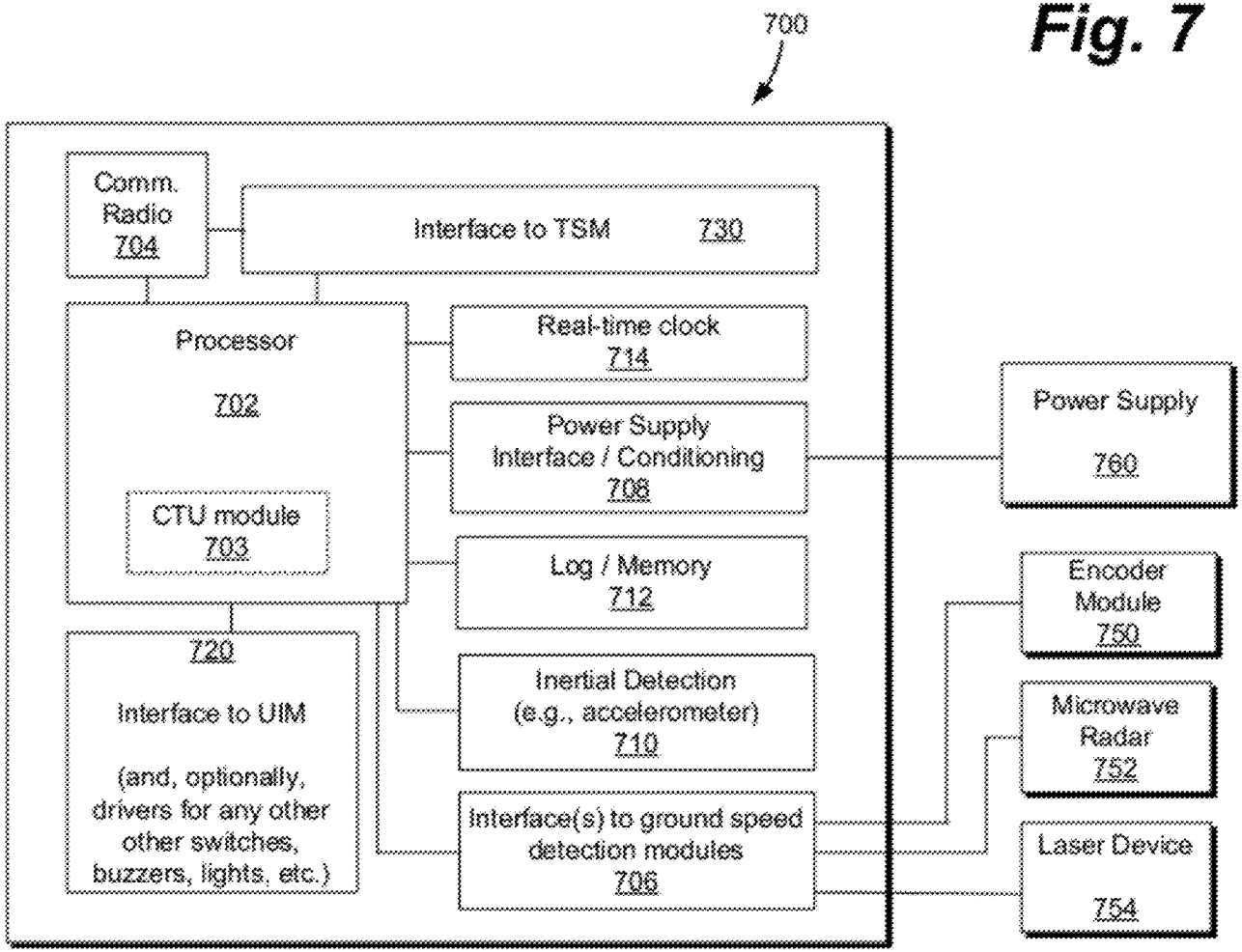

700
Comm. Radio 704
Interface to TSM 730
Processor 702
CTU module 703
Real-time clock 714
Power Supply Interface / Conditioning 708
Log / Memory 712
720
Interface to UIM
(and, optionally, drivers for any other other switches, buzzers, lights, etc.)
Inertial Detection (e.g., accelerometer) 710
Interface(s) to ground speed detection modules 706
Power Supply 760
Encoder Module 750
Microwave Radar 752
Laser Device 754

Fig. 8

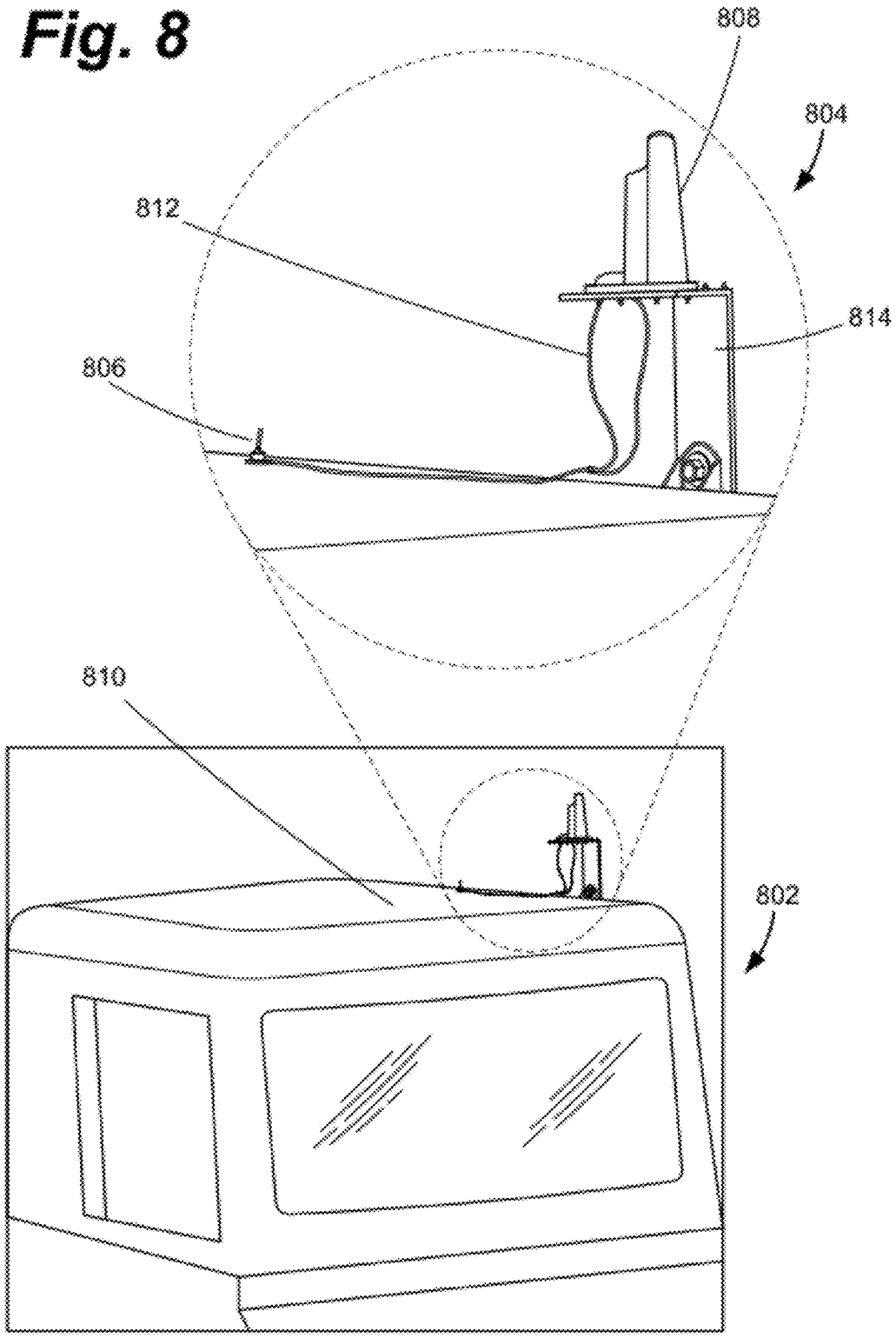
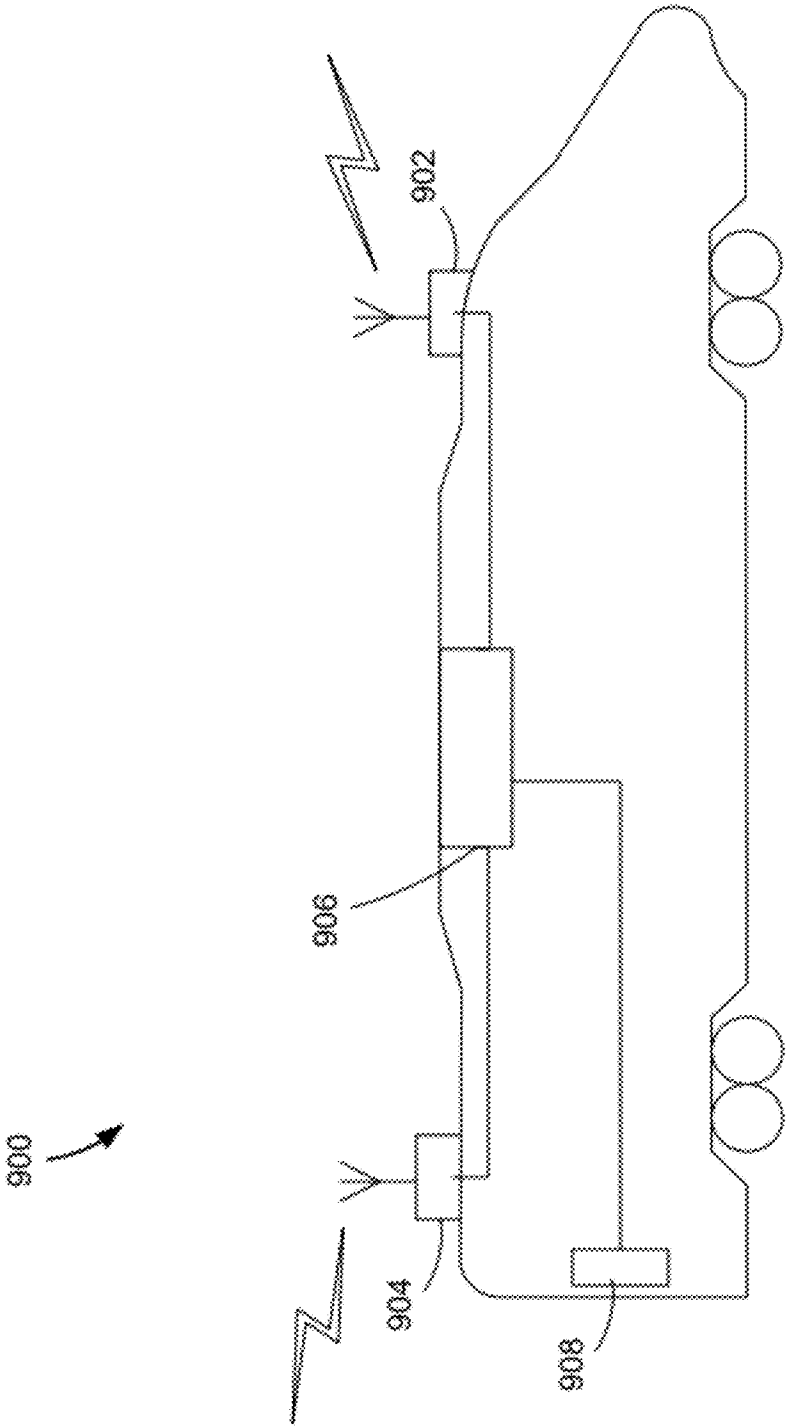


Fig. 9



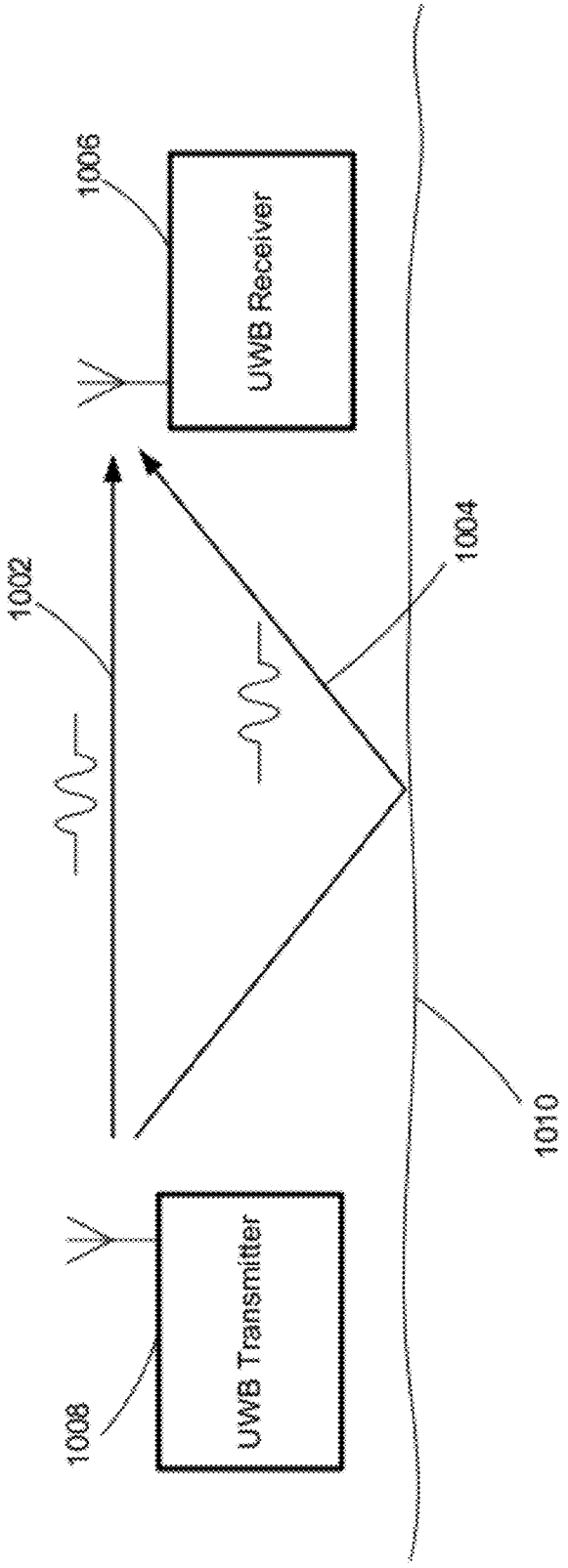


Fig. 10

Fig. 11

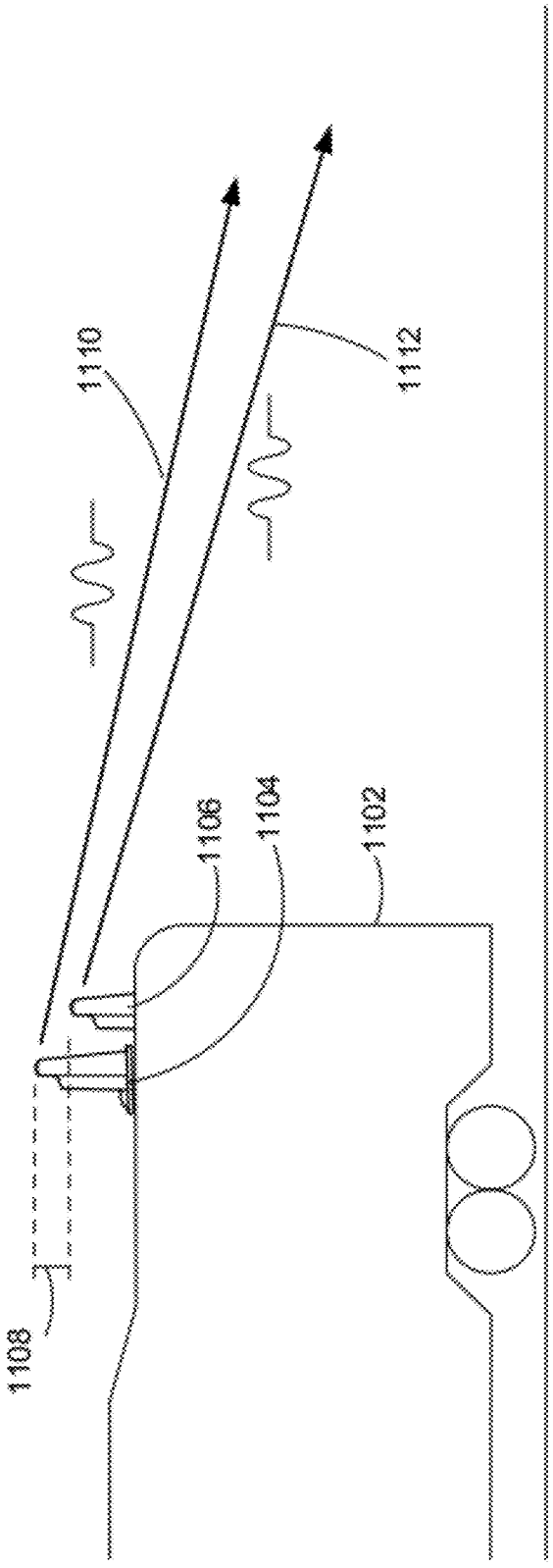


Fig. 12A

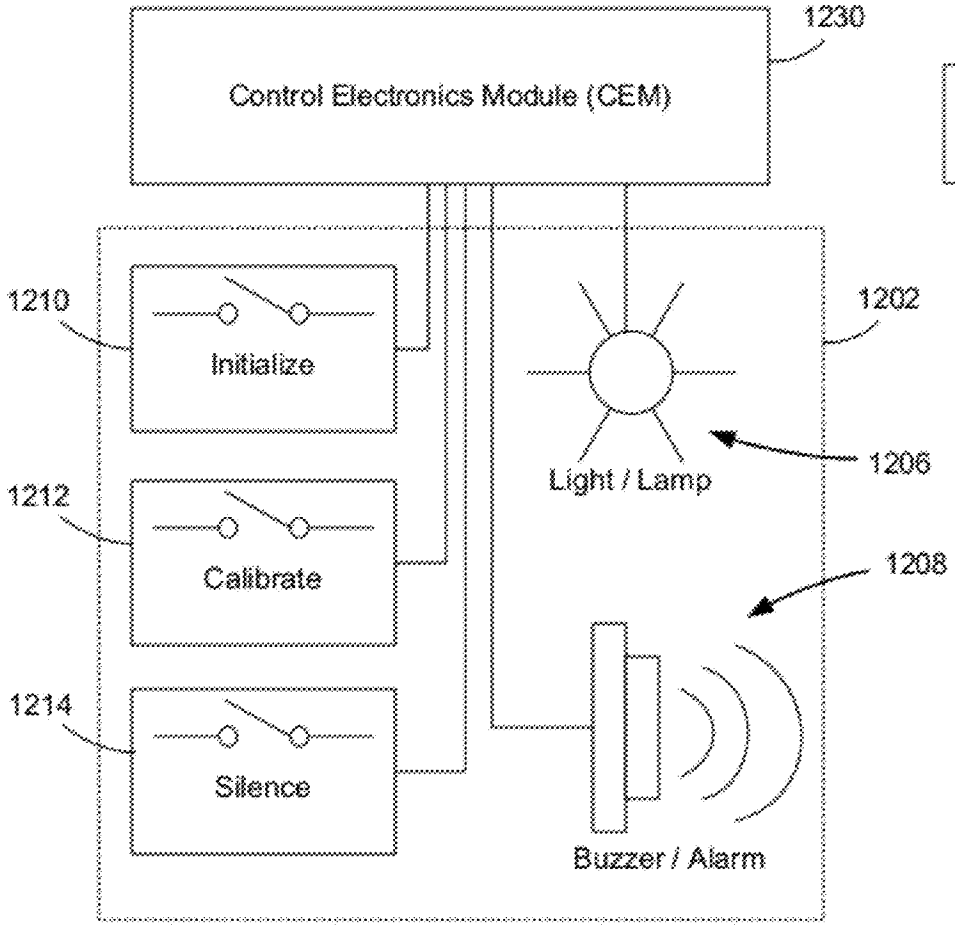
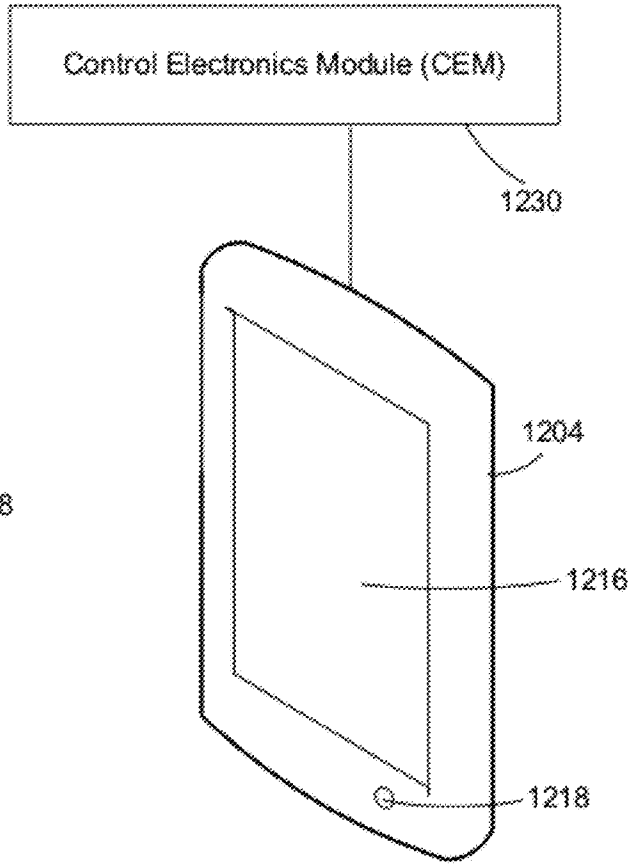


Fig. 12B



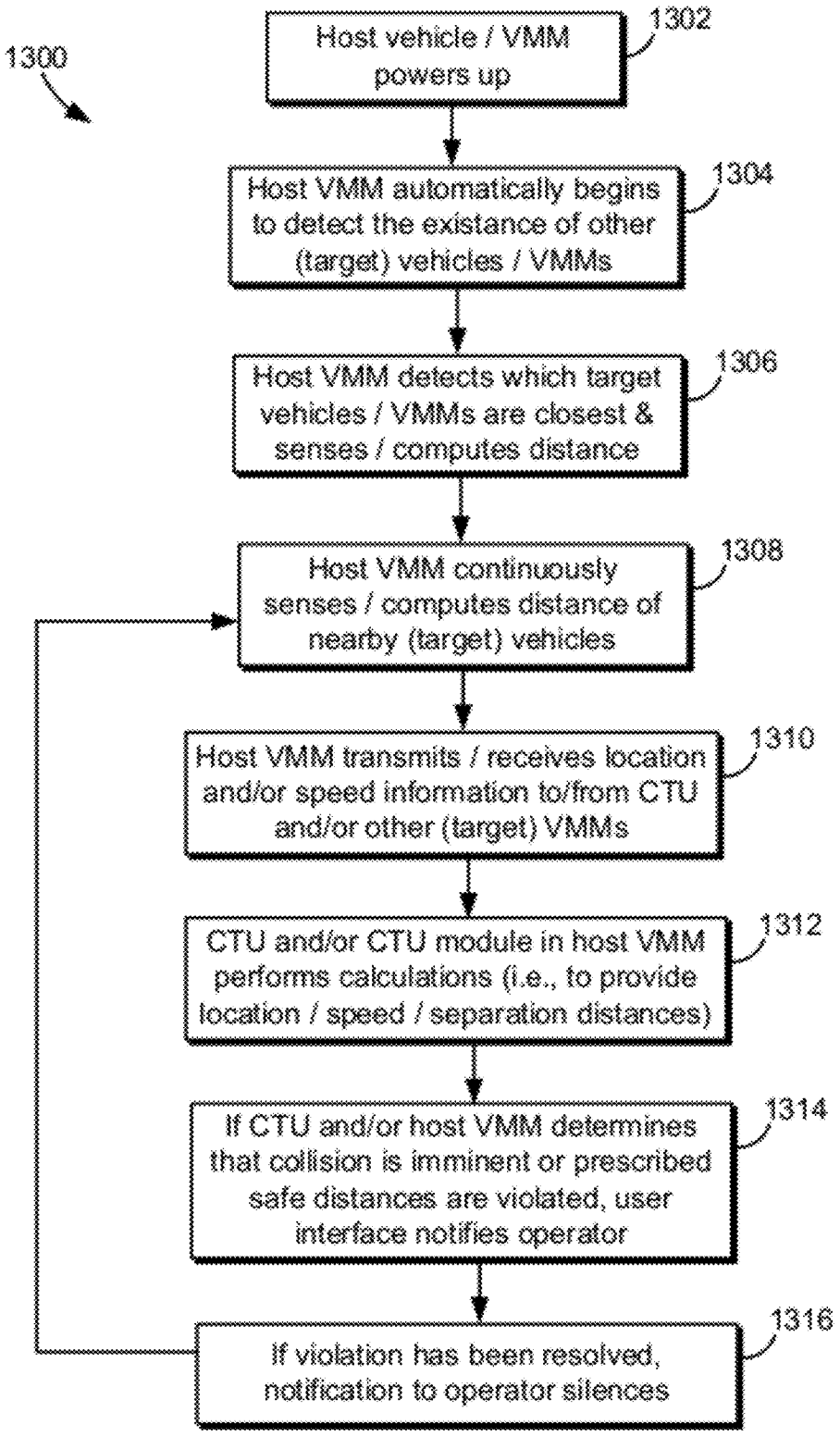

1300
Host vehicle / VMM powers up
1302
Host VMM automatically begins to detect the existance of other (target) vehicles / VMMs
1304
Host VMM detects which target vehicles / VMMs are closest & senses / computes distance
1306
Host VMM continuously senses / computes distance of nearby (target) vehicles
1308
Host VMM transmits / receives location and/or speed information to/from CTU and/or other (target) VMMs
1310
CTU and/or CTU module in host VMM performs calculations (i.e., to provide location / speed / separation distances)
1312
If CTU and/or host VMM determines that collision is imminent or prescribed safe distances are violated, user interface notifies operator
1314
If violation has been resolved, notification to operator silences
1316

Fig. 13

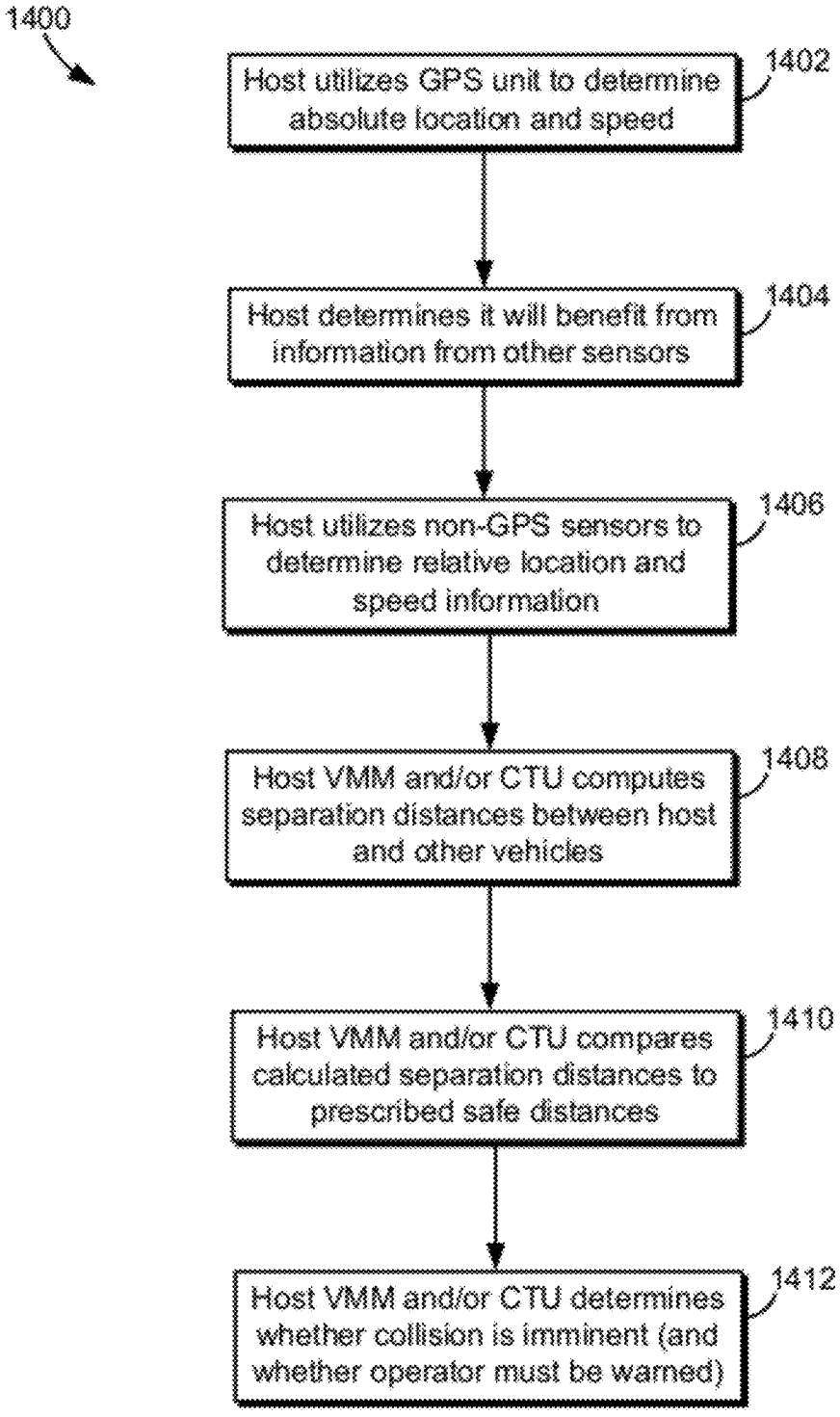

1400
Host utilizes GPS unit to determine absolute location and speed
1402
Host determines it will benefit from information from other sensors
1404
Host utilizes non-GPS sensors to determine relative location and speed information
1406
Host VMM and/or CTU computes separation distances between host and other vehicles
1408
Host VMM and/or CTU compares calculated separation distances to prescribed safe distances
1410
Host VMM and/or CTU determines whether collision is imminent (and whether operator must be warned)
1412

Fig. 14

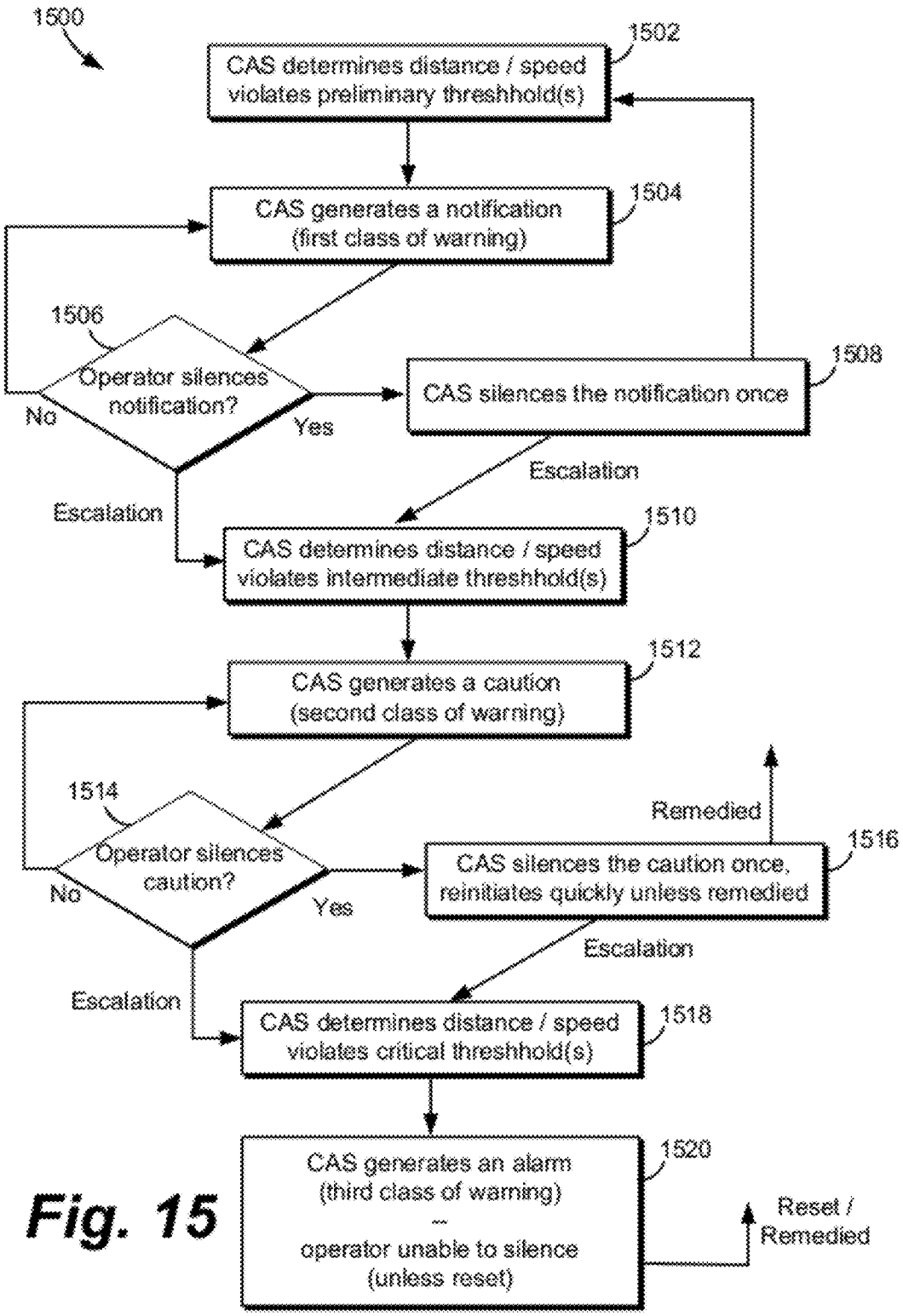

1500
1502
CAS determines distance / speed violates preliminary threshhold(s)
1504
CAS generates a notification (first class of warning)
1506
Operator silences notification?
No
Yes
1508
CAS silences the notification once
Escalation
Escalation
1510
CAS determines distance / speed violates intermediate threshhold(s)
1512
CAS generates a caution (second class of warning)
1514
Operator silences caution?
No
Yes
Remedied
1516
CAS silences the caution once, reinitiates quickly unless remedied
Escalation
Escalation
1518
CAS determines distance / speed violates critical threshhold(s)
1520
CAS generates an alarm (third class of warning) — operator unable to silence (unless reset)
Reset / Remedied

Fig. 15

COLLISION AVOIDANCE SYSTEM FOR RAIL LINE VEHICLES

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims priority from the following three U.S. Provisional Patent Applications: (1) No. 61/519,201 filed on May 19, 2011, (2) No. 61/627,697 filed on Oct. 17 2011, and (3) No. 61/598,750 filed on Feb. 14, 2012. The disclosures of these three applications are incorporated by reference herein in their entireties.

FIELD

Certain embodiments of the present disclosure relate to a collision avoidance system for use in the railroad industry. More particularly, certain embodiments of the present disclosure relate to one or more systems, methods, techniques and/or solutions that monitor the location of and separation distance between rail line vehicles, for example, railroad maintenance vehicles.

BACKGROUND

Railroad companies must perform maintenance on their tracks and other infrastructure associated with their rail lines. The railroad companies employ many different types of rail mounted vehicles to accomplish such maintenance, and these vehicles can range widely in their size, weight and shape because the vehicles perform a variety of tasks. These vehicles may be employed in one or more work gangs, each work gang including anywhere from four to forty vehicles. As such, many vehicles may be working in close proximity on a single track.

The speed at which the work gang is traveling, and each vehicle within the gang, can vary widely at any given time. For example, the work gang may be traveling to a work site, in which case the work gang, and each vehicle, is traveling at a higher rate of speed than when the vehicles are working at a worksite. When the vehicles are working at a work site, each vehicle is generally traveling at a lower rate of speed or not at all. Within a work gang, the speeds of the vehicles may vary depending on the task that each vehicle is performing.

Railroads have had several severe collisions and other accidents, some resulting in fatalities, when adequate spacing has not been maintained between rail mounted vehicles. Railroad companies now require that a specific spacing be maintained between vehicles when traveling to/from work sites and when working at a work site.

BRIEF SUMMARY

One or more systems, methods, techniques and/or solutions are provided for a collision avoidance system for use in the railroad industry that may monitor the location of and separation distance(s) between rail line vehicles, for example railroad maintenance vehicles, substantially as shown in and/or described in connection with at least one of the figures, as set forth more completely in the claims.

These and other advantages, aspects and novel features of the present invention, as well as details of an illustrated embodiment thereof, will be more fully understood from the following description and drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. **1**A-**1**C depict illustrations of example rail line vehicles that may utilize a collision avoidance system, in accordance with one or more embodiments of the present disclosure.

FIG. **2** depicts illustrations of example rail line vehicles that may utilize a collision avoidance system, in accordance with one or more embodiments of the present disclosure.

FIG. **3** depicts an illustration of an example collision avoidance system, in accordance with one or more embodiments of the present disclosure.

FIG. **4** depicts an illustration of an example collision avoidance system, in accordance with one or more embodiments of the present disclosure.

FIG. **5** depicts an illustration of an example collision avoidance system, in accordance with one or more embodiments of the present disclosure.

FIG. **6** depicts a block diagram of an example vehicle mounted module, in accordance with one or more embodiments of the present disclosure.

FIG. **7** depicts a block diagram of an example control electronics module, in accordance with one or more embodiments of the present disclosure.

FIG. **8** depicts an illustration of side angled view of the upper portion of an example rail line vehicle and an example component mounting configuration, in accordance with one or more embodiments of the present disclosure.

FIG. **9** depicts an illustration of an example rail line vehicle, including a vehicle mounted module, in accordance with one or more embodiments of the present disclosure.

FIG. **10** depicts a block diagram illustrating example Ultra Wideband units, in accordance with one or more embodiments of the present disclosure.

FIG. **11** depicts an illustration of a side view of an example rail line vehicle including multiple Ultra Wideband units, in accordance with one or more embodiments of the present disclosure.

FIGS. **12**A and **12**B depict illustrations of example user interfaces, in accordance with one or more embodiments of the present disclosure.

FIG. **13** depicts a flow diagram that shows exemplary steps in the operation of a collision avoidance system, in accordance with one or more embodiments of the present disclosure.

FIG. **14** depicts a flow diagram that shows exemplary steps in the operation of a collision avoidance system, in accordance with one or more embodiments of the present disclosure.

FIG. **15** depicts a flow diagram that shows exemplary steps in the operation of a collision avoidance system, in accordance with one or more embodiments of the present disclosure.

DETAILED DESCRIPTION

Previous systems for preventing collisions of rail line vehicles have typically utilized a single sensor, for example a GPS or radar-based sensor, to monitor the approximate location of rail mounted vehicles. A shortcoming of single sensor systems, such as ones that depend on GPS sensors, is that the rail vehicles being monitored often enter into "blackout" areas (for example, around buildings, in the mountains, canyons, around sharp curves or in tunnels) where the single sensor may be unable to accurately determine the vehicle's location. For example, a GPS sensor may be unable to communicate with satellites when the vehicle is in a tunnel. Some

previous systems attempted to solve this problem by performing a simple "dead reckoning" calculation, where the last known speed and direction of the vehicle are used to estimate the current position of the vehicle until the sensor signal is reestablished. This estimation calculation may not be precise enough to prevent collisions in work gangs because of the speed variation between vehicles. When the vehicles are traveling to a work site, the higher speeds introduce the risk of collision, and when the vehicles are working at a work site, the vehicle are frequently stopping and starting, and this variation in speed between vehicles renders the dead reckoning approach an unsuitable approximation.

A limitation of radar-based sensors in particular is that they may initiate numerous false positives (warning alarms that are not warranted). With the normal clutter of maintenance operations (people, equipment, trains on adjacent tracks, trackside structures, trestle sides, tunnel walls), radar-based sensors can become confused as to when vehicles are actually in danger of colliding. More specifically, radar-based sensors must deal with the following dilemma: the sensor must scan a wide enough field so that it can detect collision risks when vehicles are traveling on curves at higher speeds, yet as radar-based sensors scan wider fields, they become more susceptible to false detections, for example because the sensor also senses clutter. False detections can result in a dangerous work environment, especially if operators become immune to warnings.

The present disclosure describes a collision avoidance system (CAS) for rail line vehicles that may utilize a combination of sensor technologies, including an Ultra Wideband (UWB) sensing technology, to counter the limitations of previous systems, and to significantly reduce the potential for vehicle collisions and to enhance the safe operation of a variety of railway vehicles. The present technology is designed to reliably track the location and speed of railway vehicles, as well as the distance between vehicles over a wide variety of track and terrain conditions. The present technology may monitor the separation distance between rail line vehicles by utilizing sensors that are mounted on each vehicle in a group or work gang, where a work gang may comprising a plurality of railway vehicles, including railway maintenance equipment.

The CAS may perform the techniques and/or solutions described herein for a wide variety of railway vehicles, for example, railway maintenance equipment/vehicles, railcars, hyrail vehicles, train cars, train engines and other rail line vehicles. FIGS. **1**A-**1**C depict illustrations of types of example rail line vehicles (vehicles **102**, **104**, **106**) that may utilize a CAS or that a CAS as described herein may track. FIGS. **1**A and **1**B may depict example rail line maintenance vehicles and FIG. **1**C may depict an example hyrail vehicle. FIG. **2** depicts illustrations of more example rail line vehicles (vehicles **202**, **204**) that may utilize a CAS or that a CAS system may track, and also shows an exemplary safe distance **206** between the two vehicles **202**, **204**. The CAS may track vehicles such as the ones depicted in FIGS. **1** and **2** (and others) over a wide range of terrain (e.g., mountains, canyons, hills, trees, tunnels, curves and trestles) and during a variety of weather conditions (e.g., rain, fog, snow, ice, bright sunlight).

The CAS may be designed to introduce redundancy into the system, for example in the form of multiple types of sensor technologies and/or multiple sensors of a particular type of technology. One benefit of utilizing redundant sensors may be that some sensors may function properly when other sensors are not functioning optimally or at all. Another benefit of utilizing redundant sensors is that different sensors may be adapted to sense objects and different distances and to different levels of accuracy. In some embodiments, a CAS may utilize a combination of distance sensors so that the CAS is adapted to detect vehicles that are either close or far away, and so that the CAS may detect vehicle separation to within a few inches if the vehicles are close.

Various embodiments of the present disclosure enable a rail line vehicle having a vehicle mounted module. The vehicle mounted module may comprise a transponder sensor module that includes an ultra wideband unit and a wireless communications antenna. The ultra wideband unit may be operable to detect a distance between the rail line vehicle and at least one other vehicle. The wireless communications antenna may be operable to send and receive data over the air. The vehicle mounted module may further comprise a control electronics module that includes a processor that is in communication with at least the ultra wideband unit. The vehicle mounted module may further comprise a user interface module including a user interface. The user interface may be operable to provide a vehicle operator with information and may be operable to accept input from the vehicle operator. The vehicle mounted module may be in communication with one or more central tracking units by way of the wireless communications antenna. The one or more central tracking units may be operable to track the location of the rail line vehicle and at least one other vehicle.

In some embodiments, the vehicle mounted module further comprises a central tracking unit module that is operable to track the location of at least one other vehicle. In some embodiments, the vehicle mounted module may be operable to utilize information generated by the global positioning system and the ultra wideband unit to determine whether one or more vehicle separation criteria are violated, and generate a warning if one or more vehicle separation criteria are violated. In some embodiments, the vehicle mounted modules comprises one or more additional transponder sensor modules. The vehicle mounted module may be operable to accept calibration information regarding the length of the rail line vehicle and the mounting locations of the transponder sensor module and the one or more additional transponder sensor modules.

In some embodiments, the transponder sensor module further includes a global positioning system. The global positioning system may be operable to receive information from one or more satellites and may be operable to determine the absolute position of the rail line vehicle. In some embodiments, the transponder sensor module further includes one or more of a laser device, a radar sensor and an infrared sensor. In some embodiments, the vehicle mounted modules may comprise an additional ultra wideband unit, wherein an offset exists between the ultra wideband unit and the additional ultra wideband unit once the two units are mounted on the rail line vehicle. In some embodiments, the ultra wideband unit is adapted to transmit and receive signals with varying center frequencies.

In some embodiments, the user interface module further includes a service interface that may be operable to allow the vehicle operator to configure, calibrate, service, maintain, diagnose, update and/or install information on vehicle mounted module. In some embodiments, the user interface is a touchscreen including a screen. The touchscreen may be operable to display one or more screens, menus, options and/or functions, and accept user input from the vehicle operator by allowing the vehicle operator to touch the screen of the touchscreen.

In some embodiments, the control electronics module further includes one or more interfaces that may be operable to

communicate with ground speed detection modules. The ground speed detection modules may include one or more of a microwave radar, a laser device, an infrared sensor and an ultra wideband sensor. In some embodiments, the control electronics module further includes one or more inertial measurement units. In some embodiments, the control electronics module further includes an inertial measurement unit.

In some embodiments, the vehicle mounted module may be operable to utilize a progressive warning feature that generates a warning if one or more vehicle separation thresholds are violated. The rate, frequency, prominence and/or severity of the warning may increase as the violation of the vehicle separation threshold becomes more critical. The progressive warning feature may utilize an adaptive threshold feature that modifies the one or more vehicle separation thresholds based on the speed of the rail line vehicle and the speed of one or more nearby vehicles. In some embodiments, the vehicle mounted module may be operable to utilize a stopping distance calibration feature that measures a stopping distance. The stopping distance may indicate how quickly the rail line vehicle can stop under current conditions. The measured stopping distance may be used to modify one or more safe separation distance thresholds.

Various embodiments of the present disclosure enable a collision avoidance system for rail line vehicles that may comprise one or more vehicle mounted modules, each mounted on a vehicle. Each vehicle mounted module may comprise a transponder sensor module including an ultra wideband unit and a wireless communications antenna. The ultra wideband unit may be operable to detect a distance between the vehicle on which the vehicle mounted module is mounted and at least one other vehicle. The wireless communications antenna may be operable to send and receive data over the air. Each vehicle mounted module may comprise a control electronics module including a processor that is in communication with at least the ultra wideband unit. Each vehicle mounted module may comprise a user interface module including a user interface. The user interface may be operable to provide a vehicle operator with information and may be operable to accept input from the vehicle operator.

The collision avoidance system that may comprise a central tracking unit that is in communication with the one or more vehicle mounted modules. The central tracking unit may be operable to track the location of the one or more vehicle mounted modules. In some embodiments, the central tracking unit may be distributed among the one or more vehicle mounted modules, wherein each of the one or more vehicle mounted modules includes a central tracking unit component. Each central tracking unit component may be in communication with the vehicle's control electronics module. In some embodiments, the central tracking unit may be disposed in a discrete housing.

In some embodiments, the transponder sensor module further includes a global positioning system. The global positioning system may be operable to receive information from one or more satellites and may be operable to determine the absolute position of the vehicle mounted module. Each vehicle mounted module may be operable to utilize information generated by the global positioning system, the ultra wideband unit and the central tracking unit to determine whether one or more vehicle separation criteria are violated, and generate a warning if one or more vehicle separation criteria are violated.

FIG. **3** depicts an illustration of an example collision avoidance system (CAS) **300** for rail line vehicles according to one or more embodiments of the present disclosure. For example purposes only, FIG. **3** depicts a work gang including only two vehicles **302**, **304**. In this embodiment, the CAS **300** includes four main types of components—transponder sensor modules (TSMs) (for example, TSMs **306**, **308**), control electronics modules (CEMs) (for example, CEMs **310**, **312**), user interface modules (UIMs) (for example, UIMs **314**, **316**) and a central tracking unit (CTU) (for example, CTU **318**). Referring to a single vehicle (vehicle **302** for example), modules that are located in or on the vehicle (for example, TSM **306**, CEM **310** and UIM **314**) may collectively be referred to as the vehicle mounted module (VMM), even though the individual modules and related components may or may not be housed within a unitary package/enclosure.

In some embodiments, the VMM components may not be installed on vehicles at production. In these examples, the VMM components may be designed to allow retrofitting into existing railway vehicles without requiring heavily intrusive installation.

The CAS may include a central tracking unit (CTU), for example the CTU **318** of FIG. **3**. The CTU may operate to centrally track all the vehicles in one or more work gangs. The CTU may adapt a tracking software and/or system to monitor individual vehicles. The CTU may include technology adapted to dynamically define which vehicles are in a work gang, and/or which vehicles the CTU should keep track of. The CTU may accept information from VMMs mounted inside vehicles in the work gang, information such as location, speed, separation distance and the like. The CTU may have the ability to analyze and/or store various types of data about vehicles in one or more work gangs. For example, the CTU may analyze absolute and relative positioning data and speed data from vehicles in the work gang. In some examples, the CTU may determine if a separation distance between two vehicles has been violated, indicating that an accident may be likely. Additionally, the CTU may track alarm status of the vehicles in a work gang so that the central tracking unit becomes aware when an accident may have occurred. In another example, the central tracking unit may track data regarding accidents.

In the embodiment depicted in FIG. **3**, the CTU **318** may be located in a discrete housing **320** (also referred to as a module, unit, bungalow or the like). It should be understood that the technology and features of the CTU need not reside in such a discrete housing **320** and may be distributed amongst the vehicles in the work gang, for example with a CTU module/component in each VMM. In embodiments where the CTU is located in a housing **320** that is discrete from the vehicles, the VMM may include a TSM, CEM, and UIM. In embodiments where the CTU is distributed amongst the vehicles, the VMM may further include a CTU module/component.

FIG. **4** depicts an illustration of an example collision avoidance system (CAS) **400** according to one or more embodiments of the present disclosure. In this embodiment, the system **400** does not include a discrete housing for the CTU technology. This embodiment still utilizes technology, functionality and features similar to those employed in a system (such as the CAS **300** of FIG. **3**) with a CTU disposed in a discrete housing. In this embodiment, the functionality and intelligence of the CTU is dispersed and/or distributed among the VMMs (for example VMMs **402**, **404**) in the vehicles within a work gang. With this dispersed design (also referred to as "dispersed thinking"), each VMM includes its own CTU module/component that tracks the location of other vehicles in the work gang, like a CTU disposed in discrete housing would do. It should also be understood that although this embodiment describes a central tracking unit component, the

central tracking unit circuitry and technology may be incorporated into other components/subcomponents of the VMM, such as the CEM.

For example purposes, FIGS. **3** and **4** each show a work gang including only two vehicles, but it should be understood that work gangs may include more than two vehicles. FIG. **5** depicts an illustration of an example collision avoidance system (CAS) **500** with a work gang that includes more than two vehicles, according to one or more embodiments of the present disclosure. In this embodiment, each vehicle (for example, vehicles **502**, **504**, **506**) in the work gang may be equipped with a VMM and each VMM may communicate with nearby VMMs (in nearby vehicles) as well as with a CTU **518** in a discrete housing, as can be seen in FIG. **5**. In other embodiments of the present disclosure, each vehicle in a work gang is equipped with a VMM and each VMM communicates with nearby VMMs (in nearby vehicles) including a CTU module/component within each VMM (not depicted in FIG. **5**). In these embodiments, there may be no CTU in a discrete housing such as the CTU **518** depicted in FIG. **5**. FIG. **5** depicts a work gang with three vehicles, but it should be understood that a work gang may include more than three vehicles. As the size of the work gang becomes larger, the VMM mounted on each vehicle may communicate with more VMMs (in nearby vehicles), as well as with the CTU in a discrete housing (or a CTU module/component within the VMMS in each vehicle).

FIG. **6** depicts a block diagram of an example vehicle mounted module (VMM) **600**, in accordance with one or more embodiments of the present disclosure. The VMM may include one or more control electronics modules (CEM) **602**, one or more transponder sensor modules (TSM) **604**, and one or more user interface modules (UIM) **606**. The TSM **604** may further include a wireless communications antenna **608** (for example an RF antenna such as a 2.4 GHz radio antenna) that is operable to send and receive data over the air, for example to/from remote systems. The TSM **604** may further include a GPS unit **610** one or more vehicle communication devices **612**. The UIM **606** may further include a user interface **614**, a service interface **616** (optionally including diagnostics components/interfaces) and status/fault indicators **618**. Additionally, the VMM **600** may receive power from a power supply **640** that may provide power to one or more vehicle mounted module components, for example components disposed within the CEM **602**.

Wireless communications antenna **608** may be, for example, an RF antenna such as a 2.4 GHz radio antenna. As depicted in FIG. **6**, a VMM **600** may communicate with a CTU **630** (for example a CTU located in a discrete housing or a number of CTU modules located in other VMMs) through a wireless communications antenna **608**. The wireless communications antenna **608** may be housed in the TSM, or it may be housed separately and perhaps connected to CEM **602** independently. The circuitry for the radio associated with the wireless communications antenna **608** may be disposed in the TSM **604**, or may be disposed in the CEM **602** and be connected to the wireless communications antenna **608** via a wired connection. The VMM **600** may transmit a variety of information to the CTU **630**, for example, absolute position data, relative position data and speed data of the vehicle. Such information may have been obtained by the VMM utilizing various components and/or sensors, for example, the GPS unit **610**, the UWB unit **620**, and/or other sensors. The VMM **600** may transmit other information to the CTU **630**, for example, status/fault and/or diagnostic information regarding the health of the VMM and its components. The VMM **600** may gather data from one or more satellites **634** utilizing a GPS unit **610**, for example to acquire absolute positioning information. The VMM **600** may communicate with other CAS/VMM-equipped vehicles through one or more vehicle communication devices **612** and/or through a wireless communications antenna **608**. In some embodiments, the vehicle communications devices **612** may include one or more separate wireless communications antennas (and perhaps associated radios) from antenna **608**.

Referring to FIG. **6**, in some embodiments, a CAS may not include a discrete CTU such as the one shown in FIG. **6** at CTU **630**. In these embodiments, the VMM may include a CTU module/component **631** that tracks the location of (and provides location information to) other vehicles in the work gang by communicating with other CAS/VMM-equipped vehicles directly. The CTU module/component **631** may operate like (and include similar technology to) a discrete CTU (such as CTU **630**) would operate in other embodiments. The CTU module/component may include technology adapted to dynamically define which vehicles are in the work gang, and/or which vehicles the CTU module/component should keep track of. It should also be understood that although the foregoing describes a CTU module/component, the CTU circuitry and technology may be incorporated into other modules, components and subcomponents of the VMM, such as the CEM. In some embodiments, the CTU module/component may be a software feature that is executed by a processor in the CEM.

VMM subcomponents (for example, the components included within the TSM, CEM and UIM) may be packaged together within a single enclosure. For example, in some embodiments, the CEM and UIM (and optionally, the CTU module) may be combined/disposed in a single package. One benefit of a single package may be that it simplifies the installation process. In alternate embodiments, or one or more VMM components and/or subcomponents may be packaged separately from the other components/subcomponents. The various components and/or subcomponents may be located separately, optionally within separate enclosures, and each separate component may be connected to a main VMM enclosure and/or to other VMM enclosures via wires or a short range wireless link. For example, wireless communications antenna **608** and/or one or more vehicle communication devices **612** may be mounted separately (optionally, in one or more enclosures) on the upper extremity of the vehicle, for example to reduce signal interference and to allow for proper antenna placement (see FIG. **8**). Likewise, the user interface **614** may be located in the crew area or the passenger cab. The number of physical packages/enclosures included in each VMM and the mounting location of each package/enclosure may depend on the type (height, length, etc.) of vehicle the VMM is mounted on, or may depend on the configuration of the VMM. In one example, all of the components of the vehicle mounted module are housed within a single weatherproof enclosure. In another example, the wireless communications antenna (for example, wireless communications antenna **608**) (or the entire wireless communications radio including the antenna) may be installed at a distance from other VMM enclosures/components to avoid interference between the wireless communications antenna and other components of the VMM, for example the UWB sensor.

FIG. **7** depicts an illustration of a block diagram of an example control electronics module (CEM) **700**, in accordance with one or more embodiments of the present disclosure. The CEM **700** may include a processor **702**, a wireless communications radio **704** (such as an RF radio), an interface to a TSM **730**, an interface to a UIM **720**, one or more interfaces **706** to ground speed detection modules, a power

supply interface/power conditioning system **708**, and a real-time clock **714**. Examples of ground speed detection modules that may connect to interface **706** include an encoder module **750**, a microwave radar **752** and/or a laser device **754**. The interface to the UIM **720** may further include one or more drivers to power visual and/or audio indicators. In some embodiments, the CEM **700** may include one or more vehicular interfaces (interfaces to existing vehicle systems), for example a CAN interface, braking systems, speed indicators, equipment operating mode status indications and the like. The CEM **700** may include an inertial measurement unit **710** that includes one or more devices, for example, one or more accelerometers and/or gyroscopes. The CEM **700** may include a log/memory **712**.

It should be understood that although FIG. **7** depicts some or all of the aforementioned subcomponents as being contained within the CEM **700**, different configurations of the VMM are contemplated by this disclosure, including various combinations of VMM components/enclosures. Therefore, in some embodiments, the subcomponents depicted in FIG. **7** may be disposed outside of the CEM **700**, for example in one or more other VMM enclosures. And in other embodiments, subcomponents other than those depicted in FIG. **7** may be disposed inside of the CEM **700**, for example one or more subcomponents that may reside in other VMM enclosures in other embodiments. In some examples, some of the subcomponents depicted in FIG. **7** may reside in the UIM and/or the TSM and may connect to the CEM by way of wires or wireless connection(s).

Referring again to FIG. **7**, CEM **700** may include a processor **702**. The processor **702** may, among other operations, process information received from the vehicle communication devices, for example via the interface to the TSM **730**. For example processor **702** may be in communication with and process information from a UWB unit via TSM interface **730**. The processor **702** may also process information received from other modules, components and/or subcomponents of the VMM. The processor **702** may handle information and/or perform computations to, among other things, track other vehicles in a work gang and determine which vehicles present a potential hazard. It should be understood that the CTU may also process location and speed information from vehicles in a work gang and may also track vehicles in a work gang to determine when collisions may be imminent. The present disclosure contemplates various types of configurations whereby some or all of the tracking and processing components of the CAS may be located within the VMMs (for example, within a CTU module), within a CTU in a discrete housing, or a combination of both. In the example where a CTU module/component performs tracking of other vehicles, a CTU module **703** may be disposed within the CEM **700**, perhaps implemented in processor **702**. In some embodiments, the CTU module **703** may be a software feature that is executed by the CEM processor **702**.

CEM **700** may include an inertial measurement unit **710** that includes one or more devices, for example, one or more accelerometers and/or gyroscopes. The inertial measurement unit **710** may be operable to, among other functions, detect changes in the speed of a traveling vehicle. Detecting changes in vehicle speed may be useful to aid in dead reckoning solutions instead of or in conjunction with short range distance measurement sensors. For example, if a vehicle travelled into a tunnel and the GPS unit could not establish a connection to satellites to provide positioning information, an inertial measurement unit may provide information regarding whether vehicles in a work gang have changed speeds while in the tunnel. An inertial measurement unit **710** may also be operable to detect sudden changes in speed, for example indicating that a vehicle was involved in a collision, or perhaps indicating some other event. The inertial measurement unit **710** (or some other VMM component) may then store/log data regarding the activities of the vehicle (and/or VMM components) surrounding the time of the event, similar to the way a flight recorder records events proximate to a plane crash. This recording component may collect information from the inertial measurement unit **710** and/or from other VMM components, for example from a UWB unit.

CEM **700** may include a real-time clock **714**. The real-time clock **714** may provide accurate (optionally, synced) time readings, for example to facilitate development evaluation testing. The time and date of the real-time clock may be adjusted automatically, for example by receiving updates from a GPS unit via TSM interface **730**. The time and date of the real-time clock may be adjusted by receiving change requests from the service interface or user interface via UIM interface **720**. In one example, the real-time clock **714** may exhibit an accuracy of plus/minus 5 seconds per day at 25 degrees Celsius.

The CEM **700** may be mounted in or near the vehicle cab. For example, if the CEM **700** is packaged with a UIM, the CEM may be mounted in the cab near an operator. In other examples, the CEM may be mounted on an upper frame or part of the vehicle, for example within the vicinity of the TSM. For example, if the CEM is packaged with one or more components of the TSM, a higher mounting location may reduce interference for TSM modules, for example the GPS unit and/or UWB unit. The CEM may be packaged with the TSM in shorter vehicles for example. In some embodiments, it may be beneficial to package the CEM separately from the TSM. In one particular example, the CEM may be mounted directly below the TSM, were the TSM is disposed above or on the roof of the vehicle (see FIG. **8**) and the CEM is disposed below the roof of the vehicle, for example fixed to the inner ceiling of the vehicle. In this example, the CEM may be sheltered from direct exposure to sunlight and the components of the TSM may experience minimal interference and a clear line of sight.

The CEM **700** may interface (for example via a power supply interface **708**) with a power supply **760**. The power supply interface **708** may include a power conditioning system. In one example, all power for the VMM components and subcomponents passes through the power supply interface/conditioning system **708** located in the CEM, and then power for the other VMM components is routed out from the CEM. In other examples, one or more VMM components may include their own power conditioning systems and may accept power from a power supply without receiving power that is channeled through the CEM. The power supply may be the same as the vehicle's power supply, for example a 12 VDC or 24 VDC power supply. Alternatively or in addition, the VMM may include an independent power supply such as a battery, solar panels, and the like.

Referring again to FIG. **6**, VMM **600** may include a transponder sensor module (TSM) **604**. In some implementations of the VMM, one or more components of the TSM **604** may be packaged with the CEM **602**. In other implementations, it may be beneficial to package one or more TSM components separately from other VMM components, for example on an upper extremity of a vehicle. FIG. **8** depicts an illustration of side angled view of the upper portion **802** of an example rail line vehicle (for example a vehicle similar to the vehicle of FIG. **1**C) and a mounting configuration **804** for one or more components of a TSM, in accordance with one or more embodiments of the present disclosure. One or more TSM

components may be mounted at a high point (for example, the highest point) on the vehicle, where a clear line of sight may be established between the TSM components and an area to the front and rear of the vehicle.

In the example shown in FIG. **8**, the wireless communications antenna **806** (for example, similar to the wireless communications antenna **608** of FIG. **6**) and a UWB unit **808** (for example, similar to the UWB unit **620** included in the one or more vehicle communication devices **612** of FIG. **6**) may be mounted separately from other VMM enclosures. In this example, the wireless communications antenna **806** and UWB unit **808** may be mounted on the upper extremity **810** of the vehicle to reduce signal interference and to allow for proper antenna placement. It should be understood that FIG. **8** depicts only one example of TSM components that may be mounted on the upper extremity of a vehicle. More or less TSM components (or other VMM components) than are shown in FIG. **8** may be mounted on the upper extremity of a vehicle. For example, components that may be mounted on the upper extremity of a vehicle may include the UWB unit, wireless/RF antennas and/or radios, GPS units, infrared sensors and the like.

TSM components (and/or other VMM components) may be installed on the upper extremity of a vehicle by a variety of means. Referring to FIG. **8**, for example, a hole may be drilled through the side of an upper portion **802** of a vehicle or through the roof **810** to allow hardware to thread through the vehicle's upper portion **802** and also through VMM components to fix the components to the upper portion. Additionally, brackets, flanges, sockets or other hardware may be used to fix components to the upper portion **802**. For example, FIG. **8** shows a bracket **814** that may be used to fix a UWB unit to the upper portion **802**. The bracket **814** may be fixed to the upper portion **802** of a vehicle and the UWB unit may be fixed to the bracket. Brackets may aid in attaching components to the upper portion **802**, and/or they may elevate components so that the components experience increased line of sight and decreased interference. One or more holes may be drilled through the roof **810** or a side wall of upper portion **802** to allow the passage of interface cables (for example, cable(s) **812** of FIG. **8**) into and/or out of the cab of a vehicle.

FIG. **9** depicts an illustration of an example rail line vehicle **900**, including a VMM that includes more than one TSM, in accordance with one or more embodiments of the present disclosure. In some embodiments of the disclosure, the VMM in a rail line vehicle may include more than one TSM, or may include more than one group of TSM components mounted on the upper extremity of a vehicle. With regard to the disclosure herein, when a description explains the configuration and/or benefits of multiple TSMs, it should be understood that the entire TSM may not be duplicated. Instead, one or more components of the TSM may be duplicated, while there may be a single instance of other components of the TSM. For example, the VMM may include duplicated vehicle communication devices, such as two or more UWB units. Additionally, while the disclosure herein may describe two TSMs, some embodiments may include VMMs with more than two TSMs.

Referring to FIG. **9**, a VMM installed in a vehicle **900** may include two TSMs **902**, **904** (or two groups of some TSM components), for example mounted at either end of the vehicle **900**. As shown in the example of FIG. **9**, the two TSMs **902**, **904** may be mounted at the extreme (or near extreme) front and rear ends of the vehicle **900**. Placing sensors, for example sensors included in TSMs **902**, **904**, at the extreme ends of a vehicle may improve the accuracy of some sensors, for example sensors that measure distance between vehicles (such as UWB sensors or infrared sensors). Especially if the vehicle **900** is long, a distance sensor (for example a sensor included in TSM **904**) that is placed near the end of a vehicle may more accurately calibrate itself to determine the exact location of the end of the vehicle **900**, and thus the sensor may be able to determine more accurately the distance between the end of the vehicle **900** and other vehicles. The two TSMs **902**, **904** may be connected to a single CEM **906**, which may be connected to a single UIM **908**. In other embodiments, the VMM may include more than one CEM and/or more than one UIM.

When a VMM-equipped vehicle is initialized to operate with a CAS, the VMM components of the vehicle may be calibrated (also referred to as "commissioning" the vehicle) to the particular installation configuration for that vehicle. Calibration may include an operator specifying the vehicle length in each direction from the one or more mounted TSMs. Rail line vehicles (for example, maintenance vehicles) can range in length (see FIG. **1**), for example from 12 feet to 80 feet, and the vehicles can have a variety of cab locations and configurations. Given the different lengths and configurations of vehicles, it may be necessary to program information into various components of the VMM, including the TSM and/or the CEM, such that the components are aware of (and/or can compute) the distance between the component's mounting location and the ends of the vehicle.

In some embodiments of the disclosure, circuitry within the VMM (for example in the CEM) may automatically compensate (calibrate) for the length of the vehicle and the mounting location. In one example, the VMM may include a single TSM, and the TSM may be mounted on the vehicle (for example, at the front or center of the vehicle), and circuitry within the VMM (for example in the CEM) may automatically compensating for the length of the vehicle and the mounting location. In another example, the VMM may include multiple TSMs, and the TSMs may be mounted on the vehicle (for example, near the front and rear of the vehicle), and circuitry within the VMM (for example in the CEM) may automatically compensating for the length of the vehicle and the mounting location of the multiple VMMs. The sensors may be designed to adjust for the size of the equipment and specific location of the components. The present disclosure contemplates various methods and solutions to adjust settings of VMM's components at initial installation to aid in component awareness. Components may contain smart technology that aids in the component's calibration. The VMM components may also be operable to account for a length of a vehicle that may change on the fly. For example, some vehicles change length when retractable sections are extended. The VMM components may be designed to accommodate this change in length, either by manual user input or automatic detection of the vehicle configuration.

Referring again to FIG. **6**, the TSM **604** may include one or more vehicle communication devices **612**. It should be understood that throughout this disclosure, when reference is made to vehicle communication devices, there may only exist a single vehicle communication device, for example just a UWB unit. In other examples, there may be more than one vehicle communication device. Vehicle communication devices **612** may be packaged together, or they may be packaged independently, or they may be packaged with other TSM components. The vehicle communication devices **612** may be in close communication with the CEM **602** via either a wired connection or a short range wireless connection. One benefit of a wired connection is that the CEM, which may contain a power conditioner unit and an interface to a power supply, can

provide power to the vehicle communication devices, along with communication functions.

The vehicle communication devices **612** may communicate wirelessly with other CAS/VMM-vehicles **638** in the work gang. The vehicle communication devices **612** may be operable to, among other functions, determine the relative location of other CAS/VMM-equipped vehicles in relation to the present vehicle. The vehicle communication devices **612** may utilize one or more communication technologies and may include one or more integrated antennas for sending and receiving signals to and from other vehicles. In one example, each vehicle may have a unique identification code that was assigned when the VMM was installed in the vehicle, or before or after such installation.

In some embodiments of the present disclosure, the vehicle communication devices **612** may include an Ultra Wideband (UWB) unit **620** to communicate with other VMMs. In one specific example, the UWB unit **620** is the only vehicle communication device. The UWB unit may include a control board, a data interface and/or a UWB antenna. The UWB unit **620** is typically adapted for sending signals to and/or receiving signals from UWB units mounted on/inside other vehicles. The UWB unit **620** may be adapted to measure the relative separation distance between properly equipped vehicles without becoming confused by interference from nearby stationary or unrelated off-track equipment that might otherwise cause false alarms in radar-based collision avoidance systems.

FIG. **10** depicts a block diagram illustrating example UWB units, in accordance with one or more embodiments of the present disclosure. Pulses emitted from a UWB transmitter may spread in many directions. A UWB unit may transmit and receive pulses that are communicated directly **1002** between UWB units (for example between a UWB transmitter/transceiver **1008** and a UWB receiver/transceiver **1006**), and/or the UWB unit may transmit and receive pulses that have been reflected **1004** (bounced) off of an object and/or surface, for example the ground. A UWB unit may be capable of resolving multipath reflections from a main signal by focusing on the first arriving pulse. Additionally, the UWB technology may take advantage of the fact that radio waves/pulses travel at a particular velocity. By measuring how long it takes a wave/pulse to travel (for example by reflecting/bouncing) between two transceivers, the distance between the UWB units can be accurately determined. This technique may be referred to as "Time of Flight" (TOF). In existing wireless radio technologies, TOF calculations have previously had limitations due to the reflection of radio waves from the wide range of objects in the vicinity. These reflections may result in the receipt of numerous conflicting signals of varying amplitudes, and in some instances one or more signals may cancel each other out, a phenomena referred to as "multi-path distortion". This may result in inaccurate distance determinations because a direct wave may have been cancelled out, and a reflected wave may travel a longer path and appear to be the first arriving pulse, resulting in a false (longer than actual) separation distance measurement.

A UWB unit may utilize a high bandwidth pulsed distance-measurement technology. A UWB transceiver may utilize a broad spectrum of frequencies simultaneously at a relatively low power levels. A UWB unit may be operable to periodically transmit short duration pulses, such as RF pulses. For example, a UWB unit may measure a distance of several hundred feet with a resolution of several inches. Precise range determination may be advantageous, for example when vehicle separations are small and/or when a potential GPS measurement error becomes significant. In one example, a GPS measurement error may be 10-15 feet. Additionally, each pulse transmitted by a UWB unit may be coded and the phase of the pulse may be modulated and the pulse repetition rate may be variable. Thus, a UWB unit may measure separation distances more accurately and be less susceptible to interference from geographic conditions and less susceptible to multi-path distortion than are other wireless technologies.

A UWB unit may transmit one or more signals that may be pseudo-randomly (and uniquely) encoded with low-amplitude RF energy spread over a 2 GHz bandwidth. The transmitted signal may be spread out over such a wide range of frequencies that the transmissions appear like normal background atmospheric noise. As a result, the signal is unlikely to cause interference with other communications systems. This encoding also means that information may be transmitted with the range finding signal, such that data communication may be accomplished while distance measurement is performed. In other words, the UWB unit may be adapted to transmit data to other UWB units in addition to detecting the distance to other UWB units. In effect, the two functions (data and distance) may be performed at the same time using the same wireless link because the UWB unit may transmit data, and then additionally, distance information may be computed by determine how long it took for the data to travel from one UWB unit to the other. It should be understood, however, that the two functions (data and distance) need not be performed at the same time.

The UWB unit may be adapted to send data as well as determine distance between vehicles. Because the UWB unit may be utilized to send data, some embodiments of the present disclosure, for example those where a central tracking component resides in the vehicle mounted module, may not need to use any other type of wireless or RF technology to communicate. This could reduce the technology components required in the system, reducing cost of the system. However, in other embodiments, a VMM may benefit by utilizing more than one data link (wireless technology capable of transmitting data). For example, a wireless RF link may provide a greater distance/range for sending data than a UWB unit, and because of this benefit and potentially other benefits of various types of data links/wireless technologies, a VMM may benefit by utilizing more than one type of data link. Additionally, a collision avoidance system may have multiple data links in order to introduce redundancy into the system. For example, the UWB unit may be capable of sending data if the RF link is not functioning properly, and vice versa.

One example of a UWB technology that the CAS may utilize is the technology described in the White Paper published by Time Domain entitled "Time Domain's Ultra Wideband (UWB): Definition and Advantages," which is incorporated by reference in its entirety herein. However, it should be understood that the collision avoidance system may utilize other designs and types of UWB technologies besides just the one described in the White Paper.

The UWB unit may be operable to measuring the vehicle separation independently. Thus, in various embodiments of the CAS, the UWB unit may replace the GPS unit, or the UWB unit may work in conjunction with the GPS unit. As explained above, the CAS may be designed to include redundancy in the system, for example in the form of multiple types of sensor technologies and/or multiple sensors of a particular type of technology. One benefit of utilizing redundant sensors may be that some sensors may function properly when other sensors are not functioning optimally or at all. For example, a GPS sensor may not communicate well with satellites when a vehicle is in a tunnel, and thus the GPS unit may not provide adequate information to the CAS in this situation. However,

in this situation, the UWB unit (or other sensors/technologies) may be fully functional. For example, tests have been performed in tunnels that stretch up to 1 mile in length (or longer), and the tests have shown that a properly configured UWB unit may accurately measure distance and relative speed of vehicles in such a tunnel. UWB sensors (and/or other non-GPS type sensors) may also work in conjunction with a GPS sensor. For example, a UWB sensor may provide better resolution (i.e., can measure separation distance at finer increments, more accurately) and the GPS sensor may provide a location/separation information over a greater area.

Referring again to FIG. **6**, once a UWB unit determines distance information, it may communicate this data to a CTU **630**, for example via wireless communications antenna **608**. Wireless communications antenna **608** may be an RF antenna, for example a 2.4 GHz radio antenna. In other embodiments, where there is no CTU in a discrete housing, UWB distance data (an optionally other data) may be communicated to CTU modules in other VMMs via wireless communications antenna **608** and/or a separate wireless communications antenna located in the TSM **604**. In embodiments where the UWB unit is adapted to operate in conjunction with a GPS unit, combined GPS and UWB distance data may be communicated between a vehicle and the CTU **630** and/or between vehicles in the work group via similar wireless communications antennas/technologies as described herein.

FIG. **11** depicts and illustration of a side view of an example rail line vehicle including multiple UWB units (or multiple UWB components), in accordance with one or more embodiments of the present disclosure. In some embodiments, a VMM installed on a vehicle **1102** may include more than one UWB unit (for example, UWB units **1104**, **1106**), for example to introduce redundancy into the system. In some embodiments, a VMM installed on a vehicle **1102** may include more than one UWB antenna, and the multiple UWB antennas may share a common control board and/or data interface. When present disclosure describes multiple UWB units, it should be understood that the entire UWB unit may be duplicated or one or more components of the UWB unit may be duplicated, for example the UWB antenna. In some embodiments, multiple UWB units (or multiple UWB components) may be housed in a single enclosure. In other embodiments, multiple UWB units (or multiple UWB components) may be housed in separate enclosures, as depicted in FIG. **11**.

In some situations, when a UWB pulse is reflected from an object or a surface (for example the ground), the UWB pulse may be destroyed (for example, by a reflected signal which is the same amplitude but **180** degrees out of phase) or altered before it gets to the UWB receiver, and/or other interference may cancel out a pulse. These situations where a UWB link might not transmit a pulse ideally may be referred to as "holes." In some embodiments, the VMMs may include more than one UWB unit (or UWB component), for example in case one UWB pulse is destroyed. In some examples, two UWB units (or two UWB antennas) may be mounted on a single vehicle with a small offset between the UWB antennas. For example, referring to FIG. **11**, two UWB units (or two UWB antennas) **1104**, **1106** may be mounted on a single vehicle **1102** with a small vertical distance **1108** between the UWB antennas. In this example, pulses **1110**, **1112** from the two UWB units **1104**, **1106** (respectively) may arrive at a UWB receiver of another vehicle after traveling slightly different distances (for example, because they reflected off the ground at different angles). Multiple/redundant UWB units may increase the probability that whatever surface and/or interference destroyed or altered one UWB pulse will not interfere with the second UWB pulse. In some examples, two UWB units (or two UWB antennas) may be mounted on a single vehicle with a small horizontal distance between the UWB antennas. The horizontal offset may provide information to the VMM to determine the orientation of nearby vehicles in relation to the immediate vehicle. For example, UWB unit information may show that a nearby/target vehicle that is in front of the immediate vehicle is closer to a front UWB antenna, and likewise for a rear vehicle/rear UWB antenna.

In some embodiments, one or more UWB units may be operable to transmit/receive signals with varying center frequencies. This multiple center frequency technique may work with a single UWB unit or it may work with multiple UWB units. In a single UWB unit example, the UWB controller may utilize adaptive output filters. The UWB unit may include a single UWB transceiver that is adapted to send multiple pulses/signals with different center frequencies at different times, for example alternating between modes (center frequencies). A corresponding UWB receiving unit may be synchronized with the UWB unit sending the signals, in that it may receive pulses/signals with different center frequencies at different times. In a multiple UWB unit example, one UWB unit may send signals at one center frequency and another UWB unit may send signals at a different center frequency. Variations in the center frequency of the UWB signals may result in a different phase delays of the signals, for example when reflected. If one signal has been significantly altered or destroyed by a reflection, another signal(s) (which utilizes a different center frequency) may be unaffected, or at least less affected, by the reflection. This may be because different frequency signal(s) over the same reflection path length may experience a different phase delay. This approach may improve the reliability of UWB communications under certain operating conditions.

Referring to FIG. **6**, in some embodiments, the vehicle communication devices **612** may include other wireless communication devices/technologies (beyond or in replacement of a UWB unit) to communicate with other VMMs. In some embodiments, a VMM may utilize a wireless communications antenna/radio (for example, an RF antenna/radio) to communicate with other VMMs. In some embodiments, the same wireless communications antenna **608** that communicates with a CTU **630** may communicate with other VMMs. In some embodiments, the vehicle communication devices **612** may include an ultrasonic or short distance laser device. Some example ultrasonic or short distance laser devices can sense distances between zero and thirty feet. In yet other examples, the vehicle communication devices may utilize radar, infrared (IR), and/or optics technologies.

Referring again to FIG. **6**, a TSM may include a Global Positioning System (GPS) unit **610**. The GPS unit **610** may be incorporated to the TSM. In some embodiments, the GPS unit **610** may be packaged with one or more vehicle communication devices **612**, or it may be packaged in the CEM. Alternatively, the GPS unit **610** may be housed separately or may be incorporated into other VMM components or subcomponents. The GPS unit may include either an integrated or separate antenna assembly.

The GPS unit **610** may be adapted to determine the absolute position and speed of a vehicle that is equipped with the GPS unit. Information/data generated by a GPS unit may allow real-time determination of vehicle velocity and location. This information/data may allow a GPS unit **610** to determine expected vehicle stopping distances and may enable logging of equipment location with respect to time and

date. For example, absolute location information provided by a GPS unit **610** may be useful to track the work performed by a work gang. A GPS unit may also provide distance information regarding the distance between two GPS-equipped vehicles.

Some GPS-based systems may experience reduced accuracy at times or may lose all connection with satellites, for example, when a vehicle enters a deep valley or a tunnel. A GPS unit may provide distance information in conjunction with other technologies that provide distance information (for example, UWB, infrared) as a form of redundancy and/or to offer a variety of distance measurement ranges and precision. A GPS unit may be operable to determine vehicle position within a wider range, for example 10 to 15 feet. A GPS unit may allow for the determination of distances between vehicles that are too far apart for other types of distance detection technologies to function accurately. Then, other technologies, for example a UWB unit, may provide a more precise distance measurement, for example a distance within 6 inches. The accuracy of a GPS unit **610** may be enhanced by utilizing a WAAS (Wide Area Augmentation System), a system of ground reference stations across North America that provide GPS signal corrections. Corrections provided by a WAAS may improve the positioning capability of the GPS unit **610**, for example by a factor of five, such that the location may be determined as accurately as within 2 to 3 feet.

Referring to FIG. **6**, the VMM may include one or more user interface modules (UIM) **606**. A UIM **606** may further include a user interface **614**, a service interface **616** (optionally with diagnostic components/interfaces) and status/fault indicators **618**. A UIM **606** may provide an operator with an interface by which the operator can engage with the technologies that are part of the VMM, and by which the operator may be alerted of events, for example if vehicle separation criteria are violated. A UIM may be located/mounted within convenient reach and view of the operator, and may be connected by an interface cable (or short range wireless connection) to other VMM modules, for example the CEM. For example, the UIM may be mounted in a vehicle cab in order to allow the operator to see and hear warning and alarm indications.

Status/fault indicators **618** may alert an operator that one or more VMM components and/or subcomponents are not operating in an optimal manner. In some embodiments of the present disclosure, the VMM components may be operable to "self-monitor," meaning they may be adapted to monitor their own operation and health. If a VMM detects degraded or non-optimal performance (for example regarding any of the sensors or other VMM components or subcomponents), the status/fault indicators **618** may alert an operator. In some embodiments, the VMM may communicate status/fault indication to the CTU (or CTU module(s), for example via a wireless communications antenna, for example wireless communications antenna **608**.

FIGS. **12**A and **12**B depict illustrations of example user interfaces, in accordance with one or more embodiments of the present disclosure. The UIM may include a user interface. Referring to FIGS. **12**A and **12**B, it can be seen that a user interface (for example user interfaces **1202**, **1204**) may include one or more means of alerting an operator of events, for example if vehicle separation criteria are violated. FIG. **12**A shows one example of a user interface **1202**. In this example, the user interface **1202** may include one or more visual indicators **1206**, one or more audible indicators **1208**, one or more switches/buttons **1210**, **1212**, **1214**, and/or other input means or alerting means. Examples of visual indicators **1206** are lights, lamps, alpha-numeric character displays, LED's and the like. These indicators may provide an operator with information regarding the technologies included in the VMM, and certain indicators may alert the operator when an event occurs, for example when separation parameters (between vehicles for example) are exceeded. Examples of audible indicators **1208** are variable characteristic audible indicators, buzzers, alarms, sirens, horns and the like. The user interface **1202** may include one or more interface switches/buttons **1210**, **1212**, **1214** that may be adapted to allow an operator to configure and/or interact with components of the VMM. For example switches may be adapted to activate and deactivate component interfaces, for example component interfaces in the CEM. In one example, (and referring to FIG. **7**), an operator may use a switch to deactivate the interface **706** to an encoder module. Examples of other input switches/buttons are buttons that acknowledge (temporary mute) a buzzer, alarm or a horn.

FIG. **12**B shows another example of a user interface **1204**. The user interface **1204** may be a touchscreen, tablet, PDA, monitor or other type of digital display/interface. Even though some descriptions of user interface **1204** may refer to it as a touchscreen, it should be understood that other alternatives mentioned and others may be contemplated. In some embodiments, a touchscreen may be implemented in conjunction with other types of user interfaces or user interface components, for example the components of user interface **1202**. In some embodiments, a touchscreen may be adapted to serve as the only user interface component that interfaces with the operator. In some embodiments (and referring to FIG. **6**), if a touchscreen is used to implement the user interface **614**, other components of the UIM (for example the service interface **616** and/or the status/fault indicators **618**) may be incorporated into the same touchscreen.

User interface/touchscreen **1204** may offer more flexibility and functionality than "hard" switches, lights, buzzers and the like. For example, a touchscreen may include on or more physical buttons (for example button **1218**), but may also allow an operator to engage "soft"/temporary buttons on the screen **1216** of the touchscreen. In this respect, the touchscreen may offer similar functionality to hard switches/buttons. Additionally, a touchscreen may include one or more speakers and/or audio drivers, and thus the touchscreen may offer similar functionality to hard buzzers, alarms and the like. The screen **1216** of the touchscreen **1204** may also alert an operator to an event, offering similar functionally to hard lights, lamps and the like.

A touchscreen **1204** may be adapted (i.e., programmed, etc.) to display to an operator multiple sets of screens and/or menus, with multiple sets of options, functions and the like. Additionally, a touchscreen may be adapted to display complex (for example, graphical, textual, etc.) information to an operator. For example, a touchscreen may show the operator the speed of his vehicle, or may show operator his GPS coordinates. A touchscreen **1204** may be adapted (i.e., programmed, etc.) to offer additional functionality, for example allowing operators to send messages (for example text-based or html-based message) to nearby vehicles. In some embodiments, a touchscreen may provide a GPS-augmentation feature, for example, which may adapt the touchscreen to display the location of the vehicle relative to railroad mile markers.

It should be understood that the components and/or functionalities of user interfaces **1202** and **1204** may be incorporated into or implemented in one or more physical housings and/or devices. These components may be incorporated into discrete enclosure(s) (for example mounted near an operator/cab) and/or they may be incorporated into VMM components. In some embodiments, the user interface (for example, interfaces **1202** and/or **1204**) may be mounted alongside or in the

same enclosure as the CEM **1230** or it may be mounted in a separate enclosure. For example, the user interface may be located in the passenger cab and the CEM may be located on an upper internal extremity of the vehicle. This flexible mounting arrangement may help to accommodate a wide range of equipment/vehicles that the CAS may need to track by allowing the user interface to be mounted where it is visible and accessible to the equipment operator while allowing the CEM to be mounted in close proximity to the TSM, which may improve performance, for example by allowing better reception.

The user interface (for example user interfaces **1202** and/or **1204**) may be in communication with the CEM **1230**, and/or other VMM modules. The user interface may communicate with the CEM, for example, via either a wired interface or a short range wireless connection. One benefit of a wired connection is that the CEM, may contain a power supply interface and/or a power conditioner unit and may be able to provide power to the user interfaces, along with communication functions.

Referring to FIG. **6**, the UIM **606** may include a service interface **616** that provides for installation, configuration, maintenance and/or diagnostic activities. The service interface **616** may be incorporated as part of the user interface, or it may be housed separately. In some embodiments, the service interface **616** may be located in the CEM **602**. The service interface **616** may also be used to initialize the vehicle mounted module. In other embodiments, the user interface **614** may be used to initialize the vehicle mounted module. For example, the CEM may include a setup program that initializes the various VMM components and subcomponents. An operator may use the user interface **614** or the service interface **616** to input initialization information into the setup program. Such information may include the physical location where various VMM components are mounted on the vehicle, as well as vehicle size and vehicle type. This information may be input when the vehicle mounted module is initially installed on the vehicle.

The service interface **616** may include a variety of technologies that may enable fast and easy communication between an operator and the service interface, and between the service interface and other VMM components and subcomponents. For example, service interface **616** may include one or more USB ports, Ethernet ports, and/or SD memory card slots. Service interface **616** may be configured, for example, with an industry standard Ethernet port to allow the use of commercially available laptop computers that may interface with service interface **616**, for example to perform status inquiries, to configure settings of VMM components, and/or to update the software/firmware of VMM components. Ethernet ports generally will conform to the IEEE 802.3 communication standard for 10BASE-T Ethernet (or alternatively 100BASE-T). In addition to Ethernet ports, or in conjunction with Ethernet ports, the service interface **616** may be configured with an 8-position RJ45 modular jack for interconnection. The service interface **616** may also operate as a DHCP server, thus allowing an operator to connect a laptop to the Ethernet port and within a few seconds be automatically configured and communicating with the VMM **600**. Alternatively, the service interface **616** may require a static IP address setting to be configured on the laptop. In such a configuration, the service interface may conform to the Internet Protocol Version 4 (IPv4). In some examples, the service interface connectors, such as the Ethernet connectors and the RJ45 connectors, may include environmental dust shields for protection.

In some embodiments, service interface **616** may include wireless capabilities. For example, service interface **616** may include a wireless radio (for example an RF radio), WIFI components and/or other wireless technology. A service interface **616** with wireless capabilities may be adapted to accept "field updates." Field updates refer to updates to the software and/or firmware of VMM modules that are "pushed" to the modules over a wireless link. In one example, a foreman may drive up to a group of vehicles and may push updates to all the vehicles simultaneously, for example without having to physically connect to the vehicles. Alternatively or in addition, wireless communications antenna **608** (and/or other wireless communication antenna(s)) may be used to perform field updates.

In one or more embodiments of the present disclosure, the VMM may include (or may interface with) one or more non-GPS type sensors. These non-GPS type sensors may be adapted to measure speed (also referred to as ground speed) and direction of a rail vehicle. A GPS unit may provide speed and direction information, but in some embodiments and/or in some situations, the non-GPS type sensors may either supplement or replace GPS speed and direction information. For example, non-GPS type sensors may supplement a GPS sensor as a form of redundancy in the system, or may provide speed and direction information when the GPS unit cannot communicate with satellites (for example, when a vehicle is inside a tunnel). Additionally, these non-GPS type sensors may allow the CAS to determine relative vehicle position. For example, the non-GPS type sensors may calculate relative vehicle position as a function of the offset from the last known GPS location.

One type of non-GPS type sensor is an encoder module. An encoder module may be adapted to measure ground speed and direction of a rail line vehicle. The encoder module may supplement the UWB technology or replace the UWB technology, for example as a method of providing more precise "dead reckoning" data to the CAS, helping to overcome the "dead reckoning" limitations of earlier systems. In one embodiment, the encoder module may include a small rubber wheel which contacts the top of a rail on which the vehicle travels. The encoder module may be mounted on an adjustable preloaded assembly which maintains contact with the rail. A magnetic rotary encoder may count the rotations of the wheel. In one example, an encoder module may use a small integrated Hall-ASIC to determine the rotational speed of the wheel. This wheel rotation information may be translated into distance information which may be communicated to a CEM either through a wired or wireless connection.

The encoder module may be adapted to allow the encoder assembly be manually or automatically raised from the tracks for maintenance or lifting of the vehicle from the tracks. The encoder module may also include auto calibration features. For example, as the encoder wheel turns, it may utilize GPS data, when it is available, to review the last distance traveled, and compare that with the number of rotations of the wheel. This information can be constantly updated and used to compensate for wheel wear and or track slippage. Referring to FIG. **7**, a CEM **700** may include one or more interfaces such that a VMM may communicate with one or more non-GPS type sensors. An encoder module, for example, may be in communication with a CEM, typically connected to a module interface. As an example, FIG. **7** depicts an encoder module **750** connecting to a CEM **700** via an interface **706**.

Another type of non-GPS type sensor that may be in communication with a VMM is microwave radar, for example a Doppler radar. A microwave radar may be adapted to measure ground speed and direction of a rail vehicle. In one example,

a microwave radar may be mounted on a rail line vehicle and may be oriented to point at the ground to detect ground speed and direction of travel. A microwave radar, for example, may be in communication with a CEM, typically connected to a module interface. As an example, FIG. **7** depicts a microwave radar **752** connecting to a CEM **700** via an interface **706**.

Another type of non-GPS type sensor that may be in communication with a VMM is a laser device. A laser device may be adapted to measure ground speed and direction of a rail vehicle. In one example, laser device may be mounted on a rail line vehicle and may be oriented to point at the ground. A laser device may bounce a signal off of the ground (or other stationary object) to detect ground speed and direction of travel. A laser device, for example, may be in communication with a CEM, typically connected to a module interface. As an example, FIG. **7** depicts a laser device **754** connecting to a CEM **700** via an interface **706**.

Other types of non-GPS sensors that may be used in conjunction with the GPS sensor to detect ground speed and direction of travel include infrared sensors, UWB sensors as described herein, UWB radar sensors, and other types of radar sensors. These non-GPS type sensors may add redundancy to the GPS sensor, or they may provide information when GPS information is temporarily unavailable. One or more parts of one or more of the non-GPS type sensors may be packaged in the same enclosure as other VMM modules, or they may be packaged separately.

In operation, the CAS may be capable of precisely tracking the location and separation distances of vehicles equipped with appropriate equipment and/or components as described herein. When the CAS is tracking vehicles, a particular work gang may be operating in one of two modes for example—travel mode or work mode. For each mode, railroad companies may require that a specific spacing be maintained between vehicles. In work mode, the vehicles may be traveling at a speed of less than 10 MPH, and about 40 to 50 feet of spacing between vehicles may be required. In travel mode, the vehicles may be traveling at speeds of up to around 25 MPH, and about 300 feet to about 500 feet of spacing between vehicles may be required. Depending on the mode in which the vehicles are operating, the CAS may adjust its sensitivity and/or settings in order to better predict when collisions may be imminent.

For the CAS to operate optimally, each vehicle in a work gang may need to be equipped with a VMM. The VMMs mounted on/in the vehicles and the CTU may only be able to detect vehicles which are outfitted with a VMM. In one embodiment of the present disclosure, the CAS requires that every vehicle in a work gang be equipped with a VMM. If all vehicles in a work gang are equipped with a VMM, the CAS may be adapted to eliminate false warnings which plague existing systems, such as radar-based systems.

FIG. **13** depicts a flow diagram **1300** that shows exemplary steps in the operation of a CAS, in accordance with one or more embodiments of the present disclosure. To explain the operation of a particular vehicle/VMM, the immediate vehicle/VMM may be referred to as the "host" and nearby vehicles/VMMs with which the host links/communicates may be referred to as "targets". It should be understood that when the functionality of a host in relation to targets is explained, each target may also act as a host for the purposes of explaining how that target vehicle operates in relation to nearby vehicles.

Referring to FIG. **13**, at step **1302**, the host vehicle/VMM is powered up. This may be referred to as the initial start-up. The VMM may begin to operate whenever a vehicle's systems are powered up. At step **1304**, within a few seconds of initial startup, the host VMM may begin to automatically detect the existence of other vehicles/VMMs in the vicinity. For example, the host VMM may automatically activate one or more vehicle communication devices to search for/link with other vehicles (targets) both in front of the host vehicle and/or behind the host vehicle. The host may survey its surroundings to determine if there is any other VMM-type equipment nearby. At step **1306**, the host may determine which discovered targets, both in front and in back, are the closest and may sense/measure the actual separation distance between the closest target in front and the closest target in the back. In some embodiments, the host may sense and compute distances for vehicles beyond just the vehicles immediately to the front and back of the host. At step **1308**, the host VMM may continuously sense/calculate distances between the host vehicle and the target vehicles. In some embodiments, the host may sense and compute distances for vehicles beyond just the vehicles immediately to the front and back of the host.

At step **1310**, the host (and perhaps other target vehicles) may transmit location and speed information to the CTU, for example through the radio antenna. Additionally or alternatively, the host VMM may transmit (and/or receive) location and speed information, for example through one or more vehicle communication devices, to target vehicles/VMMs. At step **1312**, the CTU and/or CTU module inside the host VMM may calculate information, for example absolute and relative location of the vehicles in the work gang, speed and direction of vehicles, separation distances and/or safe distance violations. At step **1314**, if the CTU and/or host VMM determines that collision is imminent or prescribed safe distances are violated, the host VMM, for example via a user interface, may notify the operator. For example, if the speed and direction information violates preset separation criteria, one or more warning indicators and/or audible buzzers, alarms and the like will activate. Additionally, the host VMM may communicate the violation to the CTU, perhaps through the radio antenna. At step **1316**, if the separation violation has been resolved, for example by the movement of vehicles away from each other, the warning/notification indicator to the operator may silence, and the host may resume monitoring for other potential violations by continuously sensing nearby vehicles and computing separation distances (return to step **1308**).

FIG. **14** depicts a flow diagram **1400** that shows exemplary steps in the operation of a CAS, in accordance with one or more embodiments of the present disclosure. Specifically, flow diagram **1400** shows exemplary steps illustrating how a CAS may determine distances between vehicles. Each vehicle in a work gang may include a GPS unit as well as other sensor technologies such as UWB sensors.

At step **1402**, a host may utilize its GPS unit to determine its absolute location and speed (and perhaps direction of travel). At step **1404**, the host may determine that it would benefit from information from other non-GPS type sensors. For example, one or more vehicles in the work gang may become unable to utilize the vehicle's GPS unit. Vehicles may travel through tunnels, mountains and developed areas that include structures that may prevent or reduce the functionality of GPS-based technologies, resulting in the GPS signal being lost (the "dead reckoning" situation). In these types of situations, the host may determine that other types of sensors included in (or in communication with) the VMM may aid in determining the precise location of vehicles. Even if the GPS signal is not lost, these other types of sensors may be used to enhance the precision of the location information gathered with respect to a vehicle. At step **1406**, the host may utilize non-GPS sensors to determine relative location and speed

information. The host may utilize one or more vehicle communication devices. For example, the UWB unit may determine separation distance and closing speed. The host may utilize components connected to the VMM via component interfaces. For example, a Doppler radar or encoder wheel may determine ground speed and direction of travel.

At step **1408**, the host VMM and/or the CTU may compute separation distances between the host and other vehicles. For example, the microprocessor in the CEM (a component of the VMM) may compute the separation distance between the host and adjacent vehicles. In one illustrative example, a maintenance vehicle (the host) is 40 feet long, and a TSM is installed 10 feet behind the front of the vehicle. Another maintenance vehicle (the target) is also 40 feet long, and a TSM is installed 30 forward from the back of the vehicle. If there is 50 feet between the front of the host vehicle and the rear of the target vehicle, the CAS will measure a distance between the TSMs of 90 feet (10 feet+50 feet+30 feet). The CAS may then perform calculations to compensate for the placement of the TSMs relative to the front and rear of the vehicles. For example, the CAS will subtract 10 feet and 30 feet (the respective distances between the each TSM and the relevant ends of the vehicle) and determine a separation distance of 50 feet (90 feet−10 feet−30 feet).

At step **1410**, the host VMM and/or the CTU may compare computed separation distances to prescribed (safe) separation distances for the given vehicle speed/size. At step **1412**, the host VMM and/or the CTU may determine whether a collision is imminent and whether an operator must be cautioned. The CAS may consider a variety of types of data and scenarios to determine if a collision is imminent. For example, a separation distance of 40 feet may be acceptable when vehicles are traveling at 5 miles per hour, but if the vehicles are traveling at 20 miles per hour, an unsafe condition may exists and the operator will be notified with an audible and visual alert. In another example, a vehicle that is far ahead may not pose a hazard, but one that is directly ahead, and moving slower than the host vehicle may be a potential collision hazard. In another example, two vehicles may have been creeping along the tracks at a separation distance of 100 feet, and then the vehicles speed up to reach another worksite. If the separation distance does not increase with the increase in speed, the CAS may sound a warning or alarm.

Using various combinations of technologies (UWB, encoder modules, radar, etc.), the CAS can monitor the precise relative location and speed of the vehicles in a work gang, and determine whether a predetermined separation distance has been violated. The CAS may notify, caution, and/or alarm vehicle operators and/or other railroad personnel (via audible and/or visual indicators) when the separation distances between rail line vehicles becomes less than a specified safe distance, which may indicated that a vehicle is approaching another vehicle and is within a separation distance which may not be safe. The specified safe distance may be programmed by trained service technicians.

Instead of sounding a "hard" alarm through visual and audible alarms when a separation distance is violated, the CAS may utilize a "progressive" warning approach. In general, as the relative spacing between potential alarm events decreases, the collision avoidance system may increase the severity of the warning indication. For example, if a vehicle is on a collision course but has not yet reached a hard threshold, the collision avoidance system may initiate a "soft" alarm/notification initially, such as a short, quiet, visible-only or subdued alarm. The rate, frequency, prominence and/or severity of the alarm may then increase as the vehicles get closer to the hard alarm threshold (indicating a more critical threat condition).

The CAS may adjust its thresholds according to the speed of one or more vehicles. This feature may be referred to as an "adaptive threshold" feature. The adaptive threshold feature may allow for scaling of thresholds of the alarm/notification levels based upon the speed of the immediate vehicle and the relative speed of the immediate vehicle and a vehicle that may collide with the immediate vehicle. For example, when vehicles are traveling to a worksite, at a speed of about 25 miles per hour for example, the expected separation distance may be about 300 to about 500 feet. In a scenario where a vehicle is at a worksite, moving slowly, the expected separation distance may be smaller, for example about 40 to 50 feet. The relative vehicle speed determines how long we have to respond to the issue, and our vehicle speed determines how long the stopping distance will be, which is non-linear.

The CAS may also include an option, mode or switch whereby an operator or a railroad foreman can temporarily deactivate/silence (for example via a user interface) the separation warning/notification features of one or more vehicles. Once silenced, a warning/notification may not repeat until the vehicle separation has again exceeded prescribed safe distances, or, for example, the warning/notification may sound again after a defined period of time if the separation distance violation has not been improved. This silencing feature may allow for periodic, sanctioned violations of prescribed separation distances without alarms, buzzers and the like becoming a nuisance to the operators. An operator may simply acknowledge that the violation of the separation distance was deliberate and the notification may not repeat, until another violation occurs for example. If the violation is not acknowledged, the notification/alarm may repeat periodically.

In some situations, for example, a vehicle operator may be asked by his foreman to temporarily violate the prescribed work separation distances, such as when vehicles come together for a meeting. In this situation, vehicles will slowly approach other vehicles and stop close to other vehicles, so that the work gang may be in a tight group. The operators can then dismount and walk a short distance for a meeting. The collision avoidance system may be designed to accommodate this tight-group situation without needlessly activating alarms, annoying railroad personnel and causing nuisance false alarms, for example by detecting very slow-speed approaches. In some examples, a deactivation may require an operator or a foreman to use a key, code, password or the like to gain authorization to deactivate the warning features. This will prevent an accidental or unauthorized deactivation that may lead to an accident where no warning was sounded. In other examples, the collision avoidance system may automatically reactivate the separation warning features after a certain amount of time, or when the vehicles separate a certain distance (or satisfy a certain distance/speed ratio), so that the system remains in an active tracking and warning mode when the vehicles are working or traveling.

FIG. **15** depicts a flow diagram **1500** that shows exemplary steps in the operation of a CAS, in accordance with one or more embodiments of the present disclosure. Specifically, flow diagram **1500** shows exemplary steps in the operation of a progressive/graduated warning system. In some embodiments, the CAS may utilize a progressive/graduated warning approach that utilizes classes of warnings and/or notifications. The CAS may start by initiating one class of warning, and then escalate to a more severe class of warning if certain distance/speed measurements violate certain thresholds. Separation distances for progressive/graduated thresholds

may be based upon vehicle stopping distance test results as explained elsewhere herein. With regard to the following descriptions, it should be understood that a reference to the CAS or the VMM or the CTU performing a calculation, making a determination, generating a warning/alarm, or other events may actually be performed and/or generated by one or more components within the CAS, VMM and/or CTU.

At step **1502**, the CAS system may determine that a certain distance/speed measurements violate one or more certain preliminary thresholds. At step **1504**, the CAS generates a first class of warning. In one example, the first class of warning may be labeled as a "notification." In certain situations, it may not be dangerous to violate preliminary thresholds (for example, in the case of work vehicles congregating for a meeting), and thus notifications may be designed to allow operators to ignore/silence them. At step **1506**, the CAS may accept input from an operator regarding whether the operator wants to silence the notification. For example, an operator could indicate an "acknowledge" choice via a button, touch screen or the like. At step **1508**, if the operator chooses to silence/acknowledge the notification, this may silence the notification once, at least until a violation that leads to a notification reoccurs. Notifications may be auto ignored in certain situations, for example, if vehicles are moving very slowly. Notifications may be less prominent than other classes of warnings. For example, notifications may display on a screen on the user interface, and may initiate a short sound, without being too annoying or distracting to the operator.

At step **1510**, the CAS system may determine that a certain distance/speed measurements violate certain intermediate thresholds, thresholds that the CAS system has determined present a higher risk of collision. At step **1512**, the CAS may generate a second class of warning. In one example, the second class of warning may be labeled as a "caution" warning. In certain situations, it may not be dangerous to violate these intermediate thresholds, at least momentarily, and thus notifications may be designed to allow operators to ignore/silence them momentarily. At step **1514**, the CAS may accept input from an operator regarding whether the operator wants to silence the caution. At step **1516**, silenced caution warnings may reinitiate quickly if silenced, unless the situation that led to the caution warning is remedied. Caution warnings may be more prominent than notifications but may be less prominent than other more severe classes of warnings. For example, caution warnings may display on a screen on the user interface in a more prominent manner than notifications, such as by blinking, taking up more of the user interface screen, etc. Caution warnings may initiate a louder sound than notifications, but may be designed to avoid being too annoying or distracting to the operator.

At step **1518**, the CAS system may determine that certain distance/speed measurements violate certain critical thresholds, thresholds that the CAS system has determined present a high risk of collision and require immediate correction. At step **1520**, the CAS may generate a third class of warning. In one example, the third class of warning may be labeled as an "alarm" warning. In certain situations, it may be dangerous to violate these critical thresholds, and thus alarms may be designed to prevent operators from ignoring/silencing them. Caution warnings may be designed to get the attention of an operator very quickly, for example by being prominent, loud, frequent, bright and the like. For example, alarms may display on a screen on the user interface in a very prominent manner, such as by blinking, taking up the entire user interface screen, etc. Alarms may initiate a loud sound, and may be designed to be annoying and/or attention getting in order to force the operator to take steps to remedy the situation. Once the operator takes steps to remedy the situation, the warnings may scale back from "alarm" to "caution" to "notification" classification and/or may stop completely.

The progressive/graduated warning system described in relation to FIG. **15** may utilize an "adaptive threshold" feature, whereby one or more thresholds (for example the preliminary, intermediate and critical thresholds) may be modified depending on the speed of one or more vehicles. The adaptive threshold feature may allow for scaling of thresholds of the alarm/notification levels based upon the speed of the immediate vehicle and the relative speed of the immediate vehicle and a vehicle that may collide with the immediate vehicle.

As explained above, the maintenance vehicles often work in work gangs comprising a plurality of vehicles, for example, a group of between four and forty vehicles, and the collision avoidance system is capable of tracking each vehicle that is part of the work gang. In some embodiments of the present technology, however, a single collision avoidance system may be responsible for tracking vehicles that are part of more than one work gang. For example, the collision avoidance system may track group A and group B. A collision avoidance system may be designed to distinguish between multiple work gangs so that the collision avoidance system can determine which vehicles are on the same track. In the event that maintenance vehicles are on two closely-located parallel tracks, it may be difficult for the collision avoidance system to determine which vehicles are on the same track and thus present real collision risks. The CAS may be adapted and/or programmed to handle work group designations/associations in order to limit unwanted detections of other maintenance vehicles on adjacent tracks.

In some embodiments, the VMMs and/or the CTU may include a switch, button, touch screen or the like that may be adapted to allow an operator to select from multiple group associations. All maintenance vehicles on a single track, for example, may set their switch, button, touch screen or the like to select the same group association/setting, and vehicles on a second parallel or other close but separate track may select a different group association/setting. The collision avoidance system may be adapted to ignore (or distinguish) the vehicles on the other tracks (vehicles with an alternate group association/setting), when tracking vehicles within a target group. For example, the work group selections/associations may allow the VMMs/CTU to only notify or alarm an operator when a separation distance violation is detected with other vehicles on the same track/rail. In some embodiments, the CAS may calculate the locations of vehicles using GPS data (or data from other positioning components) and may determine vector locations of such vehicles from which a reasonable calculation of track location can be determined. Other vehicles on an alternate vector could be dismissed by the collision avoidance system when tracking vehicles within a target group.

In some embodiments of the present disclosure, the CAS may include a stopping distance calibration feature and/or may perform a stopping distance calibration method. The stopping distance calibration feature/method may determine how quickly a rail line vehicle can stop under current conditions. For example, during a maintenance project, the work gang generally performs a stopping distance test (for example, at the beginning of each work day) where a vehicle is run at a speed (for example, 25 miles per hour) and then the vehicle's brakes may be engaged and a distance may be measured from the point where the brakes were engaged to the point where the vehicle comes to a stop. This distance may

be referred to as the "stopping distance." If the weather changes and the tracks become wet (or dry), a similar stopping distance test may be performed again, and a new distance measured.

After the stopping distance is measured, the CAS may calculate various safety metrics based on the stopping distance. For example, a safe following distance between vehicles may be adjusted according to the stopping distance. In some embodiments, the collision avoidance system may maintain minimum/default metrics and then adjust the metrics if necessary based on the stopping distance. For example, a minimum/default following distance may be maintained in all situations, and the following distance may be adjusted upwards (extended) if the stopping distance is relatively high. The stopping distance may be used in conjunction with an adaptive threshold feature of a progressive/graduated warning system as described above. For example, one or more safe separation distance thresholds (for example preliminary, intermediate and critical thresholds) may be modified depending on the stopping distance. The adaptive threshold feature may allow for scaling of thresholds of the alarm/notification levels based upon the stopping distance. In one example, one or more alarm thresholds may be made more strict if the stopping distance is too high, resulting in earlier alarms, for example to allow sufficient time to stop under the current conditions.

The CAS may include an automatic/real-time stopping distance calibration feature that, when triggered, may automatically calculate the stopping distance using information from the vehicle mounted module's GPS unit and/or inertial measurement unit (for example an accelerometer or a gyroscope). The new following distance will then be automatically calculated and utilized automatically as the collision avoidance system monitors for proper vehicle separation distance.

The CAS may create and/or maintain one or more logs of events that occur during the operation of the collision avoidance system. The individual VMMs may log information regarding the vehicle on which the vehicle mounted module is mounted. The CTU may also log information regarding the several vehicles in the work gang that the CTU tracks. Saved logs may be downloadable by an authorized person, for example via a cable or a wireless connection to a laptop computer or via an interface card. The amount of log data and time periods of data may be adjustable. Each log entry may be stamped with various types of information, for example the time and duration of the event occurrence, an ID, speed and location of the vehicle and the nature of the event. The collision avoidance system may also log information from a vehicle mounted module's inertial measurement unit (for example an accelerometer or a gyroscope) and/or other shock and impact sensors mounted on a vehicle to record significant impact data related to an incident. All warnings and alarms may be logged as well. Detailed log information may allow railroad personnel to reconstruct the details of an incident. The CAS may allow for logging of vehicle positioning over time using GPS satellite data. This feature allows long term tracking of vehicle location and activities. The CAS may allow for logging of data related to one or more stopping distance calibration tests, for example routine/daily stopping distance calibration tests and/or automatic/real-time stopping distance calibration tests.

In some embodiments of the present disclosure, the collision avoidance system may include the ability to monitor worker presence around machines so that a worker or foreman may be alerted if a worker is standing in an unsafe location. For example, if a worker is standing on the tracks near a vehicle as another vehicle approaches and violates a predetermined separation criteria, the worker and the foreman may be alerted, and perhaps emergency brakes may be activated. The collision avoidance system may monitor the workers by communicating with a communication device that is located on the worker, for example attached to the worker's badge. In one example, the communication device may be an RFID device. In another example, the communication device may be a UWB device, for example a subset of a UWB ranging system that includes components, some that are located on vehicles and some components that are located on workers.

A communication device located on a worker may communicate with one or more components located in one or more vehicle mounted modules, and/or it may communicate with a central tracking unit in a discrete housing. For example, if the communication device communicates with a vehicle mounted module, the vehicle mounted module may determine the orientation and distance of the worker in relation to the vehicle.

In some embodiments of the present disclosure, the collision avoidance system may utilize the concepts described herein to monitor the "vehicle stretch" of a train that includes several cars. As a train starts, stops and changes speed, the "play" in the couplings between the cars may allow the total length of the train to change. For example, if the train starts to slow down, the cars may compact closer to each other as the couplings lock more closely, and the overall length of the train may decrease. The opposite may occur if the train begins to accelerate, for example. Vehicle stretch is an important concept because it may be a measure of efficiency in the vehicle. Stretching and compacting of the vehicles wastes energy, and if the stretch of a vehicle can be monitored, the vehicle may be designed to reduce stretch. The collision avoidance system technologies described herein, for example the UWB technology and other close proximity sensing technologies, may be used to monitor distance between train cars, and then calculations can be made in the collision avoidance system to determine vehicle stretch.

In some embodiments of the present disclosure, the collision avoidance system may monitor, nationwide, locations and speeds of vehicles, equipment and/or workers equipped with collision avoidance system technology. For example, this may allow a central railroad office to monitor several work projects that are underway at several different locations throughout the country.

In some embodiments of the present disclosure, the collision avoidance system may have the ability to interface with rail line crossing technology to control gates while the vehicles work under the surveillance of the collision avoidance system. For example, if the collision avoidance system and the crossing technology were engineered by the same company, group or firm, the interface may be seamless.

Regarding the benefits of the collision avoidance system, in addition to the benefits already described in this disclosure, the following describes further benefits of one or more embodiments of the present technology. It is to be understood that the described benefits are not limitations or requirements, and some embodiments may omit one or more of the described benefits. In some embodiments, a benefit of the collision avoidance system may be that it is implemented as a supplement to existing safety procedures and devices already established for railroad maintenance vehicles and personnel. Alternatively, the collision avoidance system may be implemented as a primary (and perhaps the sole) collision avoidance and safety system.

Other benefits of the collision avoidance system can be realized when the collision avoidance system is compared to a single-sensor collision avoidance technology. Single sensor technologies do not work well when the work environment includes environmental and physical limitations. In addition to the complexities of tracking vehicles that travel through tunnels, mountains, building and the like, tracking vehicles can also become more complex when the vehicles travel or operate around curves or when the vehicles operate at night or during rain, snow and fog. Curves and other weather conditions create complex sensing environments that render single sensor technologies and/or strictly line-of-sight technologies inadequate. The multi-sensor approach of the collision avoidance system described above, allows for precise tracking of vehicles in these situations.

Another benefit of the collision avoidance system is that railroad companies can use the collision avoidance system to maintain an efficiently running railroad. For example, when an accident occurs in a remote area with single track, it may take days to re-open track after an accident. If the railroad companies can avoid more collisions and keep the tracks open, users of the railroad can make more efficient use of the railroad. A related benefit is that the collision avoidance system can significantly reduce the cost of running a railroad. Not only will the collision avoidance system help the railroad reduce the number of accidents, but the collision avoidance system logging functionality will give the railroads the ability to store data regarding accidents. This information may be used to alleviate rail payouts in the event of worker liability.

Although the present disclosure describes a collision avoidance system that may be applied to a work gang of railroad vehicles, the technology and the concepts described herein may be utilized in other vehicles, applications and/or industries, for example, in industries where spacing, location and status is important. Some industries that may utilize the concepts described herein are (1) the construction industry, (2) the mining industry, (3) the airport industry, specifically on airport tarmacs.

In some alternative implementations of the present disclosure, the function or functions illustrated in the blocks or symbols of a block diagram or flowchart may occur out of the order noted in the figures, and/or may include more or less steps than are shown in the figures. For example in some cases two blocks or symbols shown in succession may be executed substantially concurrently or the blocks may sometimes be executed in the reverse order depending upon the functionality involved.

One or more embodiments of the present disclosure may be realized in hardware, software, or a combination of hardware and software. The present disclosure may be realized in a centralized fashion in at least one machine, computer and/or data processing system; or in a distributed fashion where different elements are spread across several interconnected machines, computers and/or data processing systems. Any kind of machine, computer and/or data processing system or other apparatus adapted for carrying out the methods described herein is suited. A typical combination of hardware and software may be a general-purpose computer system with a computer program that, when being loaded and executed, controls the computer system such that it carries out the methods and techniques described herein.

Some embodiments of the present disclosure may provide a non-transitory machine and/or computer-readable storage and/or media, having stored thereon, a machine code and/or a computer program having at least one code section executable by a machine, computer and/or data processing system, thereby causing the machine, computer and/or data processing system to perform the steps as described herein. One example of a data processing system is a general purpose computer.

Some embodiments of the present disclosure may also be embedded in a computer program product, which comprises all the features enabling the implementation of the methods described herein, and which when loaded in a computer system is able to carry out these methods. Computer program in the present context means any expression, in any language, code or notation, of a set of instructions intended to cause a system having an information processing capability to perform a particular function either directly or after either or both of the following: a) conversion to another language, code or notation; b) reproduction in a different material form.

In the present specification, use of the singular includes the plural except where specifically indicated. In the present specification, any of the functions recited herein may be performed by one or more means for performing such functions. The present systems and methods may include various means, modules, code segments, computer programs and/or software for performing one or more of the steps or actions described in this specification. It is expressly contemplated and disclosed that the present specification provides a written description for claims comprising such means, modules, steps, code segments, computer programs and/or software.

The description of the different advantageous embodiments has been presented for purposes of illustration and description and is not intended to be exhaustive or limited to the embodiments in the form disclosed. Many modifications and variations will be apparent to those of ordinary skill in the art. Further different advantageous embodiments may provide different advantages as compared to other advantageous embodiments. The embodiment or embodiments selected are chosen and described in order to best explain the principles of the embodiments the practical application and to enable others of ordinary skill in the art to understand the disclosure for various embodiments with various modifications as are suited to the particular use contemplated.

The invention claimed is:

1. A collision avoidance system comprising:

one or more vehicle mounted modules, each vehicle mounted module mountable on a rail vehicle, each vehicle mounted module comprising:

a transponder sensor module operable to send and receive data wirelessly, the transponder module comprising a first ultra wideband unit and a first antenna;

a control electronics module comprising a processor in communication with at least the transponder sensor module unit; and

a user interface module including a user interface, the user interface being operable to provide rail vehicle information to a vehicle operator and to receive input from the vehicle operator; and wherein each vehicle mounted module is operable to communicate with at least one other vehicle mounted module mounted on at least one other rail vehicle, and wherein each vehicle mounted module is operable to apply a time of flight technique to determine a separation distance between the rail vehicles.

2. The collision avoidance system of claim **1**, further comprising a central tracking unit in communication with the first vehicle mounted module and the second vehicle mounted module, wherein the central tracking unit is operable to track the location of at least the first vehicle mounted module and the second vehicle mounted module.

3. The collision avoidance system of claim **2**, wherein the central tracking unit is distributed among a plurality of rail

vehicles, including at least the first and second rail vehicles, wherein the first vehicle mounted module comprises a first central tracking unit component.

4. The collision avoidance system of claim **2**, wherein the central tracking unit is located in a discreet housing.

5. The collision avoidance system of claim **1**, wherein the first vehicle mounted module further comprises an auxiliary transponder sensor module, the auxiliary transponder sensor module mounted on the first rail vehicle with an offset with respect to the transponder sensor module, and

wherein the user interface is operable to provide calibration information related to the length of the first rail vehicle, the mounting location of the first transponder sensor module, and the mounting location of the auxiliary transponder sensor module.

6. The collision avoidance system of claim **5**, wherein the auxiliary transponder sensor module comprises an auxiliary antenna, the auxiliary antenna being connected to at least one of the first ultra wideband unit or an auxiliary ultra wideband unit, and

wherein the auxiliary antenna is mounted on the first rail vehicle with an offset with respect to the first antenna.

7. The collision avoidance system of claim **1**, wherein the first vehicle mounted module further comprises a global positioning system unit, the global positioning system unit operable to receive information from one or more satellites to determine an absolute position of the rail vehicle, wherein the global positioning system unit is in communication with the control electronics module.

8. The collision avoidance system of claim **7**, wherein the first vehicle mounted module receives information generated by the global positioning system unit and the first ultra wideband unit to determine whether one or more vehicle separation criteria are violated, and generates a warning signal when one or more vehicle separation criteria are violated.

9. The collision avoidance system of claim **1**, wherein the first vehicle mounted module is operable to execute a progressive warning signal if one or more vehicle separation criteria are violated, and

wherein the progressive warning signal increases in at least one of signal rate, signal frequency, signal prominence, signal volume, or signal severity as the violation of the vehicle separation criteria approaches or extends beyond a vehicle separation threshold.

10. The collision avoidance system of claim **9**, wherein the first vehicle mounted module executes an adaptive threshold feature that modifies one or more vehicle separation thresholds based on the speed of the first rail vehicle and the speed of the second rail vehicle.

11. The collision avoidance system of claim **1**, further comprising at least one ground speed detection module operable to determine the speed of the rail vehicle, wherein the first vehicle mounted module communicates with the at least one ground speed detection module.

12. The collision avoidance system of claim **1**, further comprising an inertial measurement unit in communication with at least the control electronics module, the inertial measurement unit being operable to detect changes in the speed of the first rail vehicle.

13. The collision avoidance system of claim **12**, wherein the inertial measurement unit comprises at least one of an accelerometer or a gyroscope.

14. The collision avoidance system of claim **1** wherein the ultra wideband unit is adapted to transmit and receive signals with varying center frequencies.

15. The collision avoidance system of claim **1**, wherein the first vehicle mounted module is operable to execute a stopping distance calibration feature that measures a stopping distance under existing conditions, wherein the stopping distance measures the distance between the point where the brakes are engaged to the point where the vehicle comes to a stop under the existing conditions.

16. The collision avoidance system of claim **15**, wherein the first vehicle mounted module executes a progressive warning signal if one or more vehicle separation criteria are violated, wherein the progressive warning signal increases in at least one of signal rate, signal frequency, signal prominence, signal volume, or signal severity as the violation of the vehicle separation criteria approaches or extends beyond a vehicle separation threshold, and wherein the first vehicle mounted module executes an adaptive threshold feature that modifies one or more vehicle separation thresholds based on the measured stopping distance.

17. A rail vehicle module mountable on a rail vehicle, the module comprising:

a transponder sensor module comprising:

a radio communication unit operable to employ time of flight techniques to detect a distance between the rail vehicle and at least one other vehicle;

a wireless communications antenna operable to send and receive data over the air; and

a global positioning system unit operable to receive information from one or more satellites to determine an absolute position of the rail vehicle;

a control electronics module comprising a processor in communication with at least the first transponder sensor module; and

a user interface module including a user interface operable to provide rail vehicle information to a vehicle operator and to receive input from the vehicle operator; wherein the rail vehicle module communicates with at least one other module mounted on at least one other vehicle to detect a separation distance between the rail vehicle and the at least one other vehicle.

18. The rail vehicle module of claim **17**, wherein the radio communication unit comprises an ultra wideband unit configured to send and receive ultra wideband signals.

19. The rail vehicle module of claim **18**, wherein the ultra wideband unit is adapted to transmit and receive signals with varying center frequencies.

20. The rail vehicle module of claim **17**, further comprising a second wireless communications antenna mounted on the rail vehicle with an offset with respect to the first antenna, wherein the rail vehicle module is operable to receive calibration information related to the length of the rail vehicle, the mounting location of the first wireless communications antenna and the mounting location of the second wireless communications antenna.

21. The rail vehicle module of claim **17**, wherein the rail vehicle module is operable to utilize information generated by the radio communication unit and the global positioning system unit to determine whether one or more vehicle separation criteria are violated, and generate a progressive warning signal if one or more vehicle separation criteria are violated, wherein the progressive warning signal increases in at least one of signal rate, signal frequency, signal prominence, signal volume, or signal severity as the violation of the vehicle separation criteria approaches or extends beyond a vehicle separation threshold.

22. The rail vehicle module of claim **17**, further comprising a central tracking unit component, wherein the central tracking unit component is in communication with a central tracking unit component mounted on the at least one other vehicle.

23. The collision avoidance system of claim 16, further comprising an inertial measurement unit in communication with at least the control electronics module, the inertial measurement unit being operable to detect changes in the speed of the first rail vehicle.

24. A collision avoidance system comprising

one or more vehicle mounted modules, each vehicle mounted module mountable on a rail vehicle, each vehicle mounted module comprising:

a transponder sensor module comprising:

a radio communication unit operable to employ time of flight techniques to detect a distance between rail vehicles; and

a global positioning system unit operable to receive information from one or more satellites to determine an absolute position of the rail line vehicle;

a control electronics module comprising a processor, the control electronics module being in communication with at least the transponder sensor module; and

a user interface operable to provide rail vehicle information to a vehicle operator and to receive input from the vehicle operator;

wherein each of the two or more rail vehicle modules communicate to determine a separation distance between each rail vehicle, and wherein each rail vehicle module is operable to use information provided by the radio communication unit and the global positioning system unit to determine whether one or more vehicle separation criteria are violated, and to generate a warning signal if one or more vehicle separation criteria are violated.

25. The collision avoidance system of claim 24, wherein each radio communication unit comprises an ultra wideband unit.

26. The collision avoidance system of claim 24, wherein the progressive warning signal increases in at least one of signal rate, signal frequency, signal prominence, signal volume, or signal severity as the violation of the vehicle separation criteria approaches or extends beyond a vehicle separation threshold.

27. The collision avoidance system of claim 24, further comprising a central tracking unit in communication with each rail vehicle module, the central tracking unit operable to track the location of each rail vehicle module.

28. The collision avoidance system of claim 27, wherein the central tracking unit is distributed among the rail vehicle modules, wherein each of the one or more rail vehicle modules includes a central tracking unit component, each central tracking unit component being in communication with the control electronics module of the rail vehicle module.

* * * * *

EXHIBIT C

US009043131B2

(12) **United States Patent**
Carlson et al.

(10) **Patent No.: US 9,043,131 B2**
(45) **Date of Patent: *May 26, 2015**

(54) **COLLISION AVOIDANCE SYSTEM FOR RAIL LINE VEHICLES**

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(73) Assignee: **Metrom Rail, LLC**, Lake Zurich, IL (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **14/252,987**

(22) Filed: **Apr. 15, 2014**

(65) **Prior Publication Data**

US 2014/0229096 A1 Aug. 14, 2014

Related U.S. Application Data

(63) Continuation of application No. 13/474,428, filed on May 17, 2012, now Pat. No. 8,812,227.

(60) Provisional application No. 61/598,750, filed on Feb. 14, 2012, provisional application No. 61/627,697, filed on Oct. 17, 2011, provisional application No. 61/519,201, filed on May 19, 2011.

(51) **Int. Cl.**
G05D 1/02 (2006.01)
G06F 17/10 (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC ***B61L 15/0027*** (2013.01); ***B61L 23/06*** (2013.01); ***B61L 25/025*** (2013.01); *B61L 2205/04* (2013.01); ***G08G 1/161*** (2013.01); ***G08G 1/166*** (2013.01); ***B61L 23/34*** (2013.01)

(58) **Field of Classification Search**
CPC . B61L 15/0027; B61L 23/06; B61L 2205/04; B61L 25/025; B61L 23/34; G08G 1/161; G08G 1/166
USPC 701/19, 300, 301, 408, 468–470, 538; 340/436, 988
See application file for complete search history.

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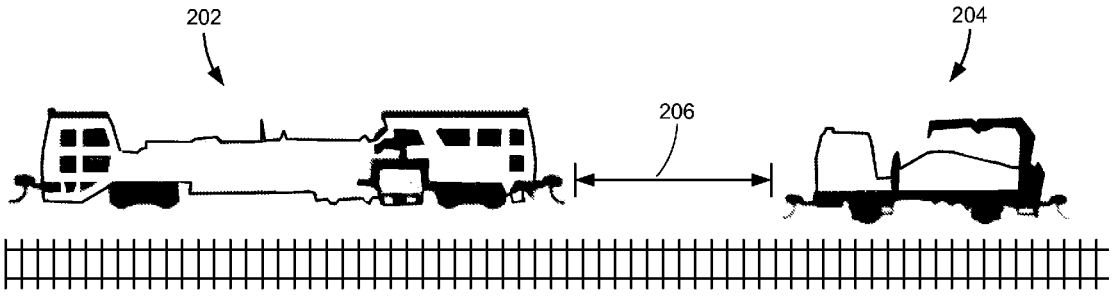
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Primary Examiner — Russell Frejd
(74) *Attorney, Agent, or Firm* — McAndrews, Held & Malloy, Ltd.

(57) **ABSTRACT**

A collision avoidance system (CAS) is described that includes one or more sensor technologies, including, for example, an Ultra Wideband (UWB) sensing technology. The collision avoidance system is designed to reliably track the location and speed of vehicles and the distance between vehicles over a wide variety of track and terrain. The collision avoidance system may utilize information from a variety of sensor technologies to determine whether one or more vehicles violate speed and/or separation criteria, and may generate a warning.

20 Claims, 15 Drawing Sheets



(51) **Int. Cl.**

G06G 7/78	(2006.01)
B61L 25/02	(2006.01)
B61L 15/00	(2006.01)
B61L 23/06	(2006.01)
G08G 1/16	(2006.01)
B61L 23/34	(2006.01)

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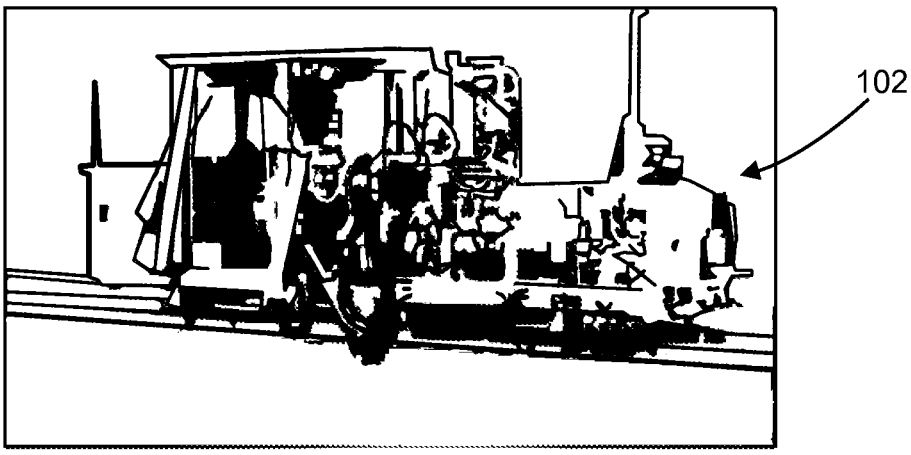


Fig. 1A

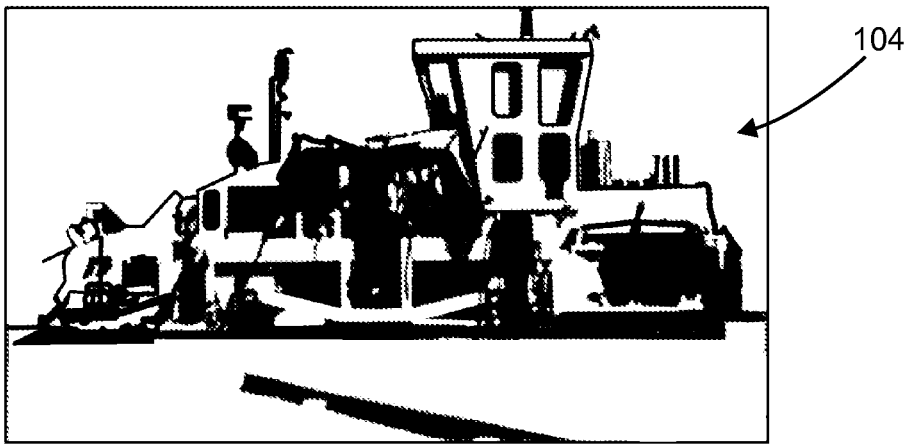


Fig. 1B

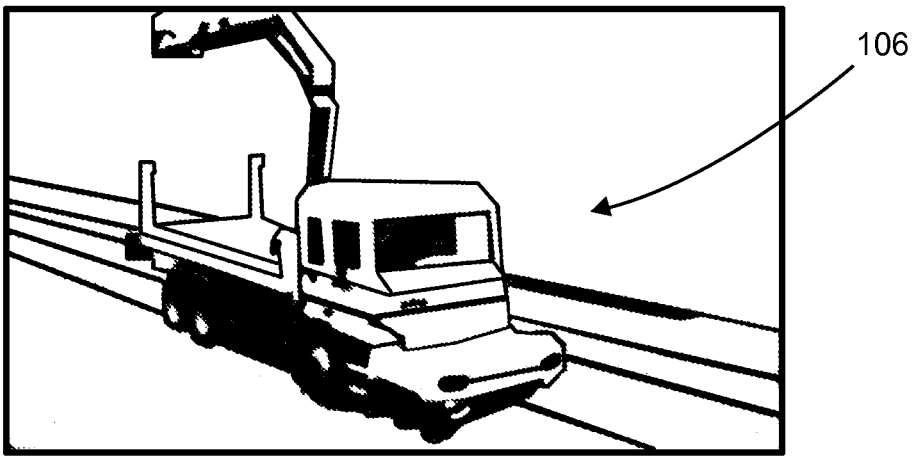


Fig. 1C

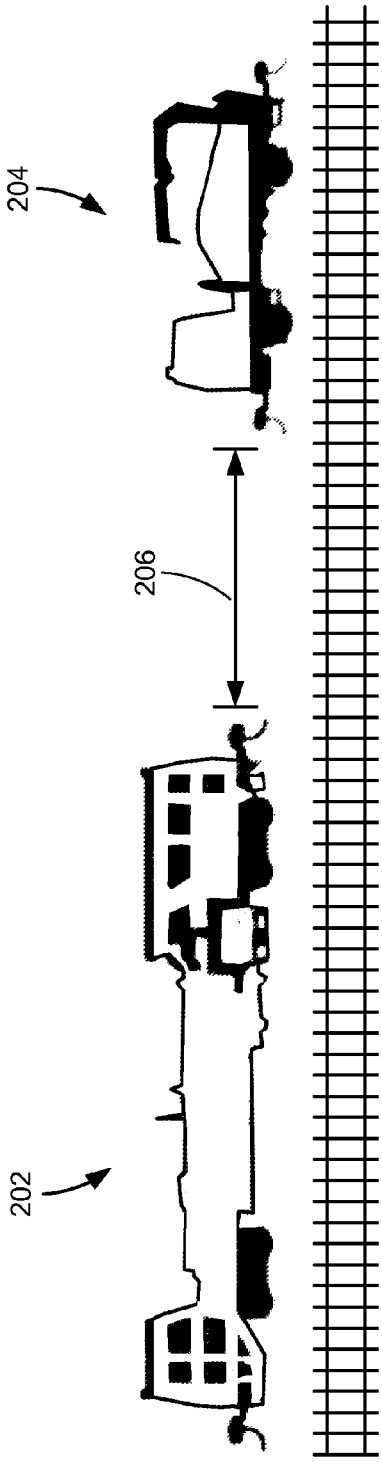


Fig. 2

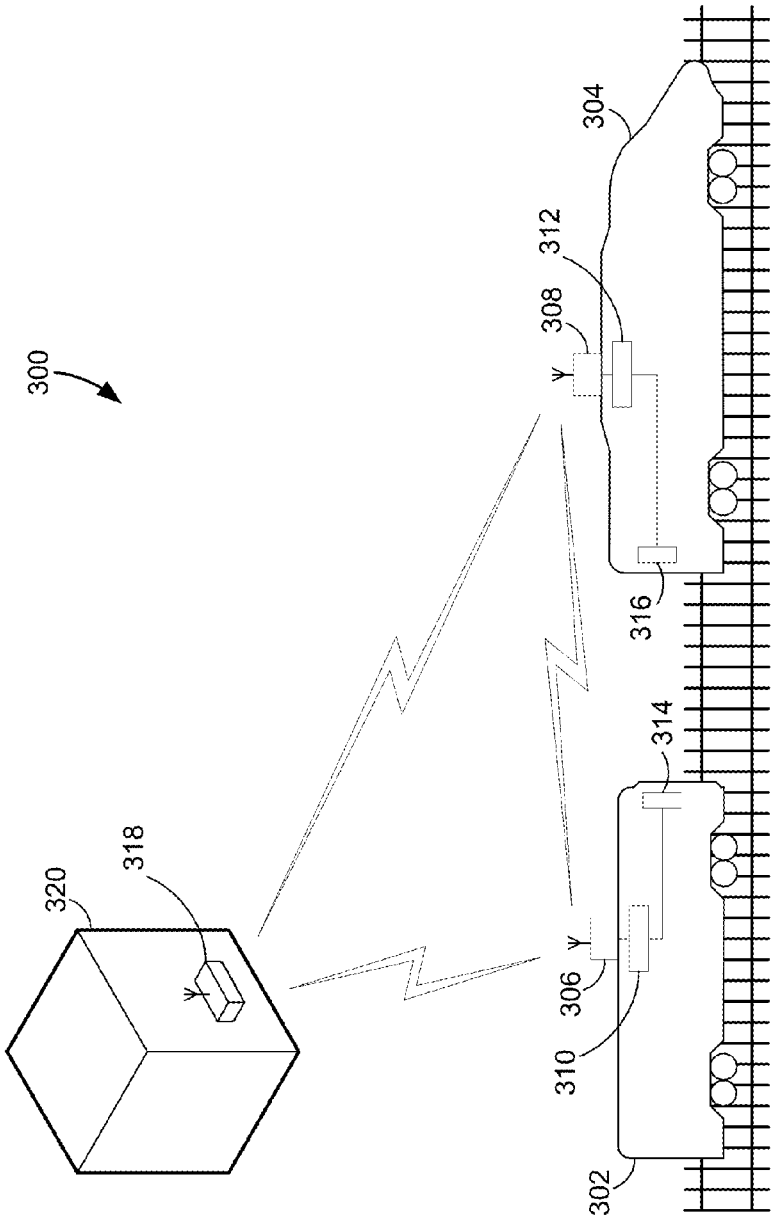


Fig. 3

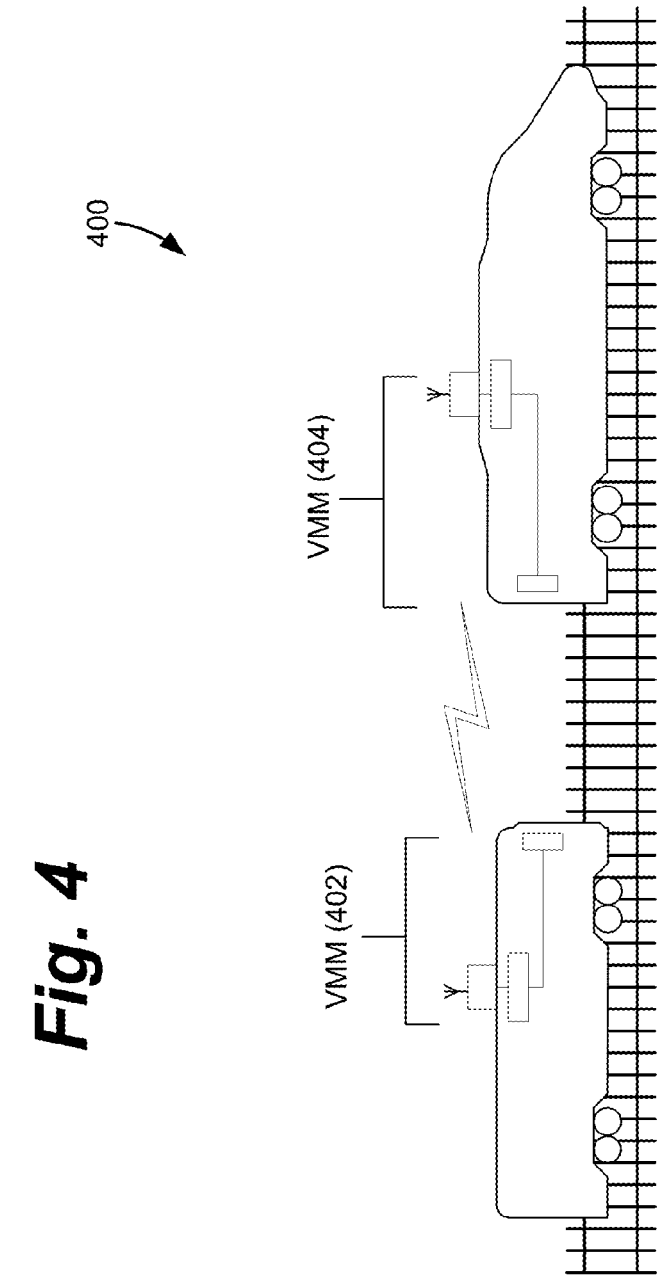


Fig. 4

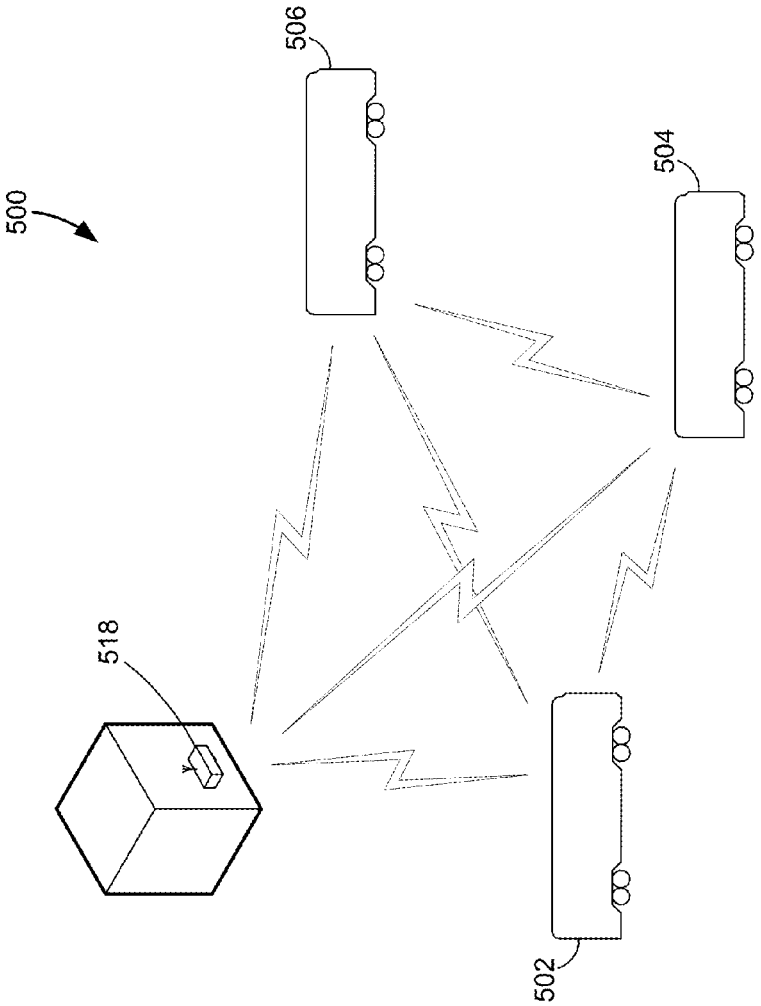


Fig. 5

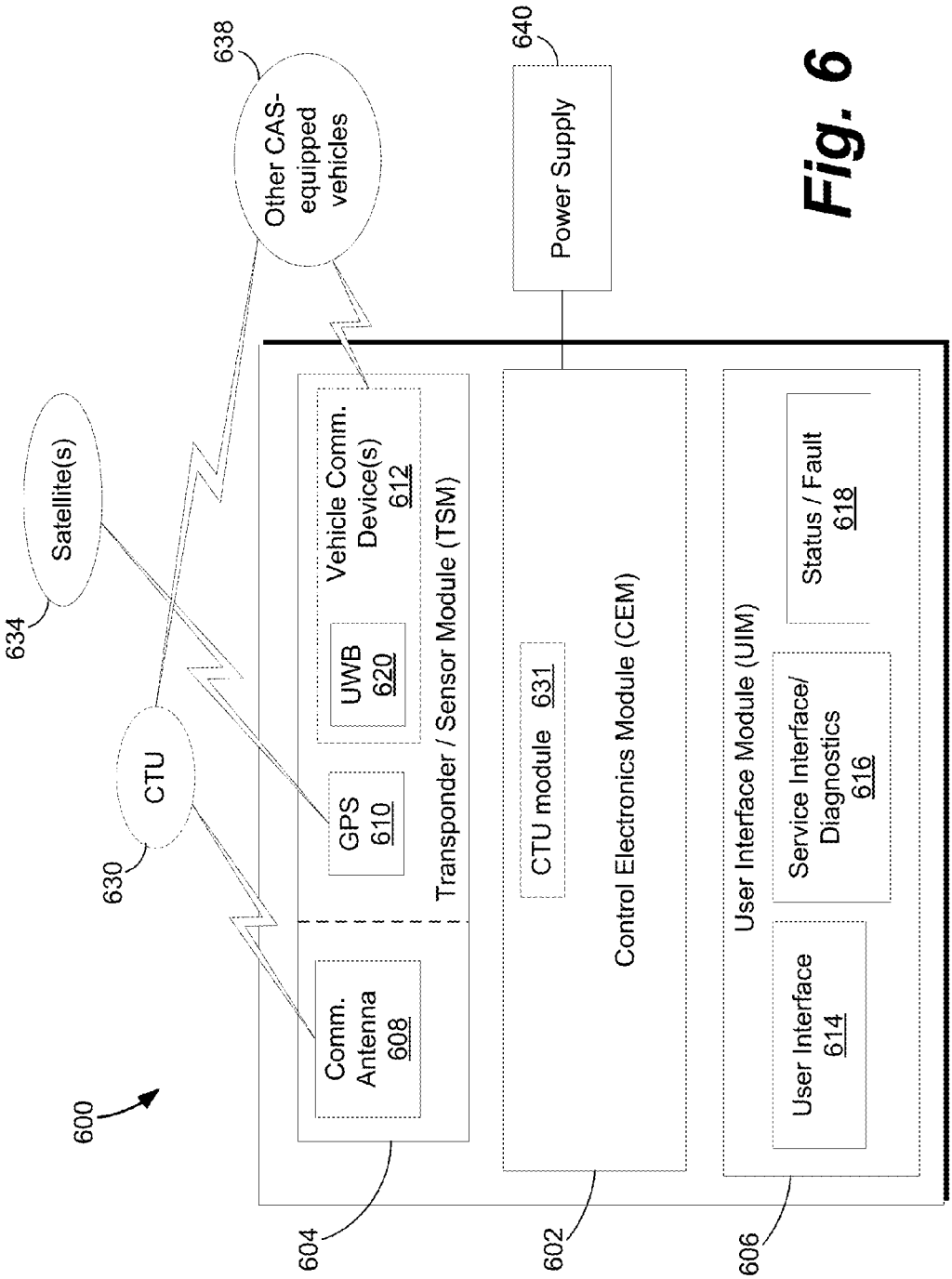

600
604
602
606
Transponder / Sensor Module (TSM)
Comm. Antenna 608
GPS 610
Vehicle Comm. Device(s) 612
UWB 620
Control Electronics Module (CEM)
CTU module 631
User Interface Module (UIM)
User Interface 614
Service Interface/ Diagnostics 616
Status / Fault 618
Power Supply
640
CTU
630
Satellite(s)
634
Other CAS-equipped vehicles
638

Fig. 6

Fig. 7

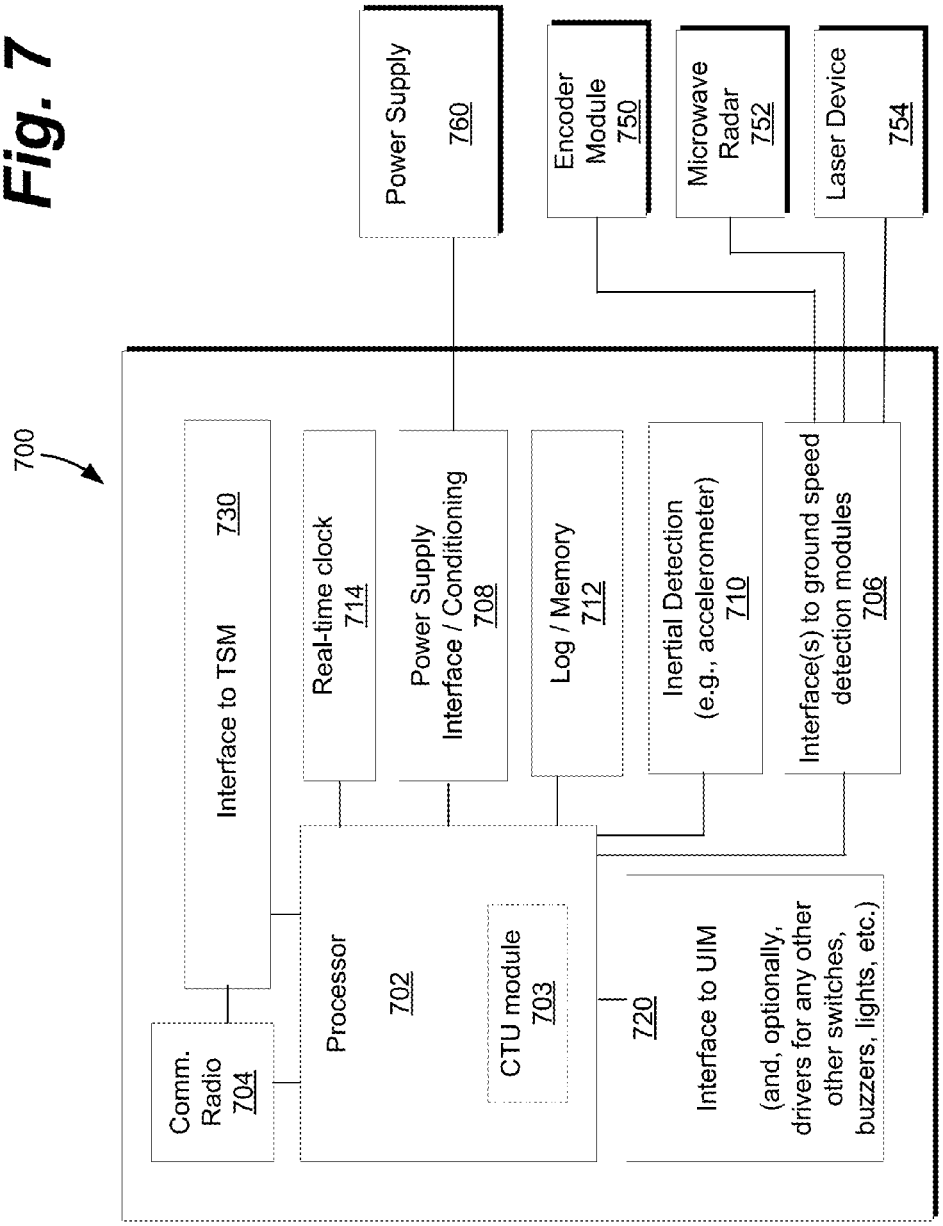

700
Power Supply 760
Encoder Module 750
Microwave Radar 752
Laser Device 754
Interface to TSM 730
Real-time clock 714
Power Supply Interface / Conditioning 708
Log / Memory 712
Inertial Detection (e.g., accelerometer) 710
Interface(s) to ground speed detection modules 706
Comm. Radio 704
Processor 702
CTU module 703
720
Interface to UIM
(and, optionally, drivers for any other other switches, buzzers, lights, etc.)

Fig. 8

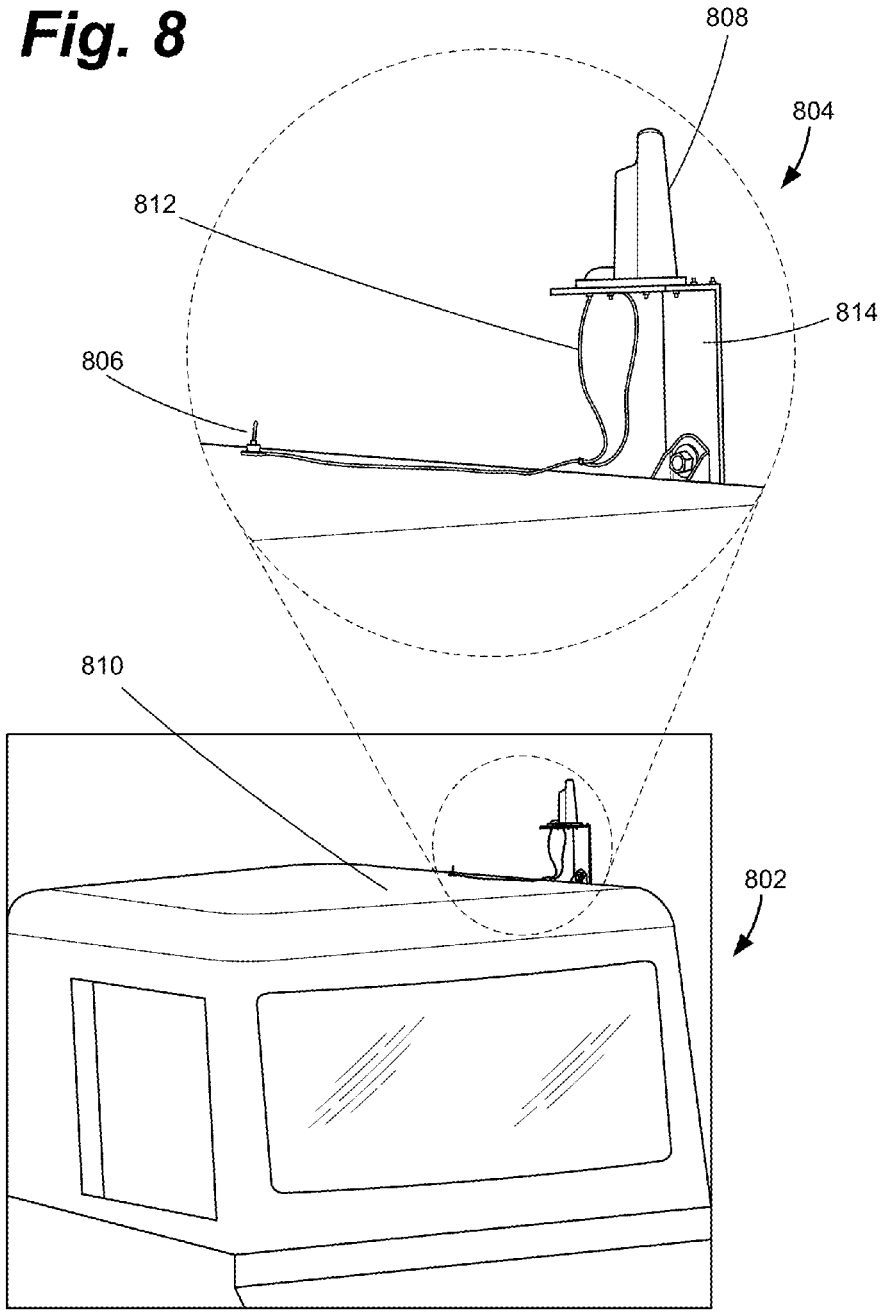
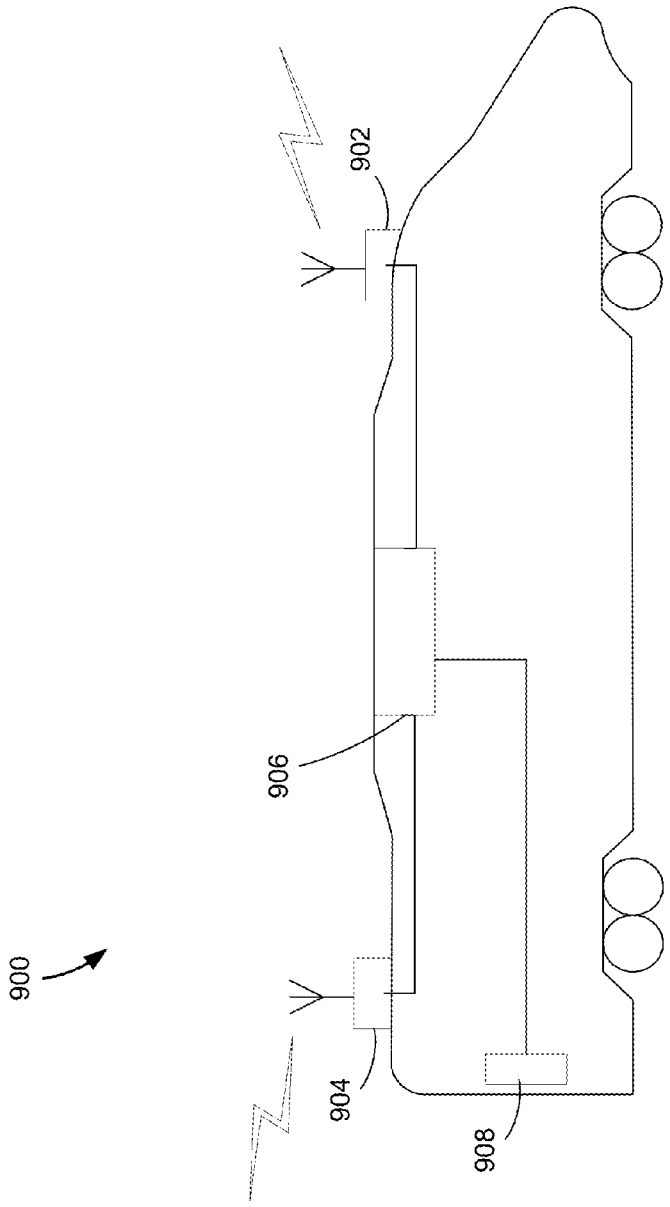


Fig. 9



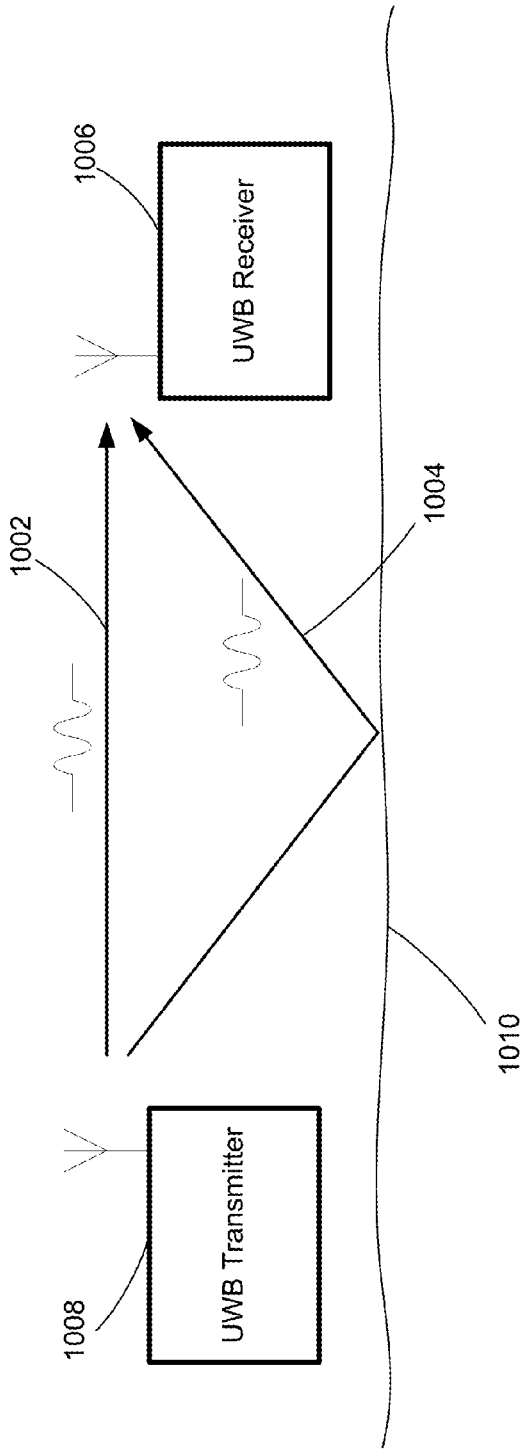


Fig. 10

Fig. 11

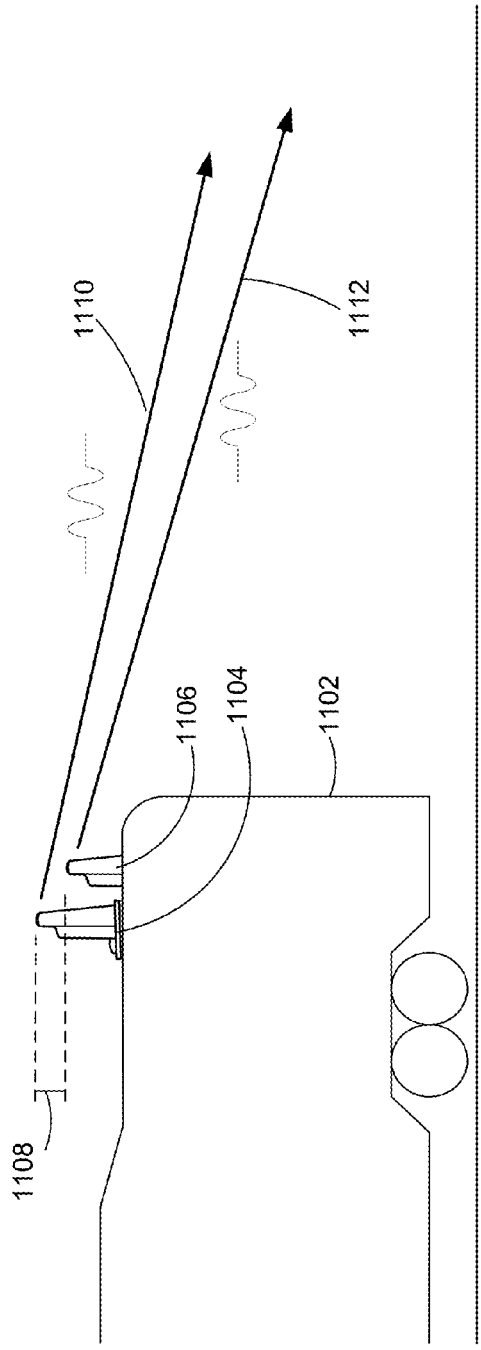


Fig. 12B

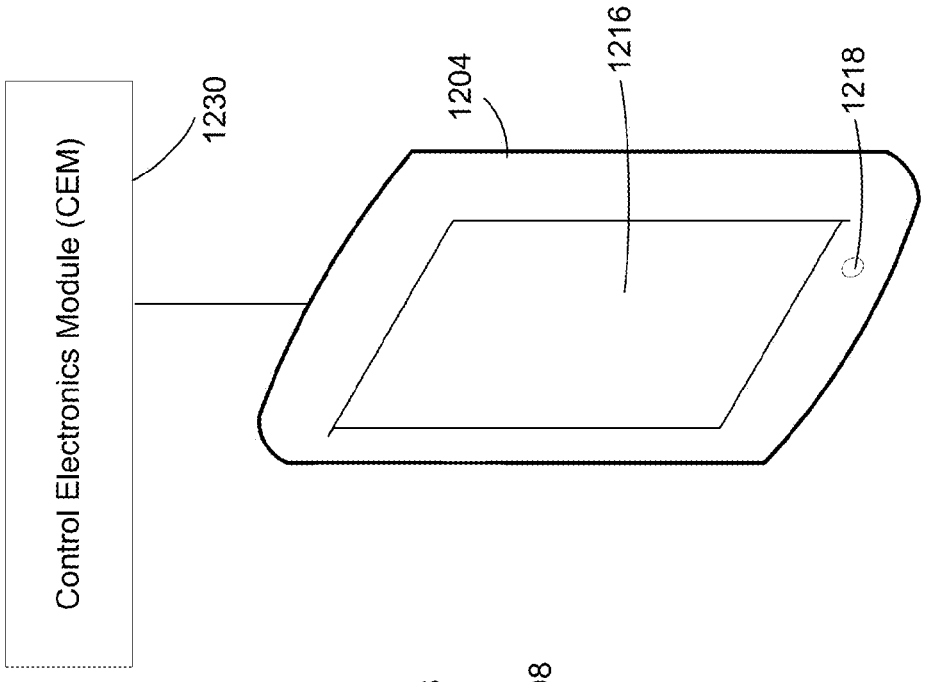
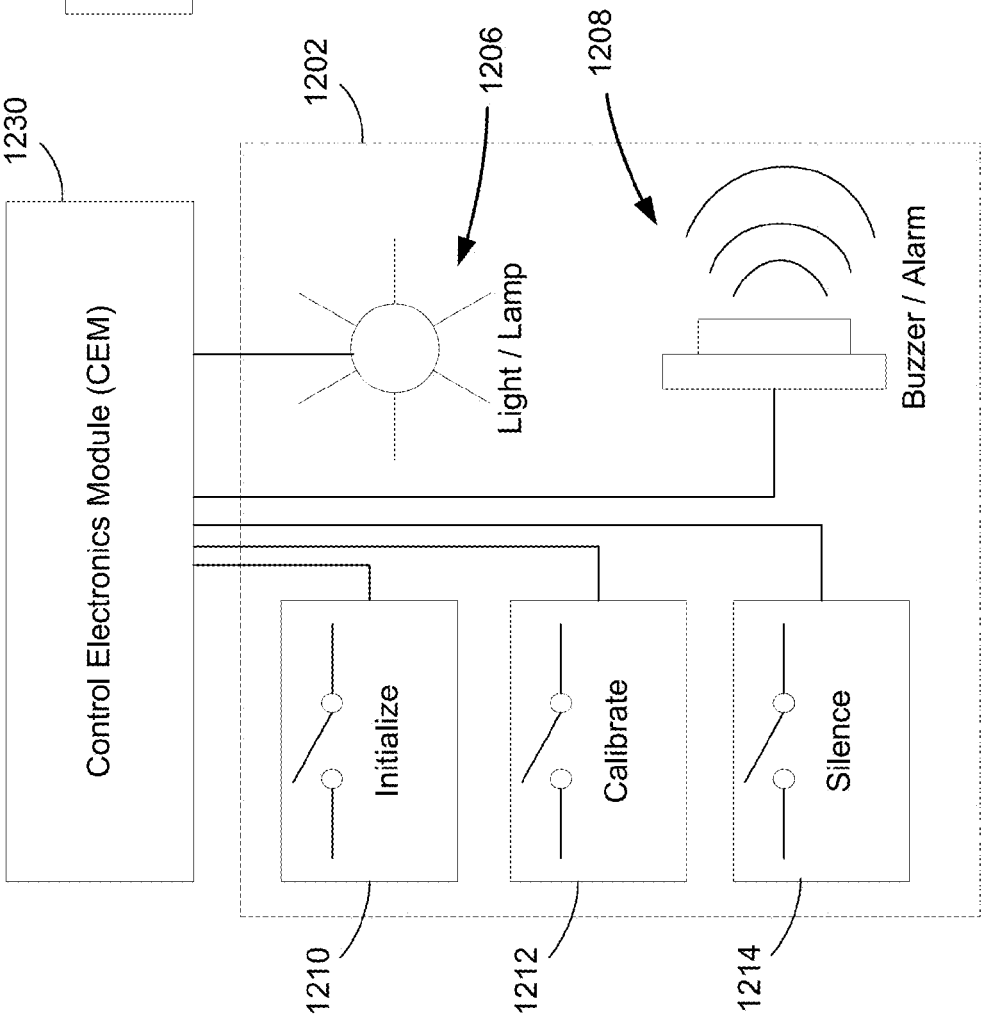


Fig. 12A



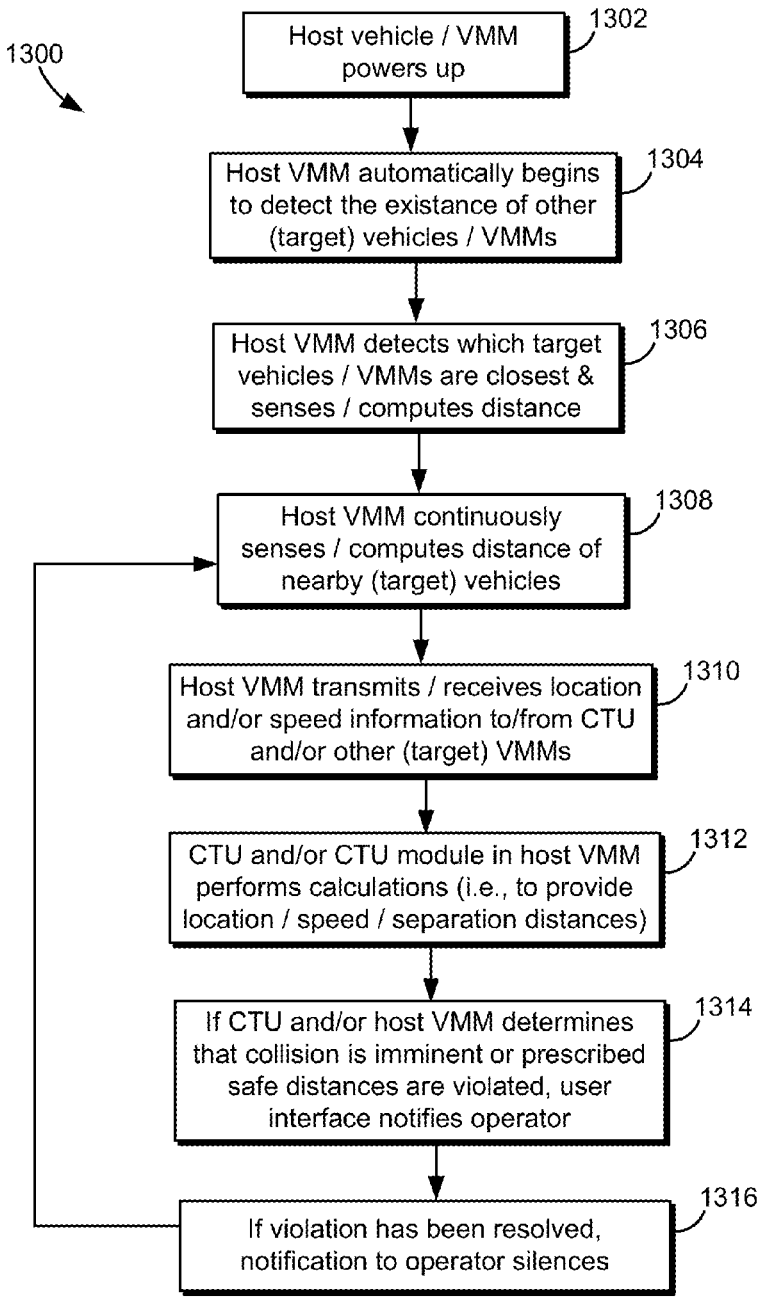

1300
Host vehicle / VMM powers up
1302
Host VMM automatically begins to detect the existance of other (target) vehicles / VMMs
1304
Host VMM detects which target vehicles / VMMs are closest & senses / computes distance
1306
Host VMM continuously senses / computes distance of nearby (target) vehicles
1308
Host VMM transmits / receives location and/or speed information to/from CTU and/or other (target) VMMs
1310
CTU and/or CTU module in host VMM performs calculations (i.e., to provide location / speed / separation distances)
1312
If CTU and/or host VMM determines that collision is imminent or prescribed safe distances are violated, user interface notifies operator
1314
If violation has been resolved, notification to operator silences
1316

Fig. 13

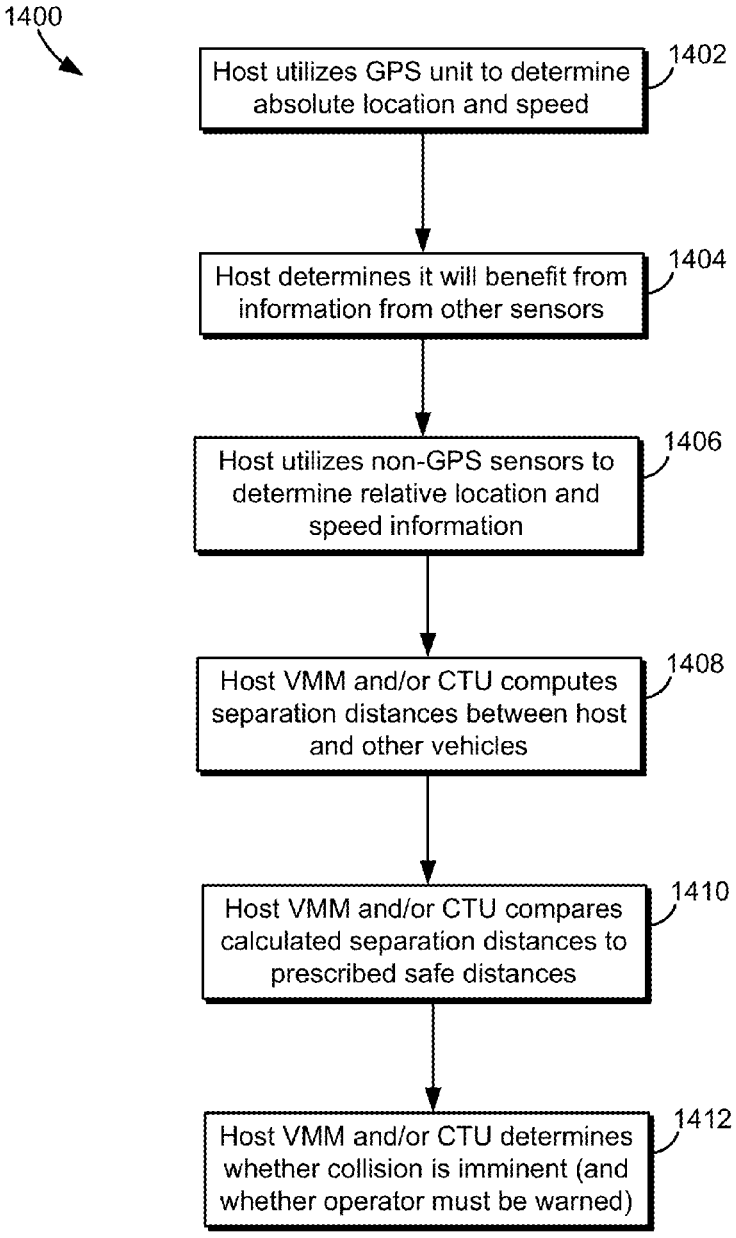

1400
Host utilizes GPS unit to determine absolute location and speed
1402
Host determines it will benefit from information from other sensors
1404
Host utilizes non-GPS sensors to determine relative location and speed information
1406
Host VMM and/or CTU computes separation distances between host and other vehicles
1408
Host VMM and/or CTU compares calculated separation distances to prescribed safe distances
1410
Host VMM and/or CTU determines whether collision is imminent (and whether operator must be warned)
1412

Fig. 14

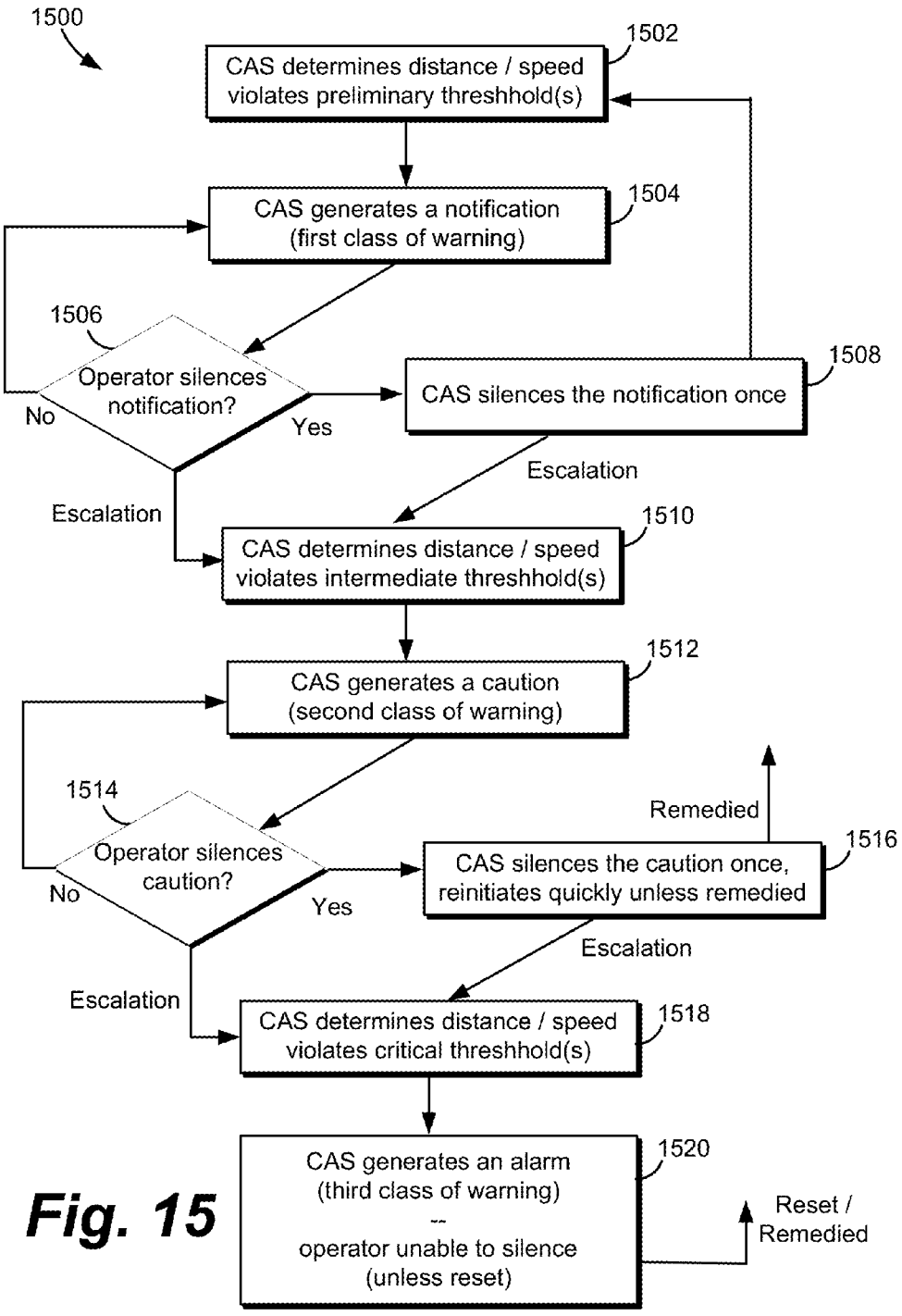

1500
1502
CAS determines distance / speed violates preliminary threshhold(s)
1504
CAS generates a notification (first class of warning)
1506
Operator silences notification?
No
Yes
1508
CAS silences the notification once
Escalation
Escalation
1510
CAS determines distance / speed violates intermediate threshhold(s)
1512
CAS generates a caution (second class of warning)
1514
Operator silences caution?
No
Yes
Remedied
1516
CAS silences the caution once, reinitiates quickly unless remedied
Escalation
Escalation
1518
CAS determines distance / speed violates critical threshhold(s)
1520
CAS generates an alarm (third class of warning) -- operator unable to silence (unless reset)
Reset / Remedied

Fig. 15

COLLISION AVOIDANCE SYSTEM FOR RAIL LINE VEHICLES

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims priority from U.S. Non-Provisional patent application Ser. No. 13/474,428, filed on May 17, 2012 and issued as U.S. Pat. No. 8,812,227 on Aug. 19, 2014, and the following three U.S. Provisional Patent Applications: (1) Ser. No. 61/519,201 filed on May 19, 2011, (2) Ser. No. 61/627,697 filed on Oct. 17, 2011, and (3) Ser. No. 61/598,750 filed on Feb. 14, 2012. The disclosures of these applications are incorporated by reference herein in their entireties.

FIELD

Certain embodiments of the present disclosure relate to a collision avoidance system for use in the railroad industry. More particularly, certain embodiments of the present disclosure relate to one or more systems, methods, techniques and/or solutions that monitor the location of and separation distance between rail line vehicles, for example, railroad maintenance vehicles.

BACKGROUND

Railroad companies must perform maintenance on their tracks and other infrastructure associated with their rail lines. The railroad companies employ many different types of rail mounted vehicles to accomplish such maintenance, and these vehicles can range widely in their size, weight and shape because the vehicles perform a variety of tasks. These vehicles may be employed in one or more work gangs, each work gang including anywhere from four to forty vehicles. As such, many vehicles may be working in close proximity on a single track.

The speed at which the work gang is traveling, and each vehicle within the gang, can vary widely at any given time. For example, the work gang may be traveling to a work site, in which case the work gang, and each vehicle, is traveling at a higher rate of speed than when the vehicles are working at a worksite. When the vehicles are working at a work site, each vehicle is generally traveling at a lower rate of speed or not at all. Within a work gang, the speeds of the vehicles may vary depending on the task that each vehicle is performing.

Railroads have had several severe collisions and other accidents, some resulting in fatalities, when adequate spacing has not been maintained between rail mounted vehicles. Railroad companies now require that a specific spacing be maintained between vehicles when traveling to/from work sites and when working at a work site.

BRIEF SUMMARY

One or more systems, methods, techniques and/or solutions are provided for a collision avoidance system for use in the railroad industry that may monitor the location of and separation distance(s) between rail line vehicles, for example railroad maintenance vehicles, substantially as shown in and/or described in connection with at least one of the figures, as set forth more completely in the claims.

These and other advantages, aspects and novel features of the present invention, as well as details of an illustrated embodiment thereof, will be more fully understood from the following description and drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. **1**A-**1**C depict illustrations of example rail line vehicles that may utilize a collision avoidance system, in accordance with one or more embodiments of the present disclosure.

FIG. **2** depicts illustrations of example rail line vehicles that may utilize a collision avoidance system, in accordance with one or more embodiments of the present disclosure.

FIG. **3** depicts an illustration of an example collision avoidance system, in accordance with one or more embodiments of the present disclosure.

FIG. **4** depicts an illustration of an example collision avoidance system, in accordance with one or more embodiments of the present disclosure.

FIG. **5** depicts an illustration of an example collision avoidance system, in accordance with one or more embodiments of the present disclosure.

FIG. **6** depicts a block diagram of an example vehicle mounted module, in accordance with one or more embodiments of the present disclosure.

FIG. **7** depicts a block diagram of an example control electronics module, in accordance with one or more embodiments of the present disclosure.

FIG. **8** depicts an illustration of side angled view of the upper portion of an example rail line vehicle and an example component mounting configuration, in accordance with one or more embodiments of the present disclosure.

FIG. **9** depicts an illustration of an example rail line vehicle, including a vehicle mounted module, in accordance with one or more embodiments of the present disclosure.

FIG. **10** depicts a block diagram illustrating example Ultra Wideband units, in accordance with one or more embodiments of the present disclosure.

FIG. **11** depicts an illustration of a side view of an example rail line vehicle including multiple Ultra Wideband units, in accordance with one or more embodiments of the present disclosure.

FIGS. **12**A and **12**B depict illustrations of example user interfaces, in accordance with one or more embodiments of the present disclosure.

FIG. **13** depicts a flow diagram that shows exemplary steps in the operation of a collision avoidance system, in accordance with one or more embodiments of the present disclosure.

FIG. **14** depicts a flow diagram that shows exemplary steps in the operation of a collision avoidance system, in accordance with one or more embodiments of the present disclosure.

FIG. **15** depicts a flow diagram that shows exemplary steps in the operation of a collision avoidance system, in accordance with one or more embodiments of the present disclosure.

DETAILED DESCRIPTION

Previous systems for preventing collisions of rail line vehicles have typically utilized a single sensor, for example a GPS or radar-based sensor, to monitor the approximate location of rail mounted vehicles. A shortcoming of single sensor systems, such as ones that depend on GPS sensors, is that the rail vehicles being monitored often enter into "blackout" areas (for example, around buildings, in the mountains, canyons, around sharp curves or in tunnels) where the single

sensor may be unable to accurately determine the vehicle's location. For example, a GPS sensor may be unable to communicate with satellites when the vehicle is in a tunnel. Some previous systems attempted to solve this problem by performing a simple "dead reckoning" calculation, where the last known speed and direction of the vehicle are used to estimate the current position of the vehicle until the sensor signal is reestablished. This estimation calculation may not be precise enough to prevent collisions in work gangs because of the speed variation between vehicles. When the vehicles are traveling to a work site, the higher speeds introduce the risk of collision, and when the vehicles are working at a work site, the vehicle are frequently stopping and starting, and this variation in speed between vehicles renders the dead reckoning approach an unsuitable approximation.

A limitation of radar-based sensors in particular is that they may initiate numerous false positives (warning alarms that are not warranted). With the normal clutter of maintenance operations (people, equipment, trains on adjacent tracks, trackside structures, trestle sides, tunnel walls), radar-based sensors can become confused as to when vehicles are actually in danger of colliding. More specifically, radar-based sensors must deal with the following dilemma: the sensor must scan a wide enough field so that it can detect collision risks when vehicles are traveling on curves at higher speeds, yet as radar-based sensors scan wider fields, they become more susceptible to false detections, for example because the sensor also senses clutter. False detections can result in a dangerous work environment, especially if operators become immune to warnings.

The present disclosure describes a collision avoidance system (CAS) for rail line vehicles that may utilize a combination of sensor technologies, including an Ultra Wideband (UWB) sensing technology, to counter the limitations of previous systems, and to significantly reduce the potential for vehicle collisions and to enhance the safe operation of a variety of railway vehicles. The present technology is designed to reliably track the location and speed of railway vehicles, as well as the distance between vehicles over a wide variety of track and terrain conditions. The present technology may monitor the separation distance between rail line vehicles by utilizing sensors that are mounted on each vehicle in a group or work gang, where a work gang may comprising a plurality of railway vehicles, including railway maintenance equipment.

The CAS may perform the techniques and/or solutions described herein for a wide variety of railway vehicles, for example, railway maintenance equipment/vehicles, railcars, hyrail vehicles, train cars, train engines and other rail line vehicles. FIGS. **1**A-**1**C depict illustrations of types of example rail line vehicles (vehicles **102**, **104**, **106**) that may utilize a CAS or that a CAS as described herein may track. FIGS. **1**A and **1**B may depict example rail line maintenance vehicles and FIG. **1**C may depict an example hyrail vehicle. FIG. **2** depicts illustrations of more example rail line vehicles (vehicles **202**, **204**) that may utilize a CAS or that a CAS system may track, and also shows an exemplary safe distance **206** between the two vehicles **202**, **204**. The CAS may track vehicles such as the ones depicted in FIGS. **1** and **2** (and others) over a wide range of terrain (e.g., mountains, canyons, hills, trees, tunnels, curves and trestles) and during a variety of weather conditions (e.g., rain, fog, snow, ice, bright sunlight).

The CAS may be designed to introduce redundancy into the system, for example in the form of multiple types of sensor technologies and/or multiple sensors of a particular type of technology. One benefit of utilizing redundant sensors may be that some sensors may function properly when other sensors are not functioning optimally or at all. Another benefit of utilizing redundant sensors is that different sensors may be adapted to sense objects and different distances and to different levels of accuracy. In some embodiments, a CAS may utilize a combination of distance sensors so that the CAS is adapted to detect vehicles that are either close or far away, and so that the CAS may detect vehicle separation to within a few inches if the vehicles are close.

Various embodiments of the present disclosure enable a rail line vehicle having a vehicle mounted module. The vehicle mounted module may comprise a transponder sensor module that includes an ultra wideband unit and a wireless communications antenna. The ultra wideband unit may be operable to detect a distance between the rail line vehicle and at least one other vehicle. The wireless communications antenna may be operable to send and receive data over the air. The vehicle mounted module may further comprise a control electronics module that includes a processor that is in communication with at least the ultra wideband unit. The vehicle mounted module may further comprise a user interface module including a user interface. The user interface may be operable to provide a vehicle operator with information and may be operable to accept input from the vehicle operator. The vehicle mounted module may be in communication with one or more central tracking units by way of the wireless communications antenna. The one or more central tracking units may be operable to track the location of the rail line vehicle and at least one other vehicle.

In some embodiments, the vehicle mounted module further comprises a central tracking unit module that is operable to track the location of at least one other vehicle. In some embodiments, the vehicle mounted module may be operable to utilize information generated by the global positioning system and the ultra wideband unit to determine whether one or more vehicle separation criteria are violated, and generate a warning if one or more vehicle separation criteria are violated. In some embodiments, the vehicle mounted modules comprises one or more additional transponder sensor modules. The vehicle mounted module may be operable to accept calibration information regarding the length of the rail line vehicle and the mounting locations of the transponder sensor module and the one or more additional transponder sensor modules.

In some embodiments, the transponder sensor module further includes a global positioning system. The global positioning system may be operable to receive information from one or more satellites and may be operable to determine the absolute position of the rail line vehicle. In some embodiments, the transponder sensor module further includes one or more of a laser device, a radar sensor and an infrared sensor. In some embodiments, the vehicle mounted modules may comprise an additional ultra wideband unit, wherein an offset exists between the ultra wideband unit and the additional ultra wideband unit once the two units are mounted on the rail line vehicle. In some embodiments, the ultra wideband unit is adapted to transmit and receive signals with varying center frequencies.

In some embodiments, the user interface module further includes a service interface that may be operable to allow the vehicle operator to configure, calibrate, service, maintain, diagnose, update and/or install information on vehicle mounted module. In some embodiments, the user interface is a touchscreen including a screen. The touchscreen may be operable to display one or more screens, menus, options

and/or functions, and accept user input from the vehicle operator by allowing the vehicle operator to touch the screen of the touchscreen.

In some embodiments, the control electronics module further includes one or more interfaces that may be operable to communicate with ground speed detection modules. The ground speed detection modules may include one or more of a microwave radar, a laser device, an infrared sensor and an ultra wideband sensor. In some embodiments, the control electronics module further includes one or more inertial measurement units. In some embodiments, the control electronics module further includes an inertial measurement unit.

In some embodiments, the vehicle mounted module may be operable to utilize a progressive warning feature that generates a warning if one or more vehicle separation thresholds are violated. The rate, frequency, prominence and/or severity of the warning may increase as the violation of the vehicle separation threshold becomes more critical. The progressive warning feature may utilize an adaptive threshold feature that modifies the one or more vehicle separation thresholds based on the speed of the rail line vehicle and the speed of one or more nearby vehicles. In some embodiments, the vehicle mounted module may be operable to utilize a stopping distance calibration feature that measures a stopping distance. The stopping distance may indicate how quickly the rail line vehicle can stop under current conditions. The measured stopping distance may be used to modify one or more safe separation distance thresholds.

Various embodiments of the present disclosure enable a collision avoidance system for rail line vehicles that may comprise one or more vehicle mounted modules, each mounted on a vehicle. Each vehicle mounted module may comprise a transponder sensor module including an ultra wideband unit and a wireless communications antenna. The ultra wideband unit may be operable to detect a distance between the vehicle on which the vehicle mounted module is mounted and at least one other vehicle. The wireless communications antenna may be operable to send and receive data over the air. Each vehicle mounted module may comprise a control electronics module including a processor that is in communication with at least the ultra wideband unit. Each vehicle mounted module may comprise a user interface module including a user interface. The user interface may be operable to provide a vehicle operator with information and may be operable to accept input from the vehicle operator.

The collision avoidance system that may comprise a central tracking unit that is in communication with the one or more vehicle mounted modules. The central tracking unit may be operable to track the location of the one or more vehicle mounted modules. In some embodiments, the central tracking unit may be distributed among the one or more vehicle mounted modules, wherein each of the one or more vehicle mounted modules includes a central tracking unit component. Each central tracking unit component may be in communication with the vehicle's control electronics module. In some embodiments, the central tracking unit may be disposed in a discrete housing.

In some embodiments, the transponder sensor module further includes a global positioning system. The global positioning system may be operable to receive information from one or more satellites and may be operable to determine the absolute position of the vehicle mounted module. Each vehicle mounted module may be operable to utilize information generated by the global positioning system, the ultra wideband unit and the central tracking unit to determine whether one or more vehicle separation criteria are violated, and generate a warning if one or more vehicle separation criteria are violated.

FIG. **3** depicts an illustration of an example collision avoidance system (CAS) **300** for rail line vehicles according to one or more embodiments of the present disclosure. For example purposes only, FIG. **3** depicts a work gang including only two vehicles **302**, **304**. In this embodiment, the CAS **300** includes four main types of components—transponder sensor modules (TSMs) (for example, TSMs **306**, **308**), control electronics modules (CEMs) (for example, CEMs **310**, **312**), user interface modules (UIMs) (for example, UIMs **314**, **316**) and a central tracking unit (CTU) (for example, CTU **318**). Referring to a single vehicle (vehicle **302** for example), modules that are located in or on the vehicle (for example, TSM **306**, CEM **310** and UIM **314**) may collectively be referred to as the vehicle mounted module (VMM), even though the individual modules and related components may or may not be housed within a unitary package/enclosure.

In some embodiments, the VMM components may not be installed on vehicles at production. In these examples, the VMM components may be designed to allow retrofitting into existing railway vehicles without requiring heavily intrusive installation.

The CAS may include a central tracking unit (CTU), for example the CTU **318** of FIG. **3**. The CTU may operate to centrally track all the vehicles in one or more work gangs. The CTU may adapt a tracking software and/or system to monitor individual vehicles. The CTU may include technology adapted to dynamically define which vehicles are in a work gang, and/or which vehicles the CTU should keep track of. The CTU may accept information from VMMs mounted inside vehicles in the work gang, information such as location, speed, separation distance and the like. The CTU may have the ability to analyze and/or store various types of data about vehicles in one or more work gangs. For example, the CTU may analyze absolute and relative positioning data and speed data from vehicles in the work gang. In some examples, the CTU may determine if a separation distance between two vehicles has been violated, indicating that an accident may be likely. Additionally, the CTU may track alarm status of the vehicles in a work gang so that the central tracking unit becomes aware when an accident may have occurred. In another example, the central tracking unit may track data regarding accidents.

In the embodiment depicted in FIG. **3**, the CTU **318** may be located in a discrete housing **320** (also referred to as a module, unit, bungalow or the like). It should be understood that the technology and features of the CTU need not reside in such a discrete housing **320** and may be distributed amongst the vehicles in the work gang, for example with a CTU module/component in each VMM. In embodiments where the CTU is located in a housing **320** that is discrete from the vehicles, the VMM may include a TSM, CEM, and UIM. In embodiments where the CTU is distributed amongst the vehicles, the VMM may further include a CTU module/component.

FIG. **4** depicts an illustration of an example collision avoidance system (CAS) **400** according to one or more embodiments of the present disclosure. In this embodiment, the system **400** does not include a discrete housing for the CTU technology. This embodiment still utilizes technology, functionality and features similar to those employed in a system (such as the CAS **300** of FIG. **3**) with a CTU disposed in a discrete housing. In this embodiment, the functionality and intelligence of the CTU is dispersed and/or distributed among the VMMs (for example VMMs **402**, **404**) in the vehicles within a work gang. With this dispersed design (also referred

to as "dispersed thinking"), each VMM includes its own CTU module/component that tracks the location of other vehicles in the work gang, like a CTU disposed in discrete housing would do. It should also be understood that although this embodiment describes a central tracking unit component, the central tracking unit circuitry and technology may be incorporated into other components/subcomponents of the VMM, such as the CEM.

For example purposes, FIGS. **3** and **4** each show a work gang including only two vehicles, but it should be understood that work gangs may include more than two vehicles. FIG. **5** depicts an illustration of an example collision avoidance system (CAS) **500** with a work gang that includes more than two vehicles, according to one or more embodiments of the present disclosure. In this embodiment, each vehicle (for example, vehicles **502**, **504**, **506**) in the work gang may be equipped with a VMM and each VMM may communicate with nearby VMMs (in nearby vehicles) as well as with a CTU **518** in a discrete housing, as can be seen in FIG. **5**. In other embodiments of the present disclosure, each vehicle in a work gang is equipped with a VMM and each VMM communicates with nearby VMMs (in nearby vehicles) including a CTU module/component within each VMM (not depicted in FIG. **5**). In these embodiments, there may be no CTU in a discrete housing such as the CTU **518** depicted in FIG. **5**. FIG. **5** depicts a work gang with three vehicles, but it should be understood that a work gang may include more than three vehicles. As the size of the work gang becomes larger, the VMM mounted on each vehicle may communicate with more VMMs (in nearby vehicles), as well as with the CTU in a discrete housing (or a CTU module/component within the VMMS in each vehicle).

FIG. **6** depicts a block diagram of an example vehicle mounted module (VMM) **600**, in accordance with one or more embodiments of the present disclosure. The VMM may include one or more control electronics modules (CEM) **602**, one or more transponder sensor modules (TSM) **604**, and one or more user interface modules (UIM) **606**. The TSM **604** may further include a wireless communications antenna **608** (for example an RF antenna such as a 2.4 GHz radio antenna) that is operable to send and receive data over the air, for example to/from remote systems. The TSM **604** may further include a GPS unit **610** one or more vehicle communication devices **612**. The UIM **606** may further include a user interface **614**, a service interface **616** (optionally including diagnostics components/interfaces) and status/fault indicators **618**. Additionally, the VMM **600** may receive power from a power supply **640** that may provide power to one or more vehicle mounted module components, for example components disposed within the CEM **602**.

Wireless communications antenna **608** may be, for example, an RF antenna such as a 2.4 GHz radio antenna. As depicted in FIG. **6**, a VMM **600** may communicate with a CTU **630** (for example a CTU located in a discrete housing or a number of CTU modules located in other VMMs) through a wireless communications antenna **608**. The wireless communications antenna **608** may be housed in the TSM, or it may be housed separately and perhaps connected to CEM **602** independently. The circuitry for the radio associated with the wireless communications antenna **608** may be disposed in the TSM **604**, or may be disposed in the CEM **602** and be connected to the wireless communications antenna **608** via a wired connection. The VMM **600** may transmit a variety of information to the CTU **630**, for example, absolute position data, relative position data and speed data of the vehicle. Such information may have been obtained by the VMM utilizing various components and/or sensors, for example, the GPS unit **610**, the UWB unit **620**, and/or other sensors. The VMM **600** may transmit other information to the CTU **630**, for example, status/fault and/or diagnostic information regarding the health of the VMM and its components. The VMM **600** may gather data from one or more satellites **634** utilizing a GPS unit **610**, for example to acquire absolute positioning information. The VMM **600** may communicate with other CAS/VMM-equipped vehicles through one or more vehicle communication devices **612** and/or through a wireless communications antenna **608**. In some embodiments, the vehicle communications devices **612** may include one or more separate wireless communications antennas (and perhaps associated radios) from antenna **608**.

Referring to FIG. **6**, in some embodiments, a CAS may not include a discrete CTU such as the one shown in FIG. **6** at CTU **630**. In these embodiments, the VMM may include a CTU module/component **631** that tracks the location of (and provides location information to) other vehicles in the work gang by communicating with other CAS/VMM-equipped vehicles directly. The CTU module/component **631** may operate like (and include similar technology to) a discrete CTU (such as CTU **630**) would operate in other embodiments. The CTU module/component may include technology adapted to dynamically define which vehicles are in the work gang, and/or which vehicles the CTU module/component should keep track of. It should also be understood that although the foregoing describes a CTU module/component, the CTU circuitry and technology may be incorporated into other modules, components and subcomponents of the VMM, such as the CEM. In some embodiments, the CTU module/component may be a software feature that is executed by a processor in the CEM.

VMM subcomponents (for example, the components included within the TSM, CEM and UIM) may be packaged together within a single enclosure. For example, in some embodiments, the CEM and UIM (and optionally, the CTU module) may be combined/disposed in a single package. One benefit of a single package may be that it simplifies the installation process. In alternate embodiments, or one or more VMM components and/or subcomponents may be packaged separately from the other components/subcomponents. The various components and/or subcomponents may be located separately, optionally within separate enclosures, and each separate component may be connected to a main VMM enclosure and/or to other VMM enclosures via wires or a short range wireless link. For example, wireless communications antenna **608** and/or one or more vehicle communication devices **612** may be mounted separately (optionally, in one or more enclosures) on the upper extremity of the vehicle, for example to reduce signal interference and to allow for proper antenna placement (see FIG. **8**). Likewise, the user interface **614** may be located in the crew area or the passenger cab. The number of physical packages/enclosures included in each VMM and the mounting location of each package/enclosure may depend on the type (height, length, etc.) of vehicle the VMM is mounted on, or may depend on the configuration of the VMM. In one example, all of the components of the vehicle mounted module are housed within a single weatherproof enclosure. In another example, the wireless communications antenna (for example, wireless communications antenna **608**) (or the entire wireless communications radio including the antenna) may be installed at a distance from other VMM enclosures/components to avoid interference between the wireless communications antenna and other components of the VMM, for example the UWB sensor.

FIG. **7** depicts an illustration of a block diagram of an example control electronics module (CEM) **700**, in accor-

dance with one or more embodiments of the present disclosure. The CEM **700** may include a processor **702**, a wireless communications radio **704** (such as an RF radio), an interface to a TSM **730**, an interface to a UIM **720**, one or more interfaces **706** to ground speed detection modules, a power supply interface/power conditioning system **708**, and a real-time clock **714**. Examples of ground speed detection modules that may connect to interface **706** include an encoder module **750**, a microwave radar **752** and/or a laser device **754**. The interface to the UIM **720** may further include one or more drivers to power visual and/or audio indicators. In some embodiments, the CEM **700** may include one or more vehicular interfaces (interfaces to existing vehicle systems), for example a CAN interface, braking systems, speed indicators, equipment operating mode status indications and the like. The CEM **700** may include an inertial measurement unit **710** that includes one or more devices, for example, one or more accelerometers and/or gyroscopes. The CEM **700** may include a log/memory **712**.

It should be understood that although FIG. **7** depicts some or all of the aforementioned subcomponents as being contained within the CEM **700**, different configurations of the VMM are contemplated by this disclosure, including various combinations of VMM components/enclosures. Therefore, in some embodiments, the subcomponents depicted in FIG. **7** may be disposed outside of the CEM **700**, for example in one or more other VMM enclosures. And in other embodiments, subcomponents other than those depicted in FIG. **7** may be disposed inside of the CEM **700**, for example one or more subcomponents that may reside in other VMM enclosures in other embodiments. In some examples, some of the subcomponents depicted in FIG. **7** may reside in the UIM and/or the TSM and may connect to the CEM by way of wires or wireless connection(s).

Referring again to FIG. **7**, CEM **700** may include a processor **702**. The processor **702** may, among other operations, process information received from the vehicle communication devices, for example via the interface to the TSM **730**. For example processor **702** may be in communication with and process information from a UWB unit via TSM interface **730**. The processor **702** may also process information received from other modules, components and/or subcomponents of the VMM. The processor **702** may handle information and/or perform computations to, among other things, track other vehicles in a work gang and determine which vehicles present a potential hazard. It should be understood that the CTU may also process location and speed information from vehicles in a work gang and may also track vehicles in a work gang to determine when collisions may be imminent. The present disclosure contemplates various types of configurations whereby some or all of the tracking and processing components of the CAS may be located within the VMMs (for example, within a CTU module), within a CTU in a discrete housing, or a combination of both. In the example where a CTU module/component performs tracking of other vehicles, a CTU module **703** may be disposed within the CEM **700**, perhaps implemented in processor **702**. In some embodiments, the CTU module **703** may be a software feature that is executed by the CEM processor **702**.

CEM **700** may include an inertial measurement unit **710** that includes one or more devices, for example, one or more accelerometers and/or gyroscopes. The inertial measurement unit **710** may be operable to, among other functions, detect changes in the speed of a traveling vehicle. Detecting changes in vehicle speed may be useful to aid in dead reckoning solutions instead of or in conjunction with short range distance measurement sensors. For example, if a vehicle traveled into a tunnel and the GPS unit could not establish a connection to satellites to provide positioning information, an inertial measurement unit may provide information regarding whether vehicles in a work gang have changed speeds while in the tunnel. An inertial measurement unit **710** may also be operable to detect sudden changes in speed, for example indicating that a vehicle was involved in a collision, or perhaps indicating some other event. The inertial measurement unit **710** (or some other VMM component) may then store/log data regarding the activities of the vehicle (and/or VMM components) surrounding the time of the event, similar to the way a flight recorder records events proximate to a plane crash. This recording component may collect information from the inertial measurement unit **710** and/or from other VMM components, for example from a UWB unit.

CEM **700** may include a real-time clock **714**. The real-time clock **714** may provide accurate (optionally, synced) time readings, for example to facilitate development evaluation testing. The time and date of the real-time clock may be adjusted automatically, for example by receiving updates from a GPS unit via TSM interface **730**. The time and date of the real-time clock may be adjusted by receiving change requests from the service interface or user interface via UIM interface **720**. In one example, the real-time clock **714** may exhibit an accuracy of plus/minus 5 seconds per day at 25 degrees Celsius.

The CEM **700** may be mounted in or near the vehicle cab. For example, if the CEM **700** is packaged with a UIM, the CEM may be mounted in the cab near an operator. In other examples, the CEM may be mounted on an upper frame or part of the vehicle, for example within the vicinity of the TSM. For example, if the CEM is packaged with one or more components of the TSM, a higher mounting location may reduce interference for TSM modules, for example the GPS unit and/or UWB unit. The CEM may be packaged with the TSM in shorter vehicles for example. In some embodiments, it may be beneficial to package the CEM separately from the TSM. In one particular example, the CEM may be mounted directly below the TSM, were the TSM is disposed above or on the roof of the vehicle (see FIG. **8**) and the CEM is disposed below the roof of the vehicle, for example fixed to the inner ceiling of the vehicle. In this example, the CEM may be sheltered from direct exposure to sunlight and the components of the TSM may experience minimal interference and a clear line of sight.

The CEM **700** may interface (for example via a power supply interface **708**) with a power supply **760**. The power supply interface **708** may include a power conditioning system. In one example, all power for the VMM components and subcomponents passes through the power supply interface/conditioning system **708** located in the CEM, and then power for the other VMM components is routed out from the CEM. In other examples, one or more VMM components may include their own power conditioning systems and may accept power from a power supply without receiving power that is channeled through the CEM. The power supply may be the same as the vehicle's power supply, for example a 12 VDC or 24 VDC power supply. Alternatively or in addition, the VMM may include an independent power supply such as a battery, solar panels, and the like.

Referring again to FIG. **6**, VMM **600** may include a transponder sensor module (TSM) **604**. In some implementations of the VMM, one or more components of the TSM **604** may be packaged with the CEM **602**. In other implementations, it may be beneficial to package one or more TSM components separately from other VMM components, for example on an upper extremity of a vehicle. FIG. **8** depicts an illustration of

side angled view of the upper portion **802** of an example rail line vehicle (for example a vehicle similar to the vehicle of FIG. **1**C) and a mounting configuration **804** for one or more components of a TSM, in accordance with one or more embodiments of the present disclosure. One or more TSM components may be mounted at a high point (for example, the highest point) on the vehicle, where a clear line of sight may be established between the TSM components and an area to the front and rear of the vehicle.

In the example shown in FIG. **8**, the wireless communications antenna **806** (for example, similar to the wireless communications antenna **608** of FIG. **6**) and a UWB unit **808** (for example, similar to the UWB unit **620** included in the one or more vehicle communication devices **612** of FIG. **6**) may be mounted separately from other VMM enclosures. In this example, the wireless communications antenna **806** and UWB unit **808** may be mounted on the upper extremity **810** of the vehicle to reduce signal interference and to allow for proper antenna placement. It should be understood that FIG. **8** depicts only one example of TSM components that may be mounted on the upper extremity of a vehicle. More or less TSM components (or other VMM components) than are shown in FIG. **8** may be mounted on the upper extremity of a vehicle. For example, components that may be mounted on the upper extremity of a vehicle may include the UWB unit, wireless/RF antennas and/or radios, GPS units, infrared sensors and the like.

TSM components (and/or other VMM components) may be installed on the upper extremity of a vehicle by a variety of means. Referring to FIG. **8**, for example, a hole may be drilled through the side of an upper portion **802** of a vehicle or through the roof **810** to allow hardware to thread through the vehicle's upper portion **802** and also through VMM components to fix the components to the upper portion. Additionally, brackets, flanges, sockets or other hardware may be used to fix components to the upper portion **802**. For example, FIG. **8** shows a bracket **814** that may be used to fix a UWB unit to the upper portion **802**. The bracket **814** may be fixed to the upper portion **802** of a vehicle and the UWB unit may be fixed to the bracket. Brackets may aid in attaching components to the upper portion **802**, and/or they may elevate components so that the components experience increased line of sight and decreased interference. One or more holes may be drilled through the roof **810** or a side wall of upper portion **802** to allow the passage of interface cables (for example, cable(s) **812** of FIG. **8**) into and/or out of the cab of a vehicle.

FIG. **9** depicts an illustration of an example rail line vehicle **900**, including a VMM that includes more than one TSM, in accordance with one or more embodiments of the present disclosure. In some embodiments of the disclosure, the VMM in a rail line vehicle may include more than one TSM, or may include more than one group of TSM components mounted on the upper extremity of a vehicle. With regard to the disclosure herein, when a description explains the configuration and/or benefits of multiple TSMs, it should be understood that the entire TSM may not be duplicated. Instead, one or more components of the TSM may be duplicated, while there may be a single instance of other components of the TSM. For example, the VMM may include duplicated vehicle communication devices, such as two or more UWB units. Additionally, while the disclosure herein may describe two TSMs, some embodiments may include VMMs with more than two TSMs.

Referring to FIG. **9**, a VMM installed in a vehicle **900** may include two TSMs **902**, **904** (or two groups of some TSM components), for example mounted at either end of the vehicle **900**. As shown in the example of FIG. **9**, the two TSMs **902**, **904** may be mounted at the extreme (or near extreme) front and rear ends of the vehicle **900**. Placing sensors, for example sensors included in TSMs **902**, **904**, at the extreme ends of a vehicle may improve the accuracy of some sensors, for example sensors that measure distance between vehicles (such as UWB sensors or infrared sensors). Especially if the vehicle **900** is long, a distance sensor (for example a sensor included in TSM **904**) that is placed near the end of a vehicle may more accurately calibrate itself to determine the exact location of the end of the vehicle **900**, and thus the sensor may be able to determine more accurately the distance between the end of the vehicle **900** and other vehicles. The two TSMs **902**, **904** may be connected to a single CEM **906**, which may be connected to a single UIM **908**. In other embodiments, the VMM may include more than one CEM and/or more than one UIM.

When a VMM-equipped vehicle is initialized to operate with a CAS, the VMM components of the vehicle may be calibrated (also referred to as "commissioning" the vehicle) to the particular installation configuration for that vehicle. Calibration may include an operator specifying the vehicle length in each direction from the one or more mounted TSMs. Rail line vehicles (for example, maintenance vehicles) can range in length (see FIG. **1**), for example from 12 feet to 80 feet, and the vehicles can have a variety of cab locations and configurations. Given the different lengths and configurations of vehicles, it may be necessary to program information into various components of the VMM, including the TSM and/or the CEM, such that the components are aware of (and/or can compute) the distance between the component's mounting location and the ends of the vehicle.

In some embodiments of the disclosure, circuitry within the VMM (for example in the CEM) may automatically compensate (calibrate) for the length of the vehicle and the mounting location. In one example, the VMM may include a single TSM, and the TSM may be mounted on the vehicle (for example, at the front or center of the vehicle), and circuitry within the VMM (for example in the CEM) may automatically compensating for the length of the vehicle and the mounting location. In another example, the VMM may include multiple TSMs, and the TSMs may be mounted on the vehicle (for example, near the front and rear of the vehicle), and circuitry within the VMM (for example in the CEM) may automatically compensating for the length of the vehicle and the mounting location of the multiple VMMs. The sensors may be designed to adjust for the size of the equipment and specific location of the components. The present disclosure contemplates various methods and solutions to adjust settings of VMM's components at initial installation to aid in component awareness. Components may contain smart technology that aids in the component's calibration. The VMM components may also be operable to account for a length of a vehicle that may change on the fly. For example, some vehicles change length when retractable sections are extended. The VMM components may be designed to accommodate this change in length, either by manual user input or automatic detection of the vehicle configuration.

Referring again to FIG. **6**, the TSM **604** may include one or more vehicle communication devices **612**. It should be understood that throughout this disclosure, when reference is made to vehicle communication devices, there may only exist a single vehicle communication device, for example just a UWB unit. In other examples, there may be more than one vehicle communication device. Vehicle communication devices **612** may be packaged together, or they may be packaged independently, or they may be packaged with other TSM components. The vehicle communication devices **612** may be

in close communication with the CEM **602** via either a wired connection or a short range wireless connection. One benefit of a wired connection is that the CEM, which may contain a power conditioner unit and an interface to a power supply, can provide power to the vehicle communication devices, along with communication functions.

The vehicle communication devices **612** may communicate wirelessly with other CAS/VMM-vehicles **638** in the work gang. The vehicle communication devices **612** may be operable to, among other functions, determine the relative location of other CAS/VMM-equipped vehicles in relation to the present vehicle. The vehicle communication devices **612** may utilize one or more communication technologies and may include one or more integrated antennas for sending and receiving signals to and from other vehicles. In one example, each vehicle may have a unique identification code that was assigned when the VMM was installed in the vehicle, or before or after such installation.

In some embodiments of the present disclosure, the vehicle communication devices **612** may include an Ultra Wideband (UWB) unit **620** to communicate with other VMMs. In one specific example, the UWB unit **620** is the only vehicle communication device. The UWB unit may include a control board, a data interface and/or a UWB antenna. The UWB unit **620** is typically adapted for sending signals to and/or receiving signals from UWB units mounted on/inside other vehicles. The UWB unit **620** may be adapted to measure the relative separation distance between properly equipped vehicles without becoming confused by interference from nearby stationary or unrelated off-track equipment that might otherwise cause false alarms in radar-based collision avoidance systems.

FIG. **10** depicts a block diagram illustrating example UWB units, in accordance with one or more embodiments of the present disclosure. Pulses emitted from a UWB transmitter may spread in many directions. A UWB unit may transmit and receive pulses that are communicated directly **1002** between UWB units (for example between a UWB transmitter/transceiver **1008** and a UWB receiver/transceiver **1006**), and/or the UWB unit may transmit and receive pulses that have been reflected **1004** (bounced) off of an object and/or surface, for example the ground. A UWB unit may be capable of resolving multipath reflections from a main signal by focusing on the first arriving pulse. Additionally, the UWB technology may take advantage of the fact that radio waves/pulses travel at a particular velocity. By measuring how long it takes a wave/pulse to travel (for example by reflecting/bouncing) between two transceivers, the distance between the UWB units can be accurately determined. This technique may be referred to as "Time of Flight" (TOF). In existing wireless radio technologies, TOF calculations have previously had limitations due to the reflection of radio waves from the wide range of objects in the vicinity. These reflections may result in the receipt of numerous conflicting signals of varying amplitudes, and in some instances one or more signals may cancel each other out, a phenomena referred to as "multi-path distortion". This may result in inaccurate distance determinations because a direct wave may have been cancelled out, and a reflected wave may travel a longer path and appear to be the first arriving pulse, resulting in a false (longer than actual) separation distance measurement.

A UWB unit may utilize a high bandwidth pulsed distance-measurement technology. A UWB transceiver may utilize a broad spectrum of frequencies simultaneously at a relatively low power levels. A UWB unit may be operable to periodically transmit short duration pulses, such as RF pulses. For example, a UWB unit may measure a distance of several hundred feet with a resolution of several inches. Precise range determination may be advantageous, for example when vehicle separations are small and/or when a potential GPS measurement error becomes significant. In one example, a GPS measurement error may be 10-15 feet. Additionally, each pulse transmitted by a UWB unit may be coded and the phase of the pulse may be modulated and the pulse repetition rate may be variable. Thus, a UWB unit may measure separation distances more accurately and be less susceptible to interference from geographic conditions and less susceptible to multi-path distortion than are other wireless technologies.

A UWB unit may transmit one or more signals that may be pseudo-randomly (and uniquely) encoded with low-amplitude RF energy spread over a 2 GHz bandwidth. The transmitted signal may be spread out over such a wide range of frequencies that the transmissions appear like normal background atmospheric noise. As a result, the signal is unlikely to cause interference with other communications systems. This encoding also means that information may be transmitted with the range finding signal, such that data communication may be accomplished while distance measurement is performed. In other words, the UWB unit may be adapted to transmit data to other UWB units in addition to detecting the distance to other UWB units. In effect, the two functions (data and distance) may be performed at the same time using the same wireless link because the UWB unit may transmit data, and then additionally, distance information may be computed by determine how long it took for the data to travel from one UWB unit to the other. It should be understood, however, that the two functions (data and distance) need not be performed at the same time.

The UWB unit may be adapted to send data as well as determine distance between vehicles. Because the UWB unit may be utilized to send data, some embodiments of the present disclosure, for example those where a central tracking component resides in the vehicle mounted module, may not need to use any other type of wireless or RF technology to communicate. This could reduce the technology components required in the system, reducing cost of the system. However, in other embodiments, a VMM may benefit by utilizing more than one data link (wireless technology capable of transmitting data). For example, a wireless RF link may provide a greater distance/range for sending data than a UWB unit, and because of this benefit and potentially other benefits of various types of data links/wireless technologies, a VMM may benefit by utilizing more than one type of data link Additionally, a collision avoidance system may have multiple data links in order to introduce redundancy into the system. For example, the UWB unit may be capable of sending data if the RF link is not functioning properly, and vice versa.

One example of a UWB technology that the CAS may utilize is the technology described in the White Paper published by Time Domain entitled "Time Domain's Ultra Wideband (UWB): Definition and Advantages," which is incorporated by reference in its entirety herein. However, it should be understood that the collision avoidance system may utilize other designs and types of UWB technologies besides just the one described in the White Paper.

The UWB unit may be operable to measuring the vehicle separation independently. Thus, in various embodiments of the CAS, the UWB unit may replace the GPS unit, or the UWB unit may work in conjunction with the GPS unit. As explained above, the CAS may be designed to include redundancy in the system, for example in the form of multiple types of sensor technologies and/or multiple sensors of a particular type of technology. One benefit of utilizing redundant sensors may be that some sensors may function properly when other

sensors are not functioning optimally or at all. For example, a GPS sensor may not communicate well with satellites when a vehicle is in a tunnel, and thus the GPS unit may not provide adequate information to the CAS in this situation. However, in this situation, the UWB unit (or other sensors/technologies) may be fully functional. For example, tests have been performed in tunnels that stretch up to 1 mile in length (or longer), and the tests have shown that a properly configured UWB unit may accurately measure distance and relative speed of vehicles in such a tunnel. UWB sensors (and/or other non-GPS type sensors) may also work in conjunction with a GPS sensor. For example, a UWB sensor may provide better resolution (i.e., can measure separation distance at finer increments, more accurately) and the GPS sensor may provide a location/separation information over a greater area.

Referring again to FIG. **6**, once a UWB unit determines distance information, it may communicate this data to a CTU **630**, for example via wireless communications antenna **608**. Wireless communications antenna **608** may be an RF antenna, for example a 2.4 GHz radio antenna. In other embodiments, where there is no CTU in a discrete housing, UWB distance data (an optionally other data) may be communicated to CTU modules in other VMMs via wireless communications antenna **608** and/or a separate wireless communications antenna located in the TSM **604**. In embodiments where the UWB unit is adapted to operate in conjunction with a GPS unit, combined GPS and UWB distance data may be communicated between a vehicle and the CTU **630** and/or between vehicles in the work group via similar wireless communications antennas/technologies as described herein.

FIG. **11** depicts and illustration of a side view of an example rail line vehicle including multiple UWB units (or multiple UWB components), in accordance with one or more embodiments of the present disclosure. In some embodiments, a VMM installed on a vehicle **1102** may include more than one UWB unit (for example, UWB units **1104**, **1106**), for example to introduce redundancy into the system. In some embodiments, a VMM installed on a vehicle **1102** may include more than one UWB antenna, and the multiple UWB antennas may share a common control board and/or data interface. When present disclosure describes multiple UWB units, it should be understood that the entire UWB unit may be duplicated or one or more components of the UWB unit may be duplicated, for example the UWB antenna. In some embodiments, multiple UWB units (or multiple UWB components) may be housed in a single enclosure. In other embodiments, multiple UWB units (or multiple UWB components) may be housed in separate enclosures, as depicted in FIG. **11**.

In some situations, when a UWB pulse is reflected from an object or a surface (for example the ground), the UWB pulse may be destroyed (for example, by a reflected signal which is the same amplitude but 180 degrees out of phase) or altered before it gets to the UWB receiver, and/or other interference may cancel out a pulse. These situations where a UWB link might not transmit a pulse ideally may be referred to as "holes." In some embodiments, the VMMs may include more than one UWB unit (or UWB component), for example in case one UWB pulse is destroyed. In some examples, two UWB units (or two UWB antennas) may be mounted on a single vehicle with a small offset between the UWB antennas. For example, referring to FIG. **11**, two UWB units (or two UWB antennas) **1104**, **1106** may be mounted on a single vehicle **1102** with a small vertical distance **1108** between the UWB antennas. In this example, pulses **1110**, **1112** from the two UWB units **1104**, **1106** (respectively) may arrive at a UWB receiver of another vehicle after traveling slightly different distances (for example, because they reflected off the ground at different angles). Multiple/redundant UWB units may increase the probability that whatever surface and/or interference destroyed or altered one UWB pulse will not interfere with the second UWB pulse. In some examples, two UWB units (or two UWB antennas) may be mounted on a single vehicle with a small horizontal distance between the UWB antennas. The horizontal offset may provide information to the VMM to determine the orientation of nearby vehicles in relation to the immediate vehicle. For example, UWB unit information may show that a nearby/target vehicle that is in front of the immediate vehicle is closer to a front UWB antenna, and likewise for a rear vehicle/rear UWB antenna.

In some embodiments, one or more UWB units may be operable to transmit/receive signals with varying center frequencies. This multiple center frequency technique may work with a single UWB unit or it may work with multiple UWB units. In a single UWB unit example, the UWB controller may utilize adaptive output filters. The UWB unit may include a single UWB transceiver that is adapted to send multiple pulses/signals with different center frequencies at different times, for example alternating between modes (center frequencies). A corresponding UWB receiving unit may be synchronized with the UWB unit sending the signals, in that it may receive pulses/signals with different center frequencies at different times. In a multiple UWB unit example, one UWB unit may send signals at one center frequency and another UWB unit may send signals at a different center frequency. Variations in the center frequency of the UWB signals may result in a different phase delays of the signals, for example when reflected. If one signal has been significantly altered or destroyed by a reflection, another signal(s) (which utilizes a different center frequency) may be unaffected, or at least less affected, by the reflection. This may be because different frequency signal(s) over the same reflection path length may experience a different phase delay. This approach may improve the reliability of UWB communications under certain operating conditions.

Referring to FIG. **6**, in some embodiments, the vehicle communication devices **612** may include other wireless communication devices/technologies (beyond or in replacement of a UWB unit) to communicate with other VMMs. In some embodiments, a VMM may utilize a wireless communications antenna/radio (for example, an RF antenna/radio) to communicate with other VMMs. In some embodiments, the same wireless communications antenna **608** that communicates with a CTU **630** may communicate with other VMMs. In some embodiments, the vehicle communication devices **612** may include an ultrasonic or short distance laser device. Some example ultrasonic or short distance laser devices can sense distances between zero and thirty feet. In yet other examples, the vehicle communication devices may utilize radar, infrared (IR), and/or optics technologies.

Referring again to FIG. **6**, a TSM may include a Global Positioning System (GPS) unit **610**. The GPS unit **610** may be incorporated to the TSM. In some embodiments, the GPS unit **610** may be packaged with one or more vehicle communication devices **612**, or it may be packaged in the CEM. Alternatively, the GPS unit **610** may be housed separately or may be incorporated into other VMM components or subcomponents. The GPS unit may include either an integrated or separate antenna assembly.

The GPS unit **610** may be adapted to determine the absolute position and speed of a vehicle that is equipped with the GPS unit. Information/data generated by a GPS unit may

allow real-time determination of vehicle velocity and location. This information/data may allow a GPS unit **610** to determine expected vehicle stopping distances and may enable logging of equipment location with respect to time and date. For example, absolute location information provided by a GPS unit **610** may be useful to track the work performed by a work gang. A GPS unit may also provide distance information regarding the distance between two GPS-equipped vehicles.

Some GPS-based systems may experience reduced accuracy at times or may lose all connection with satellites, for example, when a vehicle enters a deep valley or a tunnel. A GPS unit may provide distance information in conjunction with other technologies that provide distance information (for example, UWB, infrared) as a form of redundancy and/or to offer a variety of distance measurement ranges and precision. A GPS unit may be operable to determine vehicle position within a wider range, for example 10 to 15 feet. A GPS unit may allow for the determination of distances between vehicles that are too far apart for other types of distance detection technologies to function accurately. Then, other technologies, for example a UWB unit, may provide a more precise distance measurement, for example a distance within 6 inches. The accuracy of a GPS unit **610** may be enhanced by utilizing a WAAS (Wide Area Augmentation System), a system of ground reference stations across North America that provide GPS signal corrections. Corrections provided by a WAAS may improve the positioning capability of the GPS unit **610**, for example by a factor of five, such that the location may be determined as accurately as within 2 to 3 feet.

Referring to FIG. **6**, the VMM may include one or more user interface modules (UIM) **606**. A UIM **606** may further include a user interface **614**, a service interface **616** (optionally with diagnostic components/interfaces) and status/fault indicators **618**. A UIM **606** may provide an operator with an interface by which the operator can engage with the technologies that are part of the VMM, and by which the operator may be alerted of events, for example if vehicle separation criteria are violated. A UIM may be located/mounted within convenient reach and view of the operator, and may be connected by an interface cable (or short range wireless connection) to other VMM modules, for example the CEM. For example, the UIM may be mounted in a vehicle cab in order to allow the operator to see and hear warning and alarm indications.

Status/fault indicators **618** may alert an operator that one or more VMM components and/or subcomponents are not operating in an optimal manner. In some embodiments of the present disclosure, the VMM components may be operable to "self-monitor," meaning they may be adapted to monitor their own operation and health. If a VMM detects degraded or non-optimal performance (for example regarding any of the sensors or other VMM components or subcomponents), the status/fault indicators **618** may alert an operator. In some embodiments, the VMM may communicate status/fault indication to the CTU (or CTU module(s), for example via a wireless communications antenna, for example wireless communications antenna **608**.

FIGS. **12**A and **12**B depict illustrations of example user interfaces, in accordance with one or more embodiments of the present disclosure. The UIM may include a user interface. Referring to FIGS. **12**A and **12**B, it can be seen that a user interface (for example user interfaces **1202**, **1204**) may include one or more means of alerting an operator of events, for example if vehicle separation criteria are violated. FIG. **12**A shows one example of a user interface **1202**. In this example, the user interface **1202** may include one or more visual indicators **1206**, one or more audible indicators **1208**, one or more switches/buttons **1210**, **1212**, **1214**, and/or other input means or alerting means. Examples of visual indicators **1206** are lights, lamps, alpha-numeric character displays, LED's and the like. These indicators may provide an operator with information regarding the technologies included in the VMM, and certain indicators may alert the operator when an event occurs, for example when separation parameters (between vehicles for example) are exceeded. Examples of audible indicators **1208** are variable characteristic audible indicators, buzzers, alarms, sirens, horns and the like. The user interface **1202** may include one or more interface switches/buttons **1210**, **1212**, **1214** that may be adapted to allow an operator to configure and/or interact with components of the VMM. For example switches may be adapted to activate and deactivate component interfaces, for example component interfaces in the CEM. In one example, (and referring to FIG. **7**), an operator may use a switch to deactivate the interface **706** to an encoder module. Examples of other input switches/buttons are buttons that acknowledge (temporary mute) a buzzer, alarm or a horn.

FIG. **12**B shows another example of a user interface **1204**. The user interface **1204** may be a touchscreen, tablet, PDA, monitor or other type of digital display/interface. Even though some descriptions of user interface **1204** may refer to it as a touchscreen, it should be understood that other alternatives mentioned and others may be contemplated. In some embodiments, a touchscreen may be implemented in conjunction with other types of user interfaces or user interface components, for example the components of user interface **1202**. In some embodiments, a touchscreen may be adapted to serve as the only user interface component that interfaces with the operator. In some embodiments (and referring to FIG. **6**), if a touchscreen is used to implement the user interface **614**, other components of the UIM (for example the service interface **616** and/or the status/fault indicators **618**) may be incorporated into the same touchscreen.

User interface/touchscreen **1204** may offer more flexibility and functionality than "hard" switches, lights, buzzers and the like. For example, a touchscreen may include on or more physical buttons (for example button **1218**), but may also allow an operator to engage "soft"/temporary buttons on the screen **1216** of the touchscreen. In this respect, the touchscreen may offer similar functionality to hard switches/buttons. Additionally, a touchscreen may include one or more speakers and/or audio drivers, and thus the touchscreen may offer similar functionality to hard buzzers, alarms and the like. The screen **1216** of the touchscreen **1204** may also alert an operator to an event, offering similar functionally to hard lights, lamps and the like.

A touchscreen **1204** may be adapted (i.e., programmed, etc.) to display to an operator multiple sets of screens and/or menus, with multiple sets of options, functions and the like. Additionally, a touchscreen may be adapted to display complex (for example, graphical, textual, etc.) information to an operator. For example, a touchscreen may show the operator the speed of his vehicle, or may show operator his GPS coordinates. A touchscreen **1204** may be adapted (i.e., programmed, etc.) to offer additional functionality, for example allowing operators to send messages (for example text-based or html-based message) to nearby vehicles. In some embodiments, a touchscreen may provide a GPS-augmentation feature, for example, which may adapt the touchscreen to display the location of the vehicle relative to railroad mile markers.

It should be understood that the components and/or functionalities of user interfaces **1202** and **1204** may be incorporated into or implemented in one or more physical housings and/or devices. These components may be incorporated into

discrete enclosure(s) (for example mounted near an operator/cab) and/or they may be incorporated into VMM components. In some embodiments, the user interface (for example, interfaces **1202** and/or **1204**) may be mounted alongside or in the same enclosure as the CEM **1230** or it may be mounted in a separate enclosure. For example, the user interface may be located in the passenger cab and the CEM may be located on an upper internal extremity of the vehicle. This flexible mounting arrangement may help to accommodate a wide range of equipment/vehicles that the CAS may need to track by allowing the user interface to be mounted where it is visible and accessible to the equipment operator while allowing the CEM to be mounted in close proximity to the TSM, which may improve performance, for example by allowing better reception.

The user interface (for example user interfaces **1202** and/or **1204**) may be in communication with the CEM **1230**, and/or other VMM modules. The user interface may communicate with the CEM, for example, via either a wired interface or a short range wireless connection. One benefit of a wired connection is that the CEM, may contain a power supply interface and/or a power conditioner unit and may be able to provide power to the user interfaces, along with communication functions.

Referring to FIG. **6**, the UIM **606** may include a service interface **616** that provides for installation, configuration, maintenance and/or diagnostic activities. The service interface **616** may be incorporated as part of the user interface, or it may be housed separately. In some embodiments, the service interface **616** may be located in the CEM **602**. The service interface **616** may also be used to initialize the vehicle mounted module. In other embodiments, the user interface **614** may be used to initialize the vehicle mounted module. For example, the CEM may include a setup program that initializes the various VMM components and subcomponents. An operator may use the user interface **614** or the service interface **616** to input initialization information into the setup program. Such information may include the physical location where various VMM components are mounted on the vehicle, as well as vehicle size and vehicle type. This information may be input when the vehicle mounted module is initially installed on the vehicle.

The service interface **616** may include a variety of technologies that may enable fast and easy communication between an operator and the service interface, and between the service interface and other VMM components and subcomponents. For example, service interface **616** may include one or more USB ports, Ethernet ports, and/or SD memory card slots. Service interface **616** may be configured, for example, with an industry standard Ethernet port to allow the use of commercially available laptop computers that may interface with service interface **616**, for example to perform status inquiries, to configure settings of VMM components, and/or to update the software/firmware of VMM components. Ethernet ports generally will conform to the IEEE 802.3 communication standard for 10 BASE-T Ethernet (or alternatively 100 BASE-T). In addition to Ethernet ports, or in conjunction with Ethernet ports, the service interface **616** may be configured with an 8-position RJ45 modular jack for interconnection. The service interface **616** may also operate as a DHCP server, thus allowing an operator to connect a laptop to the Ethernet port and within a few seconds be automatically configured and communicating with the VMM **600**. Alternatively, the service interface **616** may require a static IP address setting to be configured on the laptop. In such a configuration, the service interface may conform to the Internet Protocol Version 4 (IPv4). In some examples, the service interface connectors, such as the Ethernet connectors and the RJ45 connectors, may include environmental dust shields for protection.

In some embodiments, service interface **616** may include wireless capabilities. For example, service interface **616** may include a wireless radio (for example an RF radio), WIFI components and/or other wireless technology. A service interface **616** with wireless capabilities may be adapted to accept "field updates." Field updates refer to updates to the software and/or firmware of VMM modules that are "pushed" to the modules over a wireless link. In one example, a foreman may drive up to a group of vehicles and may push updates to all the vehicles simultaneously, for example without having to physically connect to the vehicles. Alternatively or in addition, wireless communications antenna **608** (and/or other wireless communication antenna(s)) may be used to perform field updates.

In one or more embodiments of the present disclosure, the VMM may include (or may interface with) one or more non-GPS type sensors. These non-GPS type sensors may be adapted to measure speed (also referred to as ground speed) and direction of a rail vehicle. A GPS unit may provide speed and direction information, but in some embodiments and/or in some situations, the non-GPS type sensors may either supplement or replace GPS speed and direction information. For example, non-GPS type sensors may supplement a GPS sensor as a form of redundancy in the system, or may provide speed and direction information when the GPS unit cannot communicate with satellites (for example, when a vehicle is inside a tunnel). Additionally, these non-GPS type sensors may allow the CAS to determine relative vehicle position. For example, the non-GPS type sensors may calculate relative vehicle position as a function of the offset from the last known GPS location.

One type of non-GPS type sensor is an encoder module. An encoder module may be adapted to measure ground speed and direction of a rail line vehicle. The encoder module may supplement the UWB technology or replace the UWB technology, for example as a method of providing more precise "dead reckoning" data to the CAS, helping to overcome the "dead reckoning" limitations of earlier systems. In one embodiment, the encoder module may include a small rubber wheel which contacts the top of a rail on which the vehicle travels. The encoder module may be mounted on an adjustable preloaded assembly which maintains contact with the rail. A magnetic rotary encoder may count the rotations of the wheel. In one example, an encoder module may use a small integrated Hall-ASIC to determine the rotational speed of the wheel. This wheel rotation information may be translated into distance information which may be communicated to a CEM either through a wired or wireless connection.

The encoder module may be adapted to allow the encoder assembly be manually or automatically raised from the tracks for maintenance or lifting of the vehicle from the tracks. The encoder module may also include auto calibration features. For example, as the encoder wheel turns, it may utilize GPS data, when it is available, to review the last distance traveled, and compare that with the number of rotations of the wheel. This information can be constantly updated and used to compensate for wheel wear and or track slippage. Referring to FIG. **7**, a CEM **700** may include one or more interfaces such that a VMM may communicate with one or more non-GPS type sensors. An encoder module, for example, may be in communication with a CEM, typically connected to a module interface. As an example, FIG. **7** depicts an encoder module **750** connecting to a CEM **700** via an interface **706**.

Another type of non-GPS type sensor that may be in communication with a VMM is microwave radar, for example a Doppler radar. A microwave radar may be adapted to measure ground speed and direction of a rail vehicle. In one example, a microwave radar may be mounted on a rail line vehicle and may be oriented to point at the ground to detect ground speed and direction of travel. A microwave radar, for example, may be in communication with a CEM, typically connected to a module interface. As an example, FIG. **7** depicts a microwave radar **752** connecting to a CEM **700** via an interface **706**.

Another type of non-GPS type sensor that may be in communication with a VMM is a laser device. A laser device may be adapted to measure ground speed and direction of a rail vehicle. In one example, laser device may be mounted on a rail line vehicle and may be oriented to point at the ground. A laser device may bounce a signal off of the ground (or other stationary object) to detect ground speed and direction of travel. A laser device, for example, may be in communication with a CEM, typically connected to a module interface. As an example, FIG. **7** depicts a laser device **754** connecting to a CEM **700** via an interface **706**.

Other types of non-GPS sensors that may be used in conjunction with the GPS sensor to detect ground speed and direction of travel include infrared sensors, UWB sensors as described herein, UWB radar sensors, and other types of radar sensors. These non-GPS type sensors may add redundancy to the GPS sensor, or they may provide information when GPS information is temporarily unavailable. One or more parts of one or more of the non-GPS type sensors may be packaged in the same enclosure as other VMM modules, or they may be packaged separately.

In operation, the CAS may be capable of precisely tracking the location and separation distances of vehicles equipped with appropriate equipment and/or components as described herein. When the CAS is tracking vehicles, a particular work gang may be operating in one of two modes for example—travel mode or work mode. For each mode, railroad companies may require that a specific spacing be maintained between vehicles. In work mode, the vehicles may be traveling at a speed of less than 10 MPH, and about 40 to 50 feet of spacing between vehicles may be required. In travel mode, the vehicles may be traveling at speeds of up to around 25 MPH, and about 300 feet to about 500 feet of spacing between vehicles may be required. Depending on the mode in which the vehicles are operating, the CAS may adjust its sensitivity and/or settings in order to better predict when collisions may be imminent.

For the CAS to operate optimally, each vehicle in a work gang may need to be equipped with a VMM. The VMMs mounted on/in the vehicles and the CTU may only be able to detect vehicles which are outfitted with a VMM. In one embodiment of the present disclosure, the CAS requires that every vehicle in a work gang be equipped with a VMM. If all vehicles in a work gang are equipped with a VMM, the CAS may be adapted to eliminate false warnings which plague existing systems, such as radar-based systems.

FIG. **13** depicts a flow diagram **1300** that shows exemplary steps in the operation of a CAS, in accordance with one or more embodiments of the present disclosure. To explain the operation of a particular vehicle/VMM, the immediate vehicle/VMM may be referred to as the "host" and nearby vehicles/VMMs with which the host links/communicates may be referred to as "targets". It should be understood that when the functionality of a host in relation to targets is explained, each target may also act as a host for the purposes of explaining how that target vehicle operates in relation to nearby vehicles.

Referring to FIG. **13**, at step **1302**, the host vehicle/VMM is powered up. This may be referred to as the initial start-up. The VMM may begin to operate whenever a vehicle's systems are powered up. At step **1304**, within a few seconds of initial startup, the host VMM may begin to automatically detect the existence of other vehicles/VMMs in the vicinity. For example, the host VMM may automatically activate one or more vehicle communication devices to search for/link with other vehicles (targets) both in front of the host vehicle and/or behind the host vehicle. The host may survey its surroundings to determine if there is any other VMM-type equipment nearby. At step **1306**, the host may determine which discovered targets, both in front and in back, are the closest and may sense/measure the actual separation distance between the closest target in front and the closest target in the back. In some embodiments, the host may sense and compute distances for vehicles beyond just the vehicles immediately to the front and back of the host. At step **1308**, the host VMM may continuously sense/calculate distances between the host vehicle and the target vehicles. In some embodiments, the host may sense and compute distances for vehicles beyond just the vehicles immediately to the front and back of the host.

At step **1310**, the host (and perhaps other target vehicles) may transmit location and speed information to the CTU, for example through the radio antenna. Additionally or alternatively, the host VMM may transmit (and/or receive) location and speed information, for example through one or more vehicle communication devices, to target vehicles/VMMs. At step **1312**, the CTU and/or CTU module inside the host VMM may calculate information, for example absolute and relative location of the vehicles in the work gang, speed and direction of vehicles, separation distances and/or safe distance violations. At step **1314**, if the CTU and/or host VMM determines that collision is imminent or prescribed safe distances are violated, the host VMM, for example via a user interface, may notify the operator. For example, if the speed and direction information violates preset separation criteria, one or more warning indicators and/or audible buzzers, alarms and the like will activate. Additionally, the host VMM may communicate the violation to the CTU, perhaps through the radio antenna. At step **1316**, if the separation violation has been resolved, for example by the movement of vehicles away from each other, the warning/notification indicator to the operator may silence, and the host may resume monitoring for other potential violations by continuously sensing nearby vehicles and computing separation distances (return to step **1308**).

FIG. **14** depicts a flow diagram **1400** that shows exemplary steps in the operation of a CAS, in accordance with one or more embodiments of the present disclosure. Specifically, flow diagram **1400** shows exemplary steps illustrating how a CAS may determine distances between vehicles. Each vehicle in a work gang may include a GPS unit as well as other sensor technologies such as UWB sensors.

At step **1402**, a host may utilize its GPS unit to determine its absolute location and speed (and perhaps direction of travel). At step **1404**, the host may determine that it would benefit from information from other non-GPS type sensors. For example, one or more vehicles in the work gang may become unable to utilize the vehicle's GPS unit. Vehicles may travel through tunnels, mountains and developed areas that include structures that may prevent or reduce the functionality of GPS-based technologies, resulting in the GPS signal being lost (the "dead reckoning" situation). In these types of situations, the host may determine that other types of sensors included in (or in communication with) the VMM may aid in determining the precise location of vehicles. Even if the GPS

signal is not lost, these other types of sensors may be used to enhance the precision of the location information gathered with respect to a vehicle. At step **1406**, the host may utilize non-GPS sensors to determine relative location and speed information. The host may utilize one or more vehicle communication devices. For example, the UWB unit may determine separation distance and closing speed. The host may utilize components connected to the VMM via component interfaces. For example, a Doppler radar or encoder wheel may determine ground speed and direction of travel.

At step **1408**, the host VMM and/or the CTU may compute separation distances between the host and other vehicles. For example, the microprocessor in the CEM (a component of the VMM) may compute the separation distance between the host and adjacent vehicles. In one illustrative example, a maintenance vehicle (the host) is 40 feet long, and a TSM is installed 10 feet behind the front of the vehicle. Another maintenance vehicle (the target) is also 40 feet long, and a TSM is installed 30 forward from the back of the vehicle. If there is 50 feet between the front of the host vehicle and the rear of the target vehicle, the CAS will measure a distance between the TSMs of 90 feet (10 feet+50 feet+30 feet). The CAS may then perform calculations to compensate for the placement of the TSMs relative to the front and rear of the vehicles. For example, the CAS will subtract 10 feet and 30 feet (the respective distances between the each TSM and the relevant ends of the vehicle) and determine a separation distance of 50 feet (90 feet−10 feet−30 feet).

At step **1410**, the host VMM and/or the CTU may compare computed separation distances to prescribed (safe) separation distances for the given vehicle speed/size. At step **1412**, the host VMM and/or the CTU may determine whether a collision is imminent and whether an operator must be cautioned. The CAS may consider a variety of types of data and scenarios to determine if a collision is imminent. For example, a separation distance of 40 feet may be acceptable when vehicles are traveling at 5 miles per hour, but if the vehicles are traveling at 20 miles per hour, an unsafe condition may exists and the operator will be notified with an audible and visual alert. In another example, a vehicle that is far ahead may not pose a hazard, but one that is directly ahead, and moving slower than the host vehicle may be a potential collision hazard. In another example, two vehicles may have been creeping along the tracks at a separation distance of 100 feet, and then the vehicles speed up to reach another worksite. If the separation distance does not increase with the increase in speed, the CAS may sound a warning or alarm.

Using various combinations of technologies (UWB, encoder modules, radar, etc.), the CAS can monitor the precise relative location and speed of the vehicles in a work gang, and determine whether a predetermined separation distance has been violated. The CAS may notify, caution, and/or alarm vehicle operators and/or other railroad personnel (via audible and/or visual indicators) when the separation distances between rail line vehicles becomes less than a specified safe distance, which may indicated that a vehicle is approaching another vehicle and is within a separation distance which may not be safe. The specified safe distance may be programmed by trained service technicians.

Instead of sounding a "hard" alarm through visual and audible alarms when a separation distance is violated, the CAS may utilize a "progressive" warning approach. In general, as the relative spacing between potential alarm events decreases, the collision avoidance system may increase the severity of the warning indication. For example, if a vehicle is on a collision course but has not yet reached a hard threshold, the collision avoidance system may initiate a "soft" alarm/notification initially, such as a short, quiet, visible-only or subdued alarm. The rate, frequency, prominence and/or severity of the alarm may then increase as the vehicles get closer to the hard alarm threshold (indicating a more critical threat condition).

The CAS may adjust its thresholds according to the speed of one or more vehicles. This feature may be referred to as an "adaptive threshold" feature. The adaptive threshold feature may allow for scaling of thresholds of the alarm/notification levels based upon the speed of the immediate vehicle and the relative speed of the immediate vehicle and a vehicle that may collide with the immediate vehicle. For example, when vehicles are traveling to a worksite, at a speed of about 25 miles per hour for example, the expected separation distance may be about 300 to about 500 feet. In a scenario where a vehicle is at a worksite, moving slowly, the expected separation distance may be smaller, for example about 40 to 50 feet. The relative vehicle speed determines how long we have to respond to the issue, and our vehicle speed determines how long the stopping distance will be, which is non-linear.

The CAS may also include an option, mode or switch whereby an operator or a railroad foreman can temporarily deactivate/silence (for example via a user interface) the separation warning/notification features of one or more vehicles. Once silenced, a warning/notification may not repeat until the vehicle separation has again exceeded prescribed safe distances, or, for example, the warning/notification may sound again after a defined period of time if the separation distance violation has not been improved. This silencing feature may allow for periodic, sanctioned violations of prescribed separation distances without alarms, buzzers and the like becoming a nuisance to the operators. An operator may simply acknowledge that the violation of the separation distance was deliberate and the notification may not repeat, until another violation occurs for example. If the violation is not acknowledged, the notification/alarm may repeat periodically.

In some situations, for example, a vehicle operator may be asked by his foreman to temporarily violate the prescribed work separation distances, such as when vehicles come together for a meeting. In this situation, vehicles will slowly approach other vehicles and stop close to other vehicles, so that the work gang may be in a tight group. The operators can then dismount and walk a short distance for a meeting. The collision avoidance system may be designed to accommodate this tight-group situation without needlessly activating alarms, annoying railroad personnel and causing nuisance false alarms, for example by detecting very slow-speed approaches. In some examples, a deactivation may require an operator or a foreman to use a key, code, password or the like to gain authorization to deactivate the warning features. This will prevent an accidental or unauthorized deactivation that may lead to an accident where no warning was sounded. In other examples, the collision avoidance system may automatically reactivate the separation warning features after a certain amount of time, or when the vehicles separate a certain distance (or satisfy a certain distance/speed ratio), so that the system remains in an active tracking and warning mode when the vehicles are working or traveling.

FIG. **15** depicts a flow diagram **1500** that shows exemplary steps in the operation of a CAS, in accordance with one or more embodiments of the present disclosure. Specifically, flow diagram **1500** shows exemplary steps in the operation of a progressive/graduated warning system. In some embodiments, the CAS may utilize a progressive/graduated warning approach that utilizes classes of warnings and/or notifications. The CAS may start by initiating one class of warning, and then escalate to a more severe class of warning if certain

distance/speed measurements violate certain thresholds. Separation distances for progressive/graduated thresholds may be based upon vehicle stopping distance test results as explained elsewhere herein. With regard to the following descriptions, it should be understood that a reference to the CAS or the VMM or the CTU performing a calculation, making a determination, generating a warning/alarm, or other events may actually be performed and/or generated by one or more components within the CAS, VMM and/or CTU.

At step **1502**, the CAS system may determine that a certain distance/speed measurements violate one or more certain preliminary thresholds. At step **1504**, the CAS generates a first class of warning. In one example, the first class of warning may be labeled as a "notification." In certain situations, it may not be dangerous to violate preliminary thresholds (for example, in the case of work vehicles congregating for a meeting), and thus notifications may be designed to allow operators to ignore/silence them. At step **1506**, the CAS may accept input from an operator regarding whether the operator wants to silence the notification. For example, an operator could indicate an "acknowledge" choice via a button, touch screen or the like. At step **1508**, if the operator chooses to silence/acknowledge the notification, this may silence the notification once, at least until a violation that leads to a notification reoccurs. Notifications may be auto ignored in certain situations, for example, if vehicles are moving very slowly. Notifications may be less prominent than other classes of warnings. For example, notifications may display on a screen on the user interface, and may initiate a short sound, without being too annoying or distracting to the operator.

At step **1510**, the CAS system may determine that a certain distance/speed measurements violate certain intermediate thresholds, thresholds that the CAS system has determined present a higher risk of collision. At step **1512**, the CAS may generate a second class of warning. In one example, the second class of warning may be labeled as a "caution" warning. In certain situations, it may not be dangerous to violate these intermediate thresholds, at least momentarily, and thus notifications may be designed to allow operators to ignore/silence them momentarily. At step **1514**, the CAS may accept input from an operator regarding whether the operator wants to silence the caution. At step **1516**, silenced caution warnings may reinitiate quickly if silenced, unless the situation that led to the caution warning is remedied. Caution warnings may be more prominent than notifications but may be less prominent than other more severe classes of warnings. For example, caution warnings may display on a screen on the user interface in a more prominent manner than notifications, such as by blinking, taking up more of the user interface screen, etc. Caution warnings may initiate a louder sound than notifications, but may be designed to avoid being too annoying or distracting to the operator.

At step **1518**, the CAS system may determine that certain distance/speed measurements violate certain critical thresholds, thresholds that the CAS system has determined present a high risk of collision and require immediate correction. At step **1520**, the CAS may generate a third class of warning. In one example, the third class of warning may be labeled as an "alarm" warning. In certain situations, it may be dangerous to violate these critical thresholds, and thus alarms may be designed to prevent operators from ignoring/silencing them. Caution warnings may be designed to get the attention of an operator very quickly, for example by being prominent, loud, frequent, bright and the like. For example, alarms may display on a screen on the user interface in a very prominent manner, such as by blinking, taking up the entire user interface screen, etc. Alarms may initiate a loud sound, and may be designed to be annoying and/or attention getting in order to force the operator to take steps to remedy the situation. Once the operator takes steps to remedy the situation, the warnings may scale back from "alarm" to "caution" to "notification" classification and/or may stop completely.

The progressive/graduated warning system described in relation to FIG. **15** may utilize an "adaptive threshold" feature, whereby one or more thresholds (for example the preliminary, intermediate and critical thresholds) may be modified depending on the speed of one or more vehicles. The adaptive threshold feature may allow for scaling of thresholds of the alarm/notification levels based upon the speed of the immediate vehicle and the relative speed of the immediate vehicle and a vehicle that may collide with the immediate vehicle.

As explained above, the maintenance vehicles often work in work gangs comprising a plurality of vehicles, for example, a group of between four and forty vehicles, and the collision avoidance system is capable of tracking each vehicle that is part of the work gang. In some embodiments of the present technology, however, a single collision avoidance system may be responsible for tracking vehicles that are part of more than one work gang. For example, the collision avoidance system may track group A and group B. A collision avoidance system may be designed to distinguish between multiple work gangs so that the collision avoidance system can determine which vehicles are on the same track. In the event that maintenance vehicles are on two closely-located parallel tracks, it may be difficult for the collision avoidance system to determine which vehicles are on the same track and thus present real collision risks. The CAS may be adapted and/or programmed to handle work group designations/associations in order to limit unwanted detections of other maintenance vehicles on adjacent tracks.

In some embodiments, the VMMs and/or the CTU may include a switch, button, touch screen or the like that may be adapted to allow an operator to select from multiple group associations. All maintenance vehicles on a single track, for example, may set their switch, button, touch screen or the like to select the same group association/setting, and vehicles on a second parallel or other close but separate track may select a different group association/setting. The collision avoidance system may be adapted to ignore (or distinguish) the vehicles on the other tracks (vehicles with an alternate group association/setting), when tracking vehicles within a target group. For example, the work group selections/associations may allow the VMMs/CTU to only notify or alarm an operator when a separation distance violation is detected with other vehicles on the same track/rail. In some embodiments, the CAS may calculate the locations of vehicles using GPS data (or data from other positioning components) and may determine vector locations of such vehicles from which a reasonable calculation of track location can be determined. Other vehicles on an alternate vector could be dismissed by the collision avoidance system when tracking vehicles within a target group.

In some embodiments of the present disclosure, the CAS may include a stopping distance calibration feature and/or may perform a stopping distance calibration method. The stopping distance calibration feature/method may determine how quickly a rail line vehicle can stop under current conditions. For example, during a maintenance project, the work gang generally performs a stopping distance test (for example, at the beginning of each work day) where a vehicle is run at a speed (for example, 25 miles per hour) and then the vehicle's brakes may be engaged and a distance may be

measured from the point where the brakes were engaged to the point where the vehicle comes to a stop. This distance may be referred to as the "stopping distance." If the weather changes and the tracks become wet (or dry), a similar stopping distance test may be performed again, and a new distance measured.

After the stopping distance is measured, the CAS may calculate various safety metrics based on the stopping distance. For example, a safe following distance between vehicles may be adjusted according to the stopping distance. In some embodiments, the collision avoidance system may maintain minimum/default metrics and then adjust the metrics if necessary based on the stopping distance. For example, a minimum/default following distance may be maintained in all situations, and the following distance may be adjusted upwards (extended) if the stopping distance is relatively high. The stopping distance may be used in conjunction with an adaptive threshold feature of a progressive/graduated warning system as described above. For example, one or more safe separation distance thresholds (for example preliminary, intermediate and critical thresholds) may be modified depending on the stopping distance. The adaptive threshold feature may allow for scaling of thresholds of the alarm/notification levels based upon the stopping distance. In one example, one or more alarm thresholds may be made more strict if the stopping distance is too high, resulting in earlier alarms, for example to allow sufficient time to stop under the current conditions.

The CAS may include an automatic/real-time stopping distance calibration feature that, when triggered, may automatically calculate the stopping distance using information from the vehicle mounted module's GPS unit and/or inertial measurement unit (for example an accelerometer or a gyroscope). The new following distance will then be automatically calculated and utilized automatically as the collision avoidance system monitors for proper vehicle separation distance.

The CAS may create and/or maintain one or more logs of events that occur during the operation of the collision avoidance system. The individual VMMs may log information regarding the vehicle on which the vehicle mounted module is mounted. The CTU may also log information regarding the several vehicles in the work gang that the CTU tracks. Saved logs may be downloadable by an authorized person, for example via a cable or a wireless connection to a laptop computer or via an interface card. The amount of log data and time periods of data may be adjustable. Each log entry may be stamped with various types of information, for example the time and duration of the event occurrence, an ID, speed and location of the vehicle and the nature of the event. The collision avoidance system may also log information from a vehicle mounted module's inertial measurement unit (for example an accelerometer or a gyroscope) and/or other shock and impact sensors mounted on a vehicle to record significant impact data related to an incident. All warnings and alarms may be logged as well. Detailed log information may allow railroad personnel to reconstruct the details of an incident. The CAS may allow for logging of vehicle positioning over time using GPS satellite data. This feature allows long term tracking of vehicle location and activities. The CAS may allow for logging of data related to one or more stopping distance calibration tests, for example routine/daily stopping distance calibration tests and/or automatic/real-time stopping distance calibration tests.

In some embodiments of the present disclosure, the collision avoidance system may include the ability to monitor worker presence around machines so that a worker or foreman may be alerted if a worker is standing in an unsafe location. For example, if a worker is standing on the tracks near a vehicle as another vehicle approaches and violates a predetermined separation criteria, the worker and the foreman may be alerted, and perhaps emergency brakes may be activated. The collision avoidance system may monitor the workers by communicating with a communication device that is located on the worker, for example attached to the worker's badge. In one example, the communication device may be an RFID device. In another example, the communication device may be a UWB device, for example a subset of a UWB ranging system that includes components, some that are located on vehicles and some components that are located on workers.

A communication device located on a worker may communicate with one or more components located in one or more vehicle mounted modules, and/or it may communicate with a central tracking unit in a discrete housing. For example, if the communication device communicates with a vehicle mounted module, the vehicle mounted module may determine the orientation and distance of the worker in relation to the vehicle.

In some embodiments of the present disclosure, the collision avoidance system may utilize the concepts described herein to monitor the "vehicle stretch" of a train that includes several cars. As a train starts, stops and changes speed, the "play" in the couplings between the cars may allow the total length of the train to change. For example, if the train starts to slow down, the cars may compact closer to each other as the couplings lock more closely, and the overall length of the train may decrease. The opposite may occur if the train begins to accelerate, for example. Vehicle stretch is an important concept because it may be a measure of efficiency in the vehicle. Stretching and compacting of the vehicles wastes energy, and if the stretch of a vehicle can be monitored, the vehicle may be designed to reduce stretch. The collision avoidance system technologies described herein, for example the UWB technology and other close proximity sensing technologies, may be used to monitor distance between train cars, and then calculations can be made in the collision avoidance system to determine vehicle stretch.

In some embodiments of the present disclosure, the collision avoidance system may monitor, nationwide, locations and speeds of vehicles, equipment and/or workers equipped with collision avoidance system technology. For example, this may allow a central railroad office to monitor several work projects that are underway at several different locations throughout the country.

In some embodiments of the present disclosure, the collision avoidance system may have the ability to interface with rail line crossing technology to control gates while the vehicles work under the surveillance of the collision avoidance system. For example, if the collision avoidance system and the crossing technology were engineered by the same company, group or firm, the interface may be seamless.

Regarding the benefits of the collision avoidance system, in addition to the benefits already described in this disclosure, the following describes further benefits of one or more embodiments of the present technology. It is to be understood that the described benefits are not limitations or requirements, and some embodiments may omit one or more of the described benefits. In some embodiments, a benefit of the collision avoidance system may be that it is implemented as a supplement to existing safety procedures and devices already established for railroad maintenance vehicles and personnel.

Alternatively, the collision avoidance system may be implemented as a primary (and perhaps the sole) collision avoidance and safety system.

Other benefits of the collision avoidance system can be realized when the collision avoidance system is compared to a single-sensor collision avoidance technology. Single sensor technologies do not work well when the work environment includes environmental and physical limitations. In addition to the complexities of tracking vehicles that travel through tunnels, mountains, building and the like, tracking vehicles can also become more complex when the vehicles travel or operate around curves or when the vehicles operate at night or during rain, snow and fog. Curves and other weather conditions create complex sensing environments that render single sensor technologies and/or strictly line-of-sight technologies inadequate. The multi-sensor approach of the collision avoidance system described above, allows for precise tracking of vehicles in these situations.

Another benefit of the collision avoidance system is that railroad companies can use the collision avoidance system to maintain an efficiently running railroad. For example, when an accident occurs in a remote area with single track, it may take days to re-open track after an accident. If the railroad companies can avoid more collisions and keep the tracks open, users of the railroad can make more efficient use of the railroad. A related benefit is that the collision avoidance system can significantly reduce the cost of running a railroad. Not only will the collision avoidance system help the railroad reduce the number of accidents, but the collision avoidance system logging functionality will give the railroads the ability to store data regarding accidents. This information may be used to alleviate rail payouts in the event of worker liability.

Although the present disclosure describes a collision avoidance system that may be applied to a work gang of railroad vehicles, the technology and the concepts described herein may be utilized in other vehicles, applications and/or industries, for example, in industries where spacing, location and status is important. Some industries that may utilize the concepts described herein are (1) the construction industry, (2) the mining industry, (3) the airport industry, specifically on airport tarmacs.

In some alternative implementations of the present disclosure, the function or functions illustrated in the blocks or symbols of a block diagram or flowchart may occur out of the order noted in the figures, and/or may include more or less steps than are shown in the figures. For example in some cases two blocks or symbols shown in succession may be executed substantially concurrently or the blocks may sometimes be executed in the reverse order depending upon the functionality involved.

One or more embodiments of the present disclosure may be realized in hardware, software, or a combination of hardware and software. The present disclosure may be realized in a centralized fashion in at least one machine, computer and/or data processing system; or in a distributed fashion where different elements are spread across several interconnected machines, computers and/or data processing systems. Any kind of machine, computer and/or data processing system or other apparatus adapted for carrying out the methods described herein is suited. A typical combination of hardware and software may be a general-purpose computer system with a computer program that, when being loaded and executed, controls the computer system such that it carries out the methods and techniques described herein.

Some embodiments of the present disclosure may provide a non-transitory machine and/or computer-readable storage and/or media, having stored thereon, a machine code and/or a computer program having at least one code section executable by a machine, computer and/or data processing system, thereby causing the machine, computer and/or data processing system to perform the steps as described herein. One example of a data processing system is a general purpose computer.

Some embodiments of the present disclosure may also be embedded in a computer program product, which comprises all the features enabling the implementation of the methods described herein, and which when loaded in a computer system is able to carry out these methods. Computer program in the present context means any expression, in any language, code or notation, of a set of instructions intended to cause a system having an information processing capability to perform a particular function either directly or after either or both of the following: a) conversion to another language, code or notation; b) reproduction in a different material form.

In the present specification, use of the singular includes the plural except where specifically indicated. In the present specification, any of the functions recited herein may be performed by one or more means for performing such functions. The present systems and methods may include various means, modules, code segments, computer programs and/or software for performing one or more of the steps or actions described in this specification. It is expressly contemplated and disclosed that the present specification provides a written description for claims comprising such means, modules, steps, code segments, computer programs and/or software.

The description of the different advantageous embodiments has been presented for purposes of illustration and description and is not intended to be exhaustive or limited to the embodiments in the form disclosed. Many modifications and variations will be apparent to those of ordinary skill in the art. Further different advantageous embodiments may provide different advantages as compared to other advantageous embodiments. The embodiment or embodiments selected are chosen and described in order to best explain the principles of the embodiments the practical application and to enable others of ordinary skill in the art to understand the disclosure for various embodiments with various modifications as are suited to the particular use contemplated.

The invention claimed is:

1. A collision avoidance system comprising:

a first vehicle mounted module mounted on a first rail vehicle, the first vehicle mounted module comprising:

a first transponder sensor module operable to send and receive data wirelessly, the first transponder sensor module comprising a first radio communication unit and a first antenna;

a first control electronics module comprising a first processor in communication with at least the first transponder sensor module; and

a first user interface module including a first user interface, the first user interface operable to provide rail vehicle information to a vehicle operator and to receive input from the vehicle operator;

a second vehicle mounted module mounted on a second rail vehicle, the second vehicle mounted module comprising:

a second transponder sensor module operable to send and receive data wirelessly, the second transponder sensor module comprising a second radio communication unit and a second antenna;

a second control electronics module comprising a second processor in communication with at least the second transponder sensor module; and

a second user interface module including a second user interface, the second user interface operable to provide rail vehicle information to the vehicle operator and to receive input from the vehicle operator;

wherein:

the first vehicle mounted module is operable to communicate with the second vehicle mounted module mounted on the second rail vehicle; and

the first vehicle mounted module and the second vehicle mounted module are operable to apply a time of flight technique to determine a separation distance between the first rail vehicle and the second rail vehicle.

2. The collision avoidance system of claim **1**, further comprising:

a central tracking unit in communication with the first vehicle mounted module and the second vehicle mounted module, wherein the central tracking unit is operable to track a location of the first vehicle mounted module and a location of the second vehicle mounted module.

3. The collision avoidance system of claim **2**, wherein:

the central tracking unit is distributed among at least the first rail vehicle and the second rail vehicle; and

the first vehicle mounted module comprises a first central tracking unit component.

4. The collision avoidance system of claim **2**, wherein the central tracking unit is located in a discreet housing.

5. The collision avoidance system of claim **1**, wherein the first vehicle mounted module further comprises a first auxiliary transponder sensor module, the first auxiliary transponder sensor module mounted on the first rail vehicle with a first offset with respect to the first transponder sensor module.

6. The collision avoidance system of claim **5**, wherein:

the first auxiliary transponder sensor module comprises a first auxiliary antenna, the first auxiliary antenna being connected to at least one of the first radio communication unit or a first auxiliary radio communication unit; and

the first auxiliary antenna is mounted on the first rail vehicle with a first offset with respect to the first antenna.

7. The collision avoidance system of claim **1**, wherein:

the first vehicle mounted module further comprises a first global positioning system unit, the global positioning system unit operable to receive information from one or more satellites to determine an absolute position of the first rail vehicle; and

the first global positioning system unit is in communication with the first control electronics module.

8. The collision avoidance system of claim **7**, wherein:

the first vehicle mounted module receives information generated by the first global positioning system unit and the first radio communication unit to determine whether one or more vehicle separation criteria are violated; and

the first vehicle mounted module generates a warning signal when one or more vehicle separation criteria are violated.

9. The collision avoidance system of claim **1**, wherein:

the first vehicle mounted module is adapted to execute a progressive warning signal if one or more vehicle separation criteria are violated; and

the progressive warning signal increases in at least one of signal rate, signal frequency, single prominence, signal volume, or signal severity as the violation of the vehicle separation criteria approaches or extends beyond a vehicle separation threshold.

10. The collision avoidance system of claim **1**, wherein the first vehicle mounted module executes an adaptive threshold feature that modifies one or more vehicle separation thresholds based on a speed of the first rail vehicle and a speed of the second rail vehicle.

11. The collision avoidance system of claim **1**, further comprising:

at least a first ground speed detection module operable to determine the speed of the rail vehicle, wherein the first vehicle mounted module communicates with at least the first ground speed detection module.

12. The collision avoidance system of claim **1**, further comprising:

a first inertial measurement unit in communication with at least the first control electronics module, the first inertial measurement unit being operable to detect changes in a speed of the first rail vehicle.

13. The collision avoidance system of claim **12**, wherein the first inertial measurement unit comprises at least one of an accelerometer or a gyroscope.

14. The collision avoidance system of claim **1**, wherein the first radio communication unit is operable to transmit and receive signals with varying center frequencies.

15. The collision avoidance system of claim **1**, wherein;

the first vehicle mounted module is adapted to execute a stopping distance calibration feature to determine a measured stopping distance under existing conditions; and

the measured stopping distance is the distance between a first location of the first rail vehicle when brakes are engaged and a second location where the first rail vehicle comes to a stop under the existing conditions.

16. The collision avoidance system of claim **15**, wherein:

the first vehicle mounted module executes a progressive warning signal if one or more vehicle separation criteria are violated;

the progressive warning signal increases in at least one of signal rate, signal frequency, single prominence, signal volume, or signal severity as the violation of the vehicle separation criteria approaches or extends beyond a vehicle separation threshold; and

the first vehicle mounted module executes an adaptive threshold feature that modifies one or more vehicle separation thresholds based on the measured stopping distance.

17. A rail vehicle module mountable on a first rail vehicle, the module comprising:

a transponder sensor module comprising:

a radio communication unit operable to employ time of flight techniques to detect a separation distance between the first rail vehicle and a second vehicle;

a first wireless communications antenna operable to send and receive data representing the separation distance over the air;

a global positioning system unit operable to receive information from one or more satellites to determine an absolute position of the first rail vehicle;

a control electronics module comprising a processor in communication with the transponder sensor module; and

a user interface module including a user interface operable to provide rail vehicle information to a vehicle operator and to receive input from the vehicle operator,

wherein the rail vehicle module communicates with a second rail vehicle module mountable on the second vehicle to detect a separation distance between the first rail vehicle and the second vehicle.

18. The rail vehicle module mountable on a first rail vehicle of claim **17**, further comprising:

a second wireless communications antenna mounted on the first rail vehicle, wherein:

the second wireless communications antenna is mounted on the first rail vehicle at an offset from the wireless communications antenna; and

the rail vehicle module is operable to receive calibration information related to a length of the rail vehicle, a mounting location of the first wireless communications antenna, and a mounting location of the second wireless communications antenna.

19. The rail vehicle module mountable on a first rail vehicle of claim **17**, wherein:

the rail vehicle module is operable to utilize information generated by the radio communications unit and the global positioning system unit to determine whether one or more vehicle separation criteria are violated, and

the rail vehicle module is further operable to generate a progressive warning signal if one or more vehicle separation criteria are violated; and

the progressive warning signal increases in at least one of signal rate, signal frequency, signal prominence, signal volume, or signal severity as the violation of the vehicle separation criteria approaches or extends beyond a vehicle separation threshold.

20. The rail vehicle module mountable on a first rail vehicle of claim **18**, further comprising a first central tracking unit component, wherein the first central tracking unit component is in communication with a second central tracking unit component mounted on the second vehicle.

* * * * *

EXHIBIT D



Request for Proposal (RFP)
Solicitation No. W-81199

Ultra-Wideband (UWB)-based Train Control System Pilot Program

Issue Date: January 14, 2019
Proposal Due Date: February 11, 2019

Prepared by:

PARSONS

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1 INTRODUCTION, OVERVIEW, AND PROCUREMENT PROCEDURES

New York City Transit (NYCT) is seeking Competitive Proposals from qualified Contractors for the for the provisioning, design, fabrication, construction, and complete testing of an Ultra-Wideband (UWB) -based Train Control System (sometimes referred to herein as "Train Control System") as a pilot program ("Pilot") on NYCT Subways. This work shall include testing of the Wayside, Communications, Vehicle, Solid State Interlocking (SSI), and Automatic Train Supervision (ATS) systems including all hardware and software sub-systems and components. The Contractor shall provide a fully functional UWB-based Train Control System (or equivalent) which meets the functional and operation needs of NYCT. It shall be implied by submitting a Competitive Proposal:

a) That the Proposer has the necessary skills, licenses, personnel, equipment and facilities to support this project, and will comply with all federal, state and local laws and ordinances regarding the performance of this Agreement.

b) That the Proposer has discussed the insurance requirements with its agent and will be able to provide the required insurance.

c) It should be understood that the Proposer is required to submit a firm fixed price for the work as broken down on the Cost Proposal Form with the Competitive Proposal.

The Proposer shall, act as an independent Contractor and not as an agent for NYCT, provide all services, labor, materials, tools, equipment, insurance, transportation, permits, facilities and such other incidental items necessary for the provisioning, design, fabrication, construction, and complete installation of a UWB-based Train Control System (or equivalent), as more fully discussed and defined in the Technical Specification. Said work shall be performed in accordance with the terms of the Contract, but not limited to, the Exhibits so attached, and as the same are further modified or approved in writing by the Authority's Program Manager.

1.1 Scope

The primary objective of the Pilot is to demonstrate a UWB-based Train Control System (or equivalent) operating in Shadow Mode for comparison against a Revenue Service Communications Based Train Control (CBTC) System. For the purposes of this RFP, NYCT is defining a UWB-based Train Control System as a system that utilizes UWB technology for speed and position determination, at a minimum. The output of the Pilot is determining whether the proposed system is safety certifiable for consideration in a revenue deployment on NYCT.

The scope for the Pilot is confined to the provisioning, design, fabrication, construction, and testing of a UWB-based Train Control System (or equivalent). All installations will be performed by NYCT or a third party. The goal for the program is to demonstrate that the UWB-based Train Control System meets the functional requirements as specified and for the NYCT Safety Board to qualify and certify the product for use on NYCT. The Contractor shall also have their qualified Safety Department, or qualified Independent Safety Assessor (ISA), issue a Safety Certification for the system. The anticipated completion date for the program is December 31, 2019. NYCT reserves the right to extend the Shadow Mode data collection phase of the program if desired in 30-day increments for continued data collection / demonstration. At the conclusion of the program, all hardware will be uninstalled by NYCT, or a third party, and returned to the vendor within a year of project completion. The proposed system shall provide Automatic Train Protection (ATP) and Automatic Train Operation (ATO) functions as defined in the Technical Specification. The proposed system shall demonstrate a complete interface with a ATS system and an SSI system; the system interfaces shall be complaint with the following NYCT Interoperability Interface

Specification (I2S) documents:

- I2S ATS-CBTC (except section 4)
- NYCT CBTC SSI Interface – Functional Specification
- NYCT CBTC SSI Interface – Protocol Specification

Both the ATS and Interlocking systems shall either have been previously certified for service in NYCT, or a functional equivalent to an NYCT certified ATS and/or SSI as approved by the Program Manager. The ATS for this scope shall be segregated from the revenue ATS systems and shall be installed in a room designated by NYCT. The SSI shall operate in shadow mode in the Project Limits.

The complete list of project objectives and criteria for which the system will be evaluated is as follows (in no particular order):

- A UWB-based Train Control System which achieves Product Certification by NYCT, achieves Safety Certification by the Contractors Safety Department or an ISA, and meets all the Safety Requirements as defined in this Specification.
- Establishing a baseline, based on predictive calculations and supported by accumulated data, for the performance of the UWB-based Train Control System.
- Establishing a baseline, based on predictive calculations and supported by accumulated data, for the performance of the Data Communications System (DCS).
- Establishing a baseline, based on predictive calculations and supported by accumulated data, for the Reliability, Availability, and Maintainability of the UWB-based Train Control System.
- Establishing a baseline, based on predictive calculations and supported by accumulated data, for the Reliability, Availability, and Maintainability of the Data Communications System.

The deployment area will be concentrated between two territories:

- Jamaica Line (~3.5 Track Miles – 121st Street to Parsons-Archer/Jamaica Center)
- Canarsie Line (~4.1 Track Miles – South of Atlantic Avenue to North of Myrtle Avenue)

The Jamaica Line deployment shall be a complete deployment of the proposed trackside equipment. The proposed vehicle equipment shall be deployed on 48/12/6 R-160 cars/units/trains. The deployment shall include a dedicated ATS for testing and system monitoring. The deployment shall include the proposed SSI subsystem, if proposing an SSI subsystem that has not been certified by NYCT, for shadow mode operations. The proposed system will be allowed to operate in Shadow Mode for data collection. The Contractor shall propose a test program that validates the proposed Train Control System meets the requirements of this RFP.

The Canarsie Line deployment shall be limited to the trackside equipment required for UWB speed and position determination, and DCS equipment as a means to enable remote health monitoring and remote log downloads if applicable. The appropriate vehicle equipment shall also be deployed on 48/12/6 R-143 cars/units/trains. The Canarsie Line will be used for data collection of UWB speed and location data to compare against the existing Siemens CBTC speed and position data.

1.1.1 Term of Contract

The Contract term shall be from Notice of Award until an end date of December 31, 2019 with the Authority's option to extend the contract duration in 30-day increments, up to on or about 180-days.

1.2 Instructions to Vendors

No cost(s) associated with your response shall be charged to NYCT for any reason. This document shall not be construed as an authorization to perform work at NYCT's expense. Any work performed by a vendor will be at the vendor's own discretion and expense. This RFP does not represent a commitment to purchase or obligates NYCT in any manner. Submission of a response constitutes an acknowledgement that the vendor has read and agrees to be bound by such terms.

1.3 Point of Contact

Prospective Proposers are advised that the Authority's point of contact (the "Procurement Manager" or "Procurement Representative") for all matters concerning this RFP is:

Alexander Wanless, Procurement Representative
New York City Transit Authority
2 Broadway, Room C19.41
New York, New York 10004

TEL: (646) 252-6111 FAX: (646) 252-6099

EMAIL: alexander.wanless@nyct.com

1.4 Vendor Questions

Any inquiries regarding this solicitation shall be made in writing. To be considered, inquiries must be addressed to the Procurement Manager. The Authority will entertain oral inquiries at the Pre-Proposal Conference. Proposers are advised that the Authority cannot ensure that it will be able to respond to inquiries received later than five (5) business days prior to the closing date.

The Authority will issue responses to inquiries and any other corrections, amendments, and the like which it deems necessary via e-mail prior to the Closing Date.

1.4.1 Pre-Proposal Conference

In order to assist prospective Proposers in the preparation of their Proposals, prospective Proposers are advised that a **PRE-PROPOSAL CONFERENCE** will be held as follows:

DATE: January 22, 2019 TIME: 2:00 PM EST

MEETING PLACE: 2 Broadway New York, New York 10004 – Conference Room # D2.10

ATTENDANCE WILL BE LIMITED TO FOUR (4) REPRESENTATIVES PER FIRM

Proposers who desire to attend the Pre-Proposal Conference are requested to email the names of the attendees and the company represented to alexander.wanless@nyct.com no later than

noon, two working days prior to the day of the event.

The Pre-Proposal Conference will be informal to the extent that the Authority shall not be bound by any statement(s) made at such Pre-Proposal Conference unless such statement(s) are subsequently issued in an Addendum.

1.4.2 Restrictions on Contact with the Authority Employees

Prospective Proposers are advised that from the date this solicitation is issued until the award of any resultant contract, Proposers' and Prospective Proposers' sole point of contact with the Authority for all matters concerning this solicitation is the designated Procurement Representative (or "Point of Contact"). Proposers or Prospective Proposers are not permitted to contact or communicate with any other Authority employee (including officers, members of the Board, and its Consultants) regarding this solicitation unless they have received prior written consent from the Procurement Representative.

1.5 Submission of Responses

The response shall include the following components:

i. Technical Proposal (inclusive of a Gap Analysis and Preliminary Schedule)
ii. Cost Proposal
iii. Applicable Forms and/or Schedules

Technical Proposal:
The Technical Proposal shall be limited to 100 pages (or 50 double sided) and should define the approach to be taken to satisfy all sections of this document as concisely as possible while providing all information necessary. Respondents may respond to any and/or all sections of this RFP. Proposed solutions do not need to respond to all sections, but **responses should clearly identify sections or criteria their proposed solution does not address in the Gap Analysis**.

Cost Proposal:
The Proposer shall complete and execute the Proposer's Proposal document included in this RFP. The Cost Proposal shall also identify the fixed cost in the event NYCT exercise the option to extend the pilot in 30-day increments, which is not expected to exceed six (6) extensions.
Note: Cost Proposal shall be submitted in a separate, sealed package that must be clearly labeled: COST PROPOSAL.

Applicable forms and/or Schedules
The Proposer shall submit applicable Forms and/or Schedules with the Technical Proposal.

Submissions Instructions and Due Date

Important Notice to Proposers: Due to time constraints, the Authority will not entertain any request for extensions.

The Technical Proposal and applicable Forms and Schedules must be received by **12:00 noon EST on February 11, 2019**, sent by email to the NYCT Point of Contact.

Following the submission of the Technical Proposal by email, the Cost Proposal shall be submitted in a sealed package via courier by **12:00 noon EST on February 19, 2019.** The outer package shall be addressed as follows and include the information shown:

Alexander Wanless
New York City Transit Authority
Bid Reception Desk – First Floor
2 Stone Street (Side Entrance of 2 Broadway)
New York, New York 10004

RFP NUMBER AND TITLE: CONTACT W-81199 Ultra-Wideband (UWB)-based Train Control System Pilot Program – COST PROPOSAL

Hand-carried Proposals may be delivered only between the hours of 9:00 AM and 4:00 PM, Mondays through Fridays, excluding holidays observed by the Authority. Proposers are responsible for informing any commercial delivery services used of all delivery requirements and for assuring that information required on the outer wrapper of material submitted appears on any outer wrapper or envelope used by such service.

Prospective Proposers should be aware that the Authority considers it essential that thorough and precise Proposals are received so that effective evaluation and comparison can take place within the time allowed, and so that any resulting negotiations not become needlessly protracted. Accordingly, the Authority reserves the right not to consider any Proposal or alternate prepared with an apparent disregard therefore such that evaluation and comparison are determined by the Selection Committee to be difficult or impossible. Among the things which the Authority may consider as unacceptable are, blanket reservations, general objections, general offers of enhancement or general statements that the Contract Terms and Conditions, Detailed Description of the Work, Project Specifications and/or the Drawings require modification.

Proposals may be rejected if they show such items as: alterations of form; additions not called for; conditional Proposals; incomplete Proposals; irregularities which make the Proposals incomplete, indefinite, or ambiguous; skewed or illogical Authority-supplied service requirements; improper markings and identifications; obviously unbalanced prices; unacceptable Proposal security requirements; or a signature by other than an authorized person. The Authority, however, reserves the right to waive or allow corrections to informalities or irregularities which it deems minor and which do not otherwise prejudice or impair the evaluation or selection process.

Responses must agree to the statement that the vendor understands the requirements of the RFP and accepts the terms and conditions. An authorized officer must sign the original response. The original response, including all supplementary literature, must be forwarded to the Point of Contact identified in Section 1.3 of this RFP.

If including any confidential or proprietary information in the response, all proprietary or confidential information shall be clearly marked. All responses, once delivered, become the property of NYCT.
Gap Analysis

1.6 Gap Analysis

The Contractor shall submit a Gap Analysis as a part of their Proposal. The Gap Analysis shall contain a list of each section of the Specification for which the Contractor's Train Control System will not comply with. The Gap Analysis shall, at a minimum, contain:

a. A reference to the Specification Section down to the lowest level line item (e.g. 2.1.c).
b. The text as written in the referenced specification.
c. Justification for seeking a waiver for the requirement.

1. Examples of reasons for seeking a waiver can include, but are not limited to:
    i. Performance or Functional requirement is not applicable to the Train Control System
    ii. Deliverable is not applicable to the Contractor's Safety Plan and could hinder the Contractor's ability to complete the project in the documented timelines.
    iii. Functional test requirement for a subsystem or component has already been executed for the subsystem or component in question as a part of another NYCT implementation, in which case test results shall be furnished.

Along with identifying the Gaps between the proposed Train Control System or the execution of the work and the Specification, the Proposer shall also include a list of assumptions being made for NYCT scope that has not been identified in this Specification.

It should be noted that identifying gaps in the Gap Analysis does not automatically waive the requirement. The Gap Analysis will be discussed with NYCT and the Contractor during the negotiations. Once issued Notice to Proceed, the Gap Analysis will be formally transmitted as a part of the project documentation for review and approval by the NYCT Program Manager.

1.7 On-Going Responsibility

Proposers are reminded that establishing a proposer's responsibility is an on-going requirement for award and that award of Authority contracts may only be made to "responsible" proposers. **Proposers should be aware that the following criteria are considered threshold criteria that must be met.** Proposers found unqualified based upon evaluation of the following criteria will be eliminated from further consideration:

- **Record regarding integrity and business ethics;**
- **Record regarding defaults, debarments, suspensions and non-responsibility determinations;**
- **Safety Record;**

1.7.1 Proposal Evaluation Criteria

Proposers will be evaluated by the Selection Committee utilizing Criterion 1, Detailed Technical Proposal and Approach as well as Other Technical Matters, Criterion 2, Overall Project Cost and Criterion 3, Other Relevant Matters. Criteria are listed in their relevant order of importance. Those Proposers identified to be within the competitive range with respect to Criteria 1, 2 and 3, may then be invited to participate in negotiations, in most cases resulting in a request for Best and Final Offers. To the extent that competing proposals are otherwise determined to be substantially equal with regard to Criterion 1 and Criterion 3, the importance of Criterion 2 shall increase. To ensure proper consideration, Proposers shall furnish proposals with supporting Documentation to be evaluated on the following criteria:

Criterion I - Technical and Qualification Considerations as well as Other Relevant Technical Matters:

- Proposer's overall Technical and Design approach toward achieving Safety Certification of the proposed UWB-based Train Control System (or equivalent), including but not limited to, having the proposed Train Control System have completed the Shadow Mode data gathering phase on the Project Lines by 12/31/2019 to complete the safety case, schedule monitoring, and delay mitigation plans;
- The Proposer's Gap Analysis and timeline to achieve the functional requirements of the specification.
- Proposer's project schedule reflecting completion of critical milestones on time and submission of deliverables on time. Proposed schedule will be evaluated for realistic phasing and production plans as well as coordination with NYCT. Proposer must also demonstrate its approach toward schedule monitoring and delay mitigation;
- Previous experience, qualifications, depth of resources and record of timely performance of the Proposer, either as a single entity, a joint venture or a major subcontractor on similar or comparable projects;
- Proposer's prior experience and success of the Project team in engineering advanced technology rail projects demonstrating a comprehensive understanding of vehicle modification design and installation processes. Proposer must also demonstrate that they have a clear understanding of the NYCT CBTC System Architecture.

Other Relevant Technical Matters including, but not limited to:

- Pertinent items not expressly covered above and issues raised after release of the RFP or during negotiations, if any;
- Quality and thoroughness of the Technical Proposal and Oral Presentations, if any, including description of work schedule;

Criterion II - Overall Project Cost including, but not limited to:

- Net cost savings and/or additions resulting from proposed changes to Terms and Conditions, as well as from innovations with respect to the Project Schedule and Phasing; and cost implications of proposed use of NYCT or 3rd party services, facilities and materials associated with the installation of wayside cabling and equipment. In the case of alternate Proposals deemed acceptable by the Selection Committee offering reductions to the time required for satisfaction of all deliverables, the cost implications and value to the Authority of such schedule improvements will be taken into account under this criterion;
- In evaluating Overall Project Cost, the Authority may consider whether and to what extent a Proposal, a system, or other matter being offered contains realistic pricing.

Criterion III – Other Relevant Matters

- Willingness to agree to the Authority's Terms and Conditions or to negotiate same in timeframe consistent with the Authority's needs;
- Overall adherence to the requirements of the RFP in terms of quality and completeness.

In making the determination as to which proposal offers the best value to the Authority, the Authority will review all factors that contribute to the total cost of the proposal, including costs which may be incurred by the Authority as a result of the proposal even if those costs are external to the proposed price.

In making the determination as to which proposal is most advantageous and offers the best value to the Authority, the Authority will review the proposals in relation to all evaluation criteria.

Accordingly, neither the Proposer with the highest technical ranking, nor the Proposer with the lowest priced proposal, will necessarily receive the award, which will be determined by assessment of the best value to the Authority based upon all the evaluation criteria.

Although price is not the most important evaluation criterion for this solicitation, price may become the controlling factor when competing proposals are otherwise determined to be substantially equal.

1.7.2 Qualification of Proposers

Each Proposer submitting a Proposal to the Authority shall provide, with the Proposal, a Qualification Statement indicating the following information:

(a) A list of contracts satisfactorily and successfully carried to completion on work of this or a similar nature (e.g. Train Control System), giving the name of the project, owner, architect, contract amount, date of completion, and percentage of cost of the work performed with Proposer's own forces within the past ten (10) years.
(b) A list of train control contracts which the Proposer has under way at the present time, giving the name of the project, owner, architect, contract amount, percent complete, and scheduled completion date.
(c) Whether the Proposer has ever failed to complete any work awarded to it, and whether any officer or partner of the Proposer has ever been an officer or partner of another organization when it failed to complete a construction contract; if so, attach an explanation.
(d) A notarized certificate of the Proposer's ability to perform the contract in a satisfactory manner in the time limit specified.

1.8 Qualifications, Certifications, and Forms Instructions

1.8.1 Schedule A – Insurance

Proposers shall provide a letter from an acceptable insurance company or companies, which satisfactorily establishes to the Authority that such insurance company or companies will issue the necessary insurance policies, or evidence of existing policies, as required in Schedule A, Insurance Requirements. Proposers failing to supply documentation as to their ability to obtain the required insurance will not be considered for this Project.

The Contractor shall procure, at its sole cost and expense, and shall maintain in force at all times until final acceptance by the Authority, policies of insurance as set forth in **SCHEDULE A, INSURANCE REQUIREMENTS**.

Proposers are urged to carefully review the Insurance requirements and to obtain accurate pricing information well in advance of the Closing Date and to make all preparatory arrangements necessary to procure the insurance on a timely basis. Proposers are also reminded that the Authority will not accept policies written on a "claims made" basis, except for Professional Liability.

1.8.2 Schedule J – Responsibility Questionnaire

Complete, sign and include the entire Schedule J - Responsibility Questionnaire contained in attached thereto. If the Proposer consists of a joint venture, a Responsibility Questionnaire by the joint venture shall be completed and submitted. In addition, each member of the joint venture shall complete and submit a separate Responsibility Questionnaire.

NOTE: A complete and signed Schedule J must also be submitted for all known proposed Subcontractors and Suppliers, or Subcontractors or Sub-suppliers thereof, whose contracts are expected to equal or exceed $1,000,000.

1.8.3 Schedule W – Compliance with NYS State Financial Law Sections 139-J and 136-K ("Lobbying Law")

Complete and return the Disclosure of Prior Non-Responsibility Determinations and complete, sign and return the Bidder's/Proposer's Affirmation and Certification. In addition, each member of a Joint Venture (if applicable) shall complete and submit a separate Schedule W.

1.9 Reservations

The Authority reserves the right to:

i. Reject all Proposals submitted;
ii. Accept any Proposal or Alternate Proposal as submitted without oral presentations or negotiations;
iii. Require revisions to, corrections of, or other changes to any Proposal submitted as a condition to its being given any further consideration;
iv. Reject, without entertaining revisions or conducting negotiations, a Proposal with major substantive deficiencies;
v. Select for negotiations only the overall best Proposal or Alternate Proposal submitted, as determined by the Authority;
vi. Negotiate with those Proposers whose acceptable Proposals or Alternate Proposals fall within a competitive range;
vii. Negotiate with one or more Proposers in any manner it deems fit, (such negotiations may be concurrent or sequential as the Authority determines);
viii. Following the conclusion of all negotiations, issue a revised RFP or portion thereof and solicit "Best and Final Offers", or "BAFOs"; or solicit BAFOs offers utilizing another appropriate procedure;
ix. Thereafter reopen negotiations after receipt of BAFOs, if it is in the interest of the Authority to do so; and/or
x. Accept improvements to, enhancements of or other revisions to any Proposal or Alternate Proposal at any time if it deems such to be in its best interest.

At any time during the RFP process, should the Authority determine that a Proposer, including its proposed subcontractors, is found not acceptable in any area, the Authority may eliminate such Proposer from any further consideration or evaluation.

No Proposer shall have any rights against the Authority arising at any stage of the solicitation based upon any negotiations that take place, or because the Authority does not select a Proposer for negotiations or if the Authority, for any reason, determines not to make an award of the Contract.

The Authority also reserves the right to (a) incorporate into the Contract Documents the successful Proposer's Proposal or portions thereof, as accepted by the Authority, (b) revise the solicitation documents in accordance with the completed negotiations with the successful Proposer and require such Proposer to execute the resultant Contract Documents or develop new Contract Documents reflecting the completed negotiations with the successful Proposer and require such Proposer to execute same, and (c) take such other action as may be in the best interests of the Authority consistent with the law.

1.10 Withdrawal of Proposals

Proposers may withdraw their Proposals from consideration at any time prior to award of the Contract. Proposers who decide to withdraw their Proposals are asked to notify the Authority in writing of such withdrawal directed to the Procurement Representative in order to avoid unnecessary expenditure of resources in reviewing such Proposals. The Authority shall have the right to discard or retain for its records all copies of Proposals withdrawn from consideration.

1.11 Incurring Costs

The Authority shall not be held liable for any pre-Proposal or pre-contract activity or costs incurred by Proposers in the preparation of their Proposals or during any negotiations of Proposals or proposed contracts or for any work performed in connection therewith.

1.12 Joint Proposers

The Authority will consider for award of the contract to a Proposer consisting of two or more persons or entities submitting a Proposal jointly, whether denominated a "joint venture," "consortium" or otherwise (collectively referred to as a "Joint Proposer"), which is otherwise determined by the Authority to have submitted an acceptable Proposal and to be a responsible Joint Proposer, provided that the following requirements with respect to such Joint Proposer shall have been met and notwithstanding any contradictory or inconsistent terms or provisions contained in any agreement between or among the members forming the Joint Proposer, compliance with which requirements will be represented and certified to in the Joint Proposer's Proposal submission documents:

i) The Joint Proposer has as a stated purpose to perform and complete Authority Contract No. W-81199;
ii) Any required payment and/or performance bonds covering the Contract are obtained in the name of the Joint Proposer as principal and executed by an authorized representative of the Joint Proposer, as well as by each member thereof, with appropriate powers of attorney;
iii) The Joint Proposer members are jointly and severally responsible and liable to the Authority for performance of the entire scope of work and all Contractor obligations of the Contract;
iv) The Joint Proposer itself indemnifies, and members of the Joint Proposer, jointly and severally, indemnify, the Authority with respect to personal injury and property damage claims and liabilities with respect to patent, copyright and other intellectual property infringements, all as more particularly provided for in the Contract;
v) The Joint Proposer, itself, and/or all members of the Joint Proposer designate a single project manager, with overall responsibility for the entire project, to be the primary point of contact between the Joint Proposer/Joint Proposer members and the Authority (upon the consent of all members, a member of the Joint Proposer may be designated to deal separately with the Authority Engineer as to separate aspects of the work, provided overall responsibility remains with the designated Joint Proposer project manager); and
vi) All subcontractors/suppliers are retained in the name of the Joint Proposer, which shall direct the work thereof and release payments thereto.

1.13 Proposer's Responsibility

(i) In order to qualify as a Contractor satisfactory to the Authority, a Proposer must demonstrate that it is in all respects a responsible party. In addition to the other requirements herein provided, a Proposer must be prepared to prove to the satisfaction of the Authority that it has the integrity, skill, experience, facilities and financial resources and stability to successfully and faithfully perform the Contract in accordance with the Contract Documents. Among the requisites for qualification that may be required by the Authority, the Proposer must show that its other commitments and contractual obligations will not impair or adversely impact its performance of this Contract.

(ii) A Proposer in arrears in the payment of any amount due to the Authority or the Contracting Party or any of their subsidiaries will be required to pay said amount in full in order to be considered a responsible Proposer, unless and to the extent that the Authority, upon satisfactory explanation made by the Proposer, excuses it from the payment thereof, at this time or permits further deferment of payment.

(iii) The Proposer is required to be adequately financed to pay promptly for all labor and materials as such obligations become due and to avoid the necessity for assignment of any monies payable. The Proposer must be prepared to submit a sworn statement, in the form furnished by the Authority (See Schedule J- Responsibility Questionnaire), of the Proposer's financial condition.

(iv) The Proposer's submission must also set forth and document with evidence satisfactory to the Authority that the Proposer is able to procure insurance policies required to be obtained by the successful Proposer prior to any award resulting from this RFP. Such satisfactory evidence would include Certificates of Insurance, in acceptable form as described in Schedule A, prior to award.

(v) The Authority approval of all subcontractor(s) and supplier(s) is required. In order to assist the Authority in its evaluation of qualifications of subcontractor(s) and supplier(s) the Proposer shall submit with its Proposal a Statement of Qualification of Subcontractor (indicating the type of labor or supplies) for each proposed subcontractor(s) and supplier(s) supplying labor or labor and materials, with a value of less than $1,000,000. A complete Schedule J shall be provided for each proposed subcontractor(s) and supplier(s) supplying labor or labor and materials, with a value equal to or exceeding $1,000,000.

(vi) The Proposer shall state in writing to the Authority the name and place of business of each such proposed subcontractor or supplier, the portion of the work which such subcontractor is to do, or the equipment/materials which such supplier is to furnish and such other information demonstrating that the proposed subcontractor or supplier has the necessary skill, facilities, integrity, experience and financial resources to perform the work or supply equipment and materials in a satisfactory manner and in accordance with the Contract. In addition to other requirements set forth in this RFP, to be considered skilled and experienced, the proposed subcontractor or supplier must show that it has satisfactorily performed work, or supplied equipment and materials, of the same general type that it is proposing to perform for the Proposer under this Contract. The Authority requires such proposed subcontractor or supplier to submit proof of financial or other qualification to do the Work.

(vii) The Authority will notify the Proposer within a reasonable time whether use of the proposed subcontractor or supplier has been approved. Where use of a proposed subcontractor or supplier has not been approved, the Proposer may propose another subcontractor or supplier, or propose to perform such work itself. The Authority's disapproval of a subcontractor or supplier after contract award shall not be grounds for an adjustment in the Total Contract Price.

1.14 Statement of Qualification of Subcontractor

Complete, sign and submit the Statement of Qualification of Subcontractor form enclosed with this RFP. One copy shall be completed for all Subcontractor(s) and Supplier(s) supplying labor or labor and materials with a value less than $1,000,000.

1.15 Metropolitan Transportation Authority Vendor Code of Ethics

Proposer's Certification of Compliance with the MTA Vendor Code of Ethics (the "Code"): All Vendors, as defined by the Code, involved in this Solicitation and during the performance of any resultant contract are subject to the Code, which is available for Proposer's immediate review in the solicitation package (See ATTACHMENTS) and on the MTA website at http://web.mta.info/mta/compliance/pdf/Vendor_Code_of_Ethics.pdf. Accordingly, all Proposers must certify compliance with the Code in the "Proposer's Proposal" section, which includes the Certification of Compliance with the MTA Vendor Code of Ethics.

1.16 Buy America Steel Provision

This Contract is subject to Section 2603-a of the Public Authorities Law (Ch. 441, Laws of 1983) entitled "Letting of Certain Contracts Involving Steel Products". This provision, hereinafter called "Buy America Steel Provision", requires the board of each public authority to implement such law and to determine whether application of the provisions thereof would result in unreasonable costs or that steel products or steel components cannot be produced or made in the United States in sufficient and reasonably available quantities or of satisfactory quality or design. The Authority has adopted the following guidelines with respect to the implementation of such provision which will be applicable to this Contract:
GUIDELINES

1. Definition. Steel component means a product rolled, formed, shaped, drawn, extruded, forged, cast, fabricated or otherwise similarly processed or processed by a combination of two or more operations, from steel.
2. Supplies, material, or equipment shall be deemed to be made of, fabricated from or contain a steel component or steel components if the cost of the steel component or components exceeds fifty percent (50%) of the cost of the material content of the supplies, material or equipment. Such supplies, materials and equipment shall be referred to herein as "steel products".
3. A steel component, including structural steel and reinforcing steel, shall be deemed to have been produced or made in whole or in substantial part in the United States, its territories or possessions if the cost of the portion thereof, including both materials and possessions, exceeds fifty percent (50%) of the cost of the component. Such steel components shall be referred to herein as "domestic steel components".
4. Procedure.
    (a) Proposers shall be permitted and encouraged to utilize domestic steel and to submit bids for steel products containing domestic steel components. They may also submit bids for steel products not domestically produced.
    (b) Bids for steel products estimated to cost in excess of $50,000 and for contracts for the construction, reconstruction, alteration, repair, or maintenance of a facility estimated to be in excess of $100,000 and utilizing structural or reinforcing steel or major steel products shall state therein the amount of the Proposal which represents the cost of steel components, stated separately for domestic steel components and foreign steel components.
    (c) In a competitively bid Contract, the cost of a domestic steel component shall be

deemed reasonable if the lowest responsive and responsible Proposer has offered all or substantially all domestic steel components.

(d) In a competitively bid Contract, if a bid including domestic steel components is responsible and responsive, but not lowest, a credit shall be allowed in the amount of six percent (6%) of the cost of the foreign steel components contained in the lowest responsible and responsive bid, and the Contract shall be awarded to the lowest responsible and responsive Proposer offering domestic steel components if the subtraction of such credit from the amount of its bid makes such bid the lowest responsible and responsive bid.

(e) The procedure provided in subparagraph (4) above, shall not be used if its application would result in the award of a Contract utilizing domestic steel components of less total cost than if such procedure were not followed.

(f) If no Proposal is received which includes steel components produced or made in the United States, a conclusive presumption shall be made that such steel component or components are not available domestically.

(g) If a negotiation is undertaken with one party only, evidence must be submitted that the cost of foreign steel components is at least six percent (6%) less than the cost of domestic steel components if foreign steel components are offered.

5. A determination that steel products or steel components are not produced or made in the United States of satisfactory quality or design shall be made by the Board of the Authority on a case by case basis.
6. Emergency Procurements. In an emergency, steel products shall be deemed not to be produced or made in the United States in sufficient and reasonably available quantities or of satisfactory quality or design if, after reasonable inquiry, the Authority determines that such steel products cannot be obtained within the six percent (6%) cost differential referred to in subparagraph (d) within the time required by the emergency.
7. Motor vehicles and automobile equipment assembled in Canada in conformity with the United States-Canadian trade agreements known as the “Automotive Products Trade Act of 1965” shall not be deemed of foreign origin.

POST-AWARD DETERMINATION

(a) If in submitting its Proposal, the Contractor certified that it would supply domestic steel products or components but finds out after Contract award that the steel products or components cannot be produced or manufactured in the United States but may be obtained using foreign steel, the Contractor will make a request in writing, to the Authority’s Chief Officer, Procurement with a copy to the Engineer, that the Authority make a determination that the steel product(s) or steel component(s) are not produced or made in the United States of satisfactory quality or design. The Contractor’s request will contain the following information:

(1) The Authority’s Contract or purchase order number, and the Authority’s part or specification number;

(2) An explanation why the Contractor was unable to ascertain prior to award that it could not obtain the steel product(s) or component(s) of satisfactory quality or design produced or made in the United States;

(3) For both the domestic steel supplier or manufacturer and the proposed foreign steel supplier or manufacturer the following:

i) Supplier or manufacturer’s name;
ii) Supplier or manufacturer’s part number;
iii) Cost (including associated costs for the item such as shipping); and
iv) Delivery schedule or time of availability;

(4) A written statement from the domestic steel supplier or manufacturer that

it is no longer manufacturing or producing the specified item(s), or a sworn statement from the Contractor that the domestic steel supplier or manufacturer is no longer in business;

(5) An explanation as to what efforts the Contractor has made to obtain a substitute product manufactured or produced from domestic steel that meets or exceeds the Authority's requirements; and

(6) Any additional information that the Authority may request in support of the Contractor's request for a determination.

(b) If the Authority in making the award to the Contractor allowed the Contractor a six percent (6%) credit against other Proposer(s) offering foreign steel components and the Authority makes a determination that an exception to the Buy America Steel Provisions applies, then the Authority shall be entitled to a price adjustment reducing the total amount payable to the Contractor. The price adjustment shall be derived by taking the difference of the dollar value (if any) of the foreign steel components proposed by the Contractor in its Proposal and the dollar value of foreign steel components proposed by the Proposer against which the credit was taken; times (X) the sum of the six percent (6%) credit plus (+) a four percent (4%) administrative fee; times (X) a fraction of which the numerator is the dollar value of the domestic steel components proposed by the Contractor for the exception; the denominator of which is the dollar value of the domestic steel components proposed by the Contractor in its Proposal.

Example:

$ value of foreign steel components proposed by the Proposer against which the credit was taken
 	
less (-)
 	
$ value of foreign steel components proposed by the Contractor in its Proposal (if any)
	(6% credit
	X + X
	4% admin fee)
		$ value of domestic steel components proposed by the Contractor for an exception
		
		divided by (÷)
		
		$ value of domestic steel components proposed by the Contractor in its Proposal

(c) If the Authority determines that an exception to the Buy America Steel Provisions applies, a modification to this Contract will be executed allowing the use of foreign steel products or foreign steel components.

2 SYSTEMS INTEGRATION

2.1 General Requirements

a. This section specifies the systems integration requirements for furnishing the complete, integrated UWB-based Train Control System for the Project Line.
b. The Train Control System for the scope of this Contract shall be designed, furnished, tested and placed in service by a qualified supplier.
c. If the Contractor provides justification, NYCT may accept waiving some requirements in this section. If the Contractor's system does not comply with all specifications of this section, the Contractor shall identify each line item that cannot be satisfied by the Train Control System per the Gap Analysis (see Section 1.6). **Unless a written waiver is provided to the Contractor by the NYCT Program Manager, it shall not be assumed that any requirements of this section are waived**.

2.2 Scope

a. The Contractor shall perform Systems Integration activities and meet all the requirements specified in this section for the Scope of Work.
b. The activities to achieve the Joint Systems Integration for the complete interoperable Train Control System will be coordinated and facilitated by NYCT. All non-proprietary communication/ correspondence/deliverables/inquires required to perform the Joint System Integration activities shall be exchanged through the formal project communication channels through the Engineer.
c. The Contractor shall be responsible for integrating the following subsystems / activities as one functioning system that meets the requirements of this contract for the Project Line:
    1. All subsystems of the Train Control System furnished under scope of this Contract.
    2. Existing AWS/SSI interfaces furnished by others for the Project Line(s).
    3. New SSI and interfaces furnished under scope of this Contract.
    4. DCS Network subsystem and interfaces furnished under scope of this Contract.
    5. DCS Wayside Radio subsystem.
    6. ATS subsystem for testing and monitoring of this Project Line.
    7. Carborne subsystem furnished under this Contract shall have no impact on R-143 and R-160 Car fleet already equipped with Carborne CBTC equipment by others for operating on the Canarsie Project Line.
    8. Defining transition to control in the Jamaica Line (if system is safety certified).
    9. If integrating a third party UWB and/or DCS solution with an existing Train Control System, the Contractor shall supply an Interface Control Document (ICD) between the systems for review and approval by NYCT. In the event that an ICD is required, the ICD(s) shall become property of NYCT.
d. The Contractor shall integrate the Train Control System furnished under this Contract with an I2S compliant (simulated) ATS subsystem. The following distribution of scope of work shall be taken into consideration for implementing the system integration activities for the control and operation of service for the Project Line:
    1. All ATS hardware shall be furnished and installed by the Contractor at a location on NYCT Property as directed by the Engineer. The location will be identified once the Contractor's Test System Architecture, Hardware, and Software have been approved.
    2. Remote workstations shall be furnished, installed, tested, updated with Project Line specific ATS GUI, and database. Remote workstations shall be furnished and installed by the Contractor at a location on NYCT Property as directed by the

Engineer. The location will be identified once the Contractor's Test System Architecture, Hardware, and Software have been approved.

3. All ATS functional software and interfaces as specified by the I2S will be furnished and tested.
4. The Contractor shall be responsible for all ATS database definition, generation, verification, and validation which shall be provided under this Contract. If requested by the Contractor and approved by the Engineer, the Contractor will be permitted to utilize the expansion and scalability tools and processes as provided to the Contractor from the QBL CBTC project.

e. The Contractor shall integrate the Train Control System furnished under this Contract with the DCS subsystem. The following distribution of scope of work shall be taken into consideration for implementing the system integration activities for integrating the DCS for the Project Line(s):
    1. Design, furnish, install, test, and put into service the DCS wayside network on the entire Jamaica and Canarsie Project Line territories.
    2. Perform all necessary surveys to verify the DCS radio network track layout.
    3. Wire, assemble, furnish and install Wayside Radio enclosures and antennas.
    4. Install, test, and place into service the DCS radio network for the Project Line(s).
    5. Install, test, and put into service the trackside UWB radios as applicable to the entire Project Line(s).
    6. Produce test procedures and perform the tests required to verify radio coverage.
f. The Contractor shall integrate the Train Control System database(s) for the Project Line(s) under this Contract to achieve interoperability between all technologies and products for the Train Control System. The following distribution of scope of work shall be taken into consideration for implementing the system integration activities for integrating the databases for the Project Line(s):
    1. All system database definition, generation, verification and validation and certification shall be documented and furnished.
    2. All derived databases for sub systems (Wayside, Carborne, and ATS) shall be generated, verified, validated, certified, installed, and tested.
g. The Contractor shall survey the Project Lines and verify that any available existing power is sufficient for the Wayside / DCS equipment being furnished in this Program.
    1. If the Contractor determines that the existing Power is not sufficient, NYCT will provide access to existing 120v / 60hz power from a Station. If any additional power is required for the wayside equipment, the Contractor shall design and furnish all materials, filtering, and conditioning equipment for the new Wayside power.
    2. If additional power is required, NYCT or a third party will conduct the installation.

2.2.1 Codes and Standards

a. The systems integration plans and procedures shall be based upon an approach that is defined in IEEE 1220: IEEE Standard for Application and Management of the Systems Engineering Process, or approved equivalent.

2.2.2 Definitions

a. Definitions shall be in accordance with IEEE 100, "The Authoritative Dictionary of IEEE Standards Terms and Definitions".
b. UWB-based Train Control System is defined as a Train Control System which offers some form of ATO and ATP while utilizing UWB as the primary source for Speed and Position determination, at a minimum.

2.2.3 Submittals

a. The Contractor shall submit a Contract Data Requirements List (CDRL) document within 60 days after the Notice of Award. The CDRL shall list all contract deliverables required for this Pilot including the submittal dates, review times and manufacturing dates as applicable.
b. The Contractor shall furnish the following submittals:
    1. Contract Data Requirements List.
    2. Systems Integration Management Plan.
    3. Configuration Management Plan.
    4. System database definition.
    5. Subsystem databases derived from the System database (if applicable).
    6. Requirements Traceability Baseline and periodic (as determined by the Engineer) summary reports on requirements traceability and management.
    7. Periodic (as determined by the Engineer) reports on systems integration progress and concerns, together with problem resolution recommendations.
    8. Verification and Validation compliance reports as defined in the Systems Integration Management Plan.
    9. UWB to Carborne Controller ICD (if required)
    10. DCS to Carborne Controller ICD (if required)
    11. Wayside (UWB) Preliminary Design Review (PDR), which should at a minimum include:
        i. Installation Plan
        ii. Power Calculations
        iii. Cabling Plan
        iv. FCC Certifications
        v. IP Scheme
        vi. Wayside Equipment Architecture
        vii. Wayside Equipment Touchpoints
        viii. Bill of Materials
    12. Wayside Final Design Review (FDR), which should finalize the design based on comments received in PDR.
    13. Vehicle PDR, which should at a minimum include:
        i. Installation Plan
        ii. Power Calculations
        iii. Cabling Plan
        iv. FCC Certifications
        v. IP Scheme
        vi. Carborne Equipment Architecture
        vii. Carborne Equipment Touchpoints
        viii. Bill of Materials
        ix. Define the Human to Machine Interface (HMI)
    14. Vehicle FDR, which should finalize the design based on comments received in PDR.

2.3 Systems Integration Requirements

2.3.1 Interoperability

a. The Train Control System shall be designed to interface with the current I2S ATS-CBTC specification (except section 4), NYCT CBTC SSI Interface – Functional Specification, and NYCT CBTC SSI Interface – Protocol Specification. The Contractor shall propose any revisions and/or clarifications if necessary to the relevant I2S specifications referenced in Section 13.2. NYCT will approve the final revisions. All approved revisions of the I2S shall be agreed and implemented. NYCT will coordinate with other qualified CBTC Suppliers. The scope of work shall include:
    1. Project line specific functions if identified as being necessary for future NYCT CBTC applications.
    2. Updates to reflect the requirement for common form, fit and functional interfaces of CBTC carborne electronic equipment, if applicable.
    3. Any required updates to facilitate effective configuration control.
b. The Contractor shall support NYCT to keep I2S current, complete and correct throughout the Project.
c. The Contractor shall provide timely formal notification of any proposed changes to the I2S to the Engineer.
d. If the Contractor's Test Plan requires the use of NYCT's Integrated Test Facility (ITF), the Contractor shall modify/update all hardware or software of the Contractor and NYCT ITF equipment under test as required for the performance of the Test Plan.
e. The Contractor shall provide all test scripts to perform a complete integrated testing of hardware and software. Scripts shall be added/updated as necessary to test the Project Line track configuration and to utilize Project Line database.

2.3.2 System Database

a. The Contractor shall submit the tools required to generate the System database and the track layout.
b. The Contractor shall perform the surveys required for generating the system database for the Project Line(s) including any ZC overlap/handover areas, if applicable.
c. The Contractor shall submit the database tool input data and the certified System database for the Project Line(s) for review by the Engineer.
d. The Contractor shall manage and coordinate all the geographic and physical track databases that have systems integration, interoperability, and external interface implications through their approved Configuration management plan and submit for review, approval and over all coordination by the Engineer. This shall include the coordination of all line survey activities.
    1. The Contractor shall follow the approved procedure for performing the surveys utilizing the survey process and tools.
    2. The system database structure itself, as well as the tools, user interface and logic / rules for developing the system database, shall be approved by NYCT.
    3. The Contractor shall collect all current NYCT data to form the System database for the Project Line(s) alignment and shall perform a field survey and verify by measurements all data.
    4. The Contractor shall identify the sieving track circuit Insulated Joints (IJs) or Axle Counters for the entire Project line(s) in the System Database and the Track layout.
    5. The Contractor shall ensure that all stopping point locations and car markers at each platform for both directions are surveyed and confirmed by NYCT prior to inclusion into the database.

6. The Contractor shall include all cutting & combining locations for the Project Line into the database after confirmation from NYCT.
7. The location and magnitude of grades, civil speed limits, location and degree of curves will be provided by NYCT.

e. Routine track and infrastructure maintenance activities on the deployment territories will, from time-to-time, result in unavoidable changes to the locations of trackside equipment of the Train Control System that will fall outside of permissible maintenance tolerance limits, requiring updates to the corresponding System database(s). The databases shall be modular to facilitate such field upgrades without affecting the Train Control System's application software. Typical changes are listed below, together with their anticipated relative frequency of occurrence, based on NYCT's past history. Any changes to the database by the Contractor shall be notified to NYCT for review prior to design and implementation.
    1. Very Common (of the order of 2 to 3 changes a year):
        i. Relocation of Insulated Joints (Cut Section, Automatic, Approach and Home Signal).
        ii. Relocation of Signals.
        iii. Relocation of Stopping Point at a Station.
        iv. Signal Conversion (i.e. Train Order, 'GT' or 'ST' Signal).
        v. Control Line Modifications for AWS. Signals.
        vi. Speed Control Modifications on Curves, Straight Track or Over Switches.
    2. Less Often (of the order of 1 change every 1 or 2 years):
        i. Removal of Insulated Joints.
        ii. Removal of Signals.
        iii. Removal/Relocation of Switches.
        iv. Installation of Hand Throw Switches (in Yards only) or de-railers.
        v. Relocation of any AWS equipment.
        vi. Relocating the face of Bumper at terminals, Yards and Lay-up tracks.
        vii. Closure of a station.
        viii. Transforming an intermediate station into a terminal for an extended period.
    3. Least often (of the order on one change every 5 - 10 years).
        i. Addition of Insulated Joints and Track Circuits.
        ii. Addition of "Blind Stops".
        iii. Addition of Signals.
        iv. Addition of Switches.
        v. Track Reconfigurations: Removals, Extensions or Additions.
        vi. Permanently Disabling Exits.
        vii. Enabling New Exits.
        viii. Modify Approach Locking Limits.
        ix. Modify Conditional Locking of Switches.
        x. Route Request Modifications in areas designed for Automatic Operation.

f. Database changes associated with the above shall be implemented with the minimum impact to service operations.

g. The Contractor shall submit all database updates for the approval of the Engineer.

2.3.3 Configuration Management

a. The Contractor shall prepare a Configuration Management Plan (can be included as a part of the Systems Integration Management Plan or can be a separate document) to document a configuration management program including processes for declaration of configuration baselines, change requests, modifications, and update releases. Corrections that materially affect the configuration, or have the potential for affecting the

configuration, shall be treated as change requests.

b. The Configuration Management Plan shall cover all hardware and software for the Train Control System including a Product Breakdown Structure detailing component relationship, all equipment documentation, test plans and procedures, test equipment and simulation tools, the Test Facilities, and all other items that are normally placed under configuration control for a safety and mission critical system. Software Configuration Management plan requirements for subsystems are defined in Section 7.3.6.
c. The Contractor shall coordinate the cross-subsystem configuration releases to ensure stepwise compatibility of hardware and software functionality, and interoperability.

2.3.4 System Testing

a. The Contractor shall perform integrated testing as follows as per Section 9:
    1. Train Control functions utilizing trains equipped with the Carborne Train Control Systems on the entire Jamaica Line limits of the Project including transitions into and out of the project limits.
    2. Seamless automatic upload of Project Line database onto the Carborne Train Control Systems installed on the Project for operation on both Canarsie Line and Jamaica Line.
    3. Verification of the Health check status of Carborne systems assigned to the Project Lines service whilst equipped commissioned trains are outside, inside the Project Line limits and moving at Line speed in operation within the Project Line limits.
    4. Verification of the Health check status of Wayside UWB systems assigned to the Project Lines service.
    5. Verification of UWB Speed and Position data of commissioned trains whilst inside the Project Line limits and moving at Line speed in operation within the Canarsie Project Line limits. Speed and Position shall be verified against the commissioned CBTC system of Canarsie.
    6. Test results from the testing conducted shall be submitted for approval by the Engineer.

2.3.5 Systems Integration Management Plan

a. The Contractor shall provide a Systems Integration Management Plan that delineates all systems integration activities throughout the lifecycle of the project for their scope of work.
b. The Systems Integration Management Plan shall describe the organization, the processes and the means set up to achieve the objectives of the project.
c. The Systems Integration Management Plan shall:
    1. Describe:
        i. The project organization.
        ii. The project delivery approach with an emphasis on the key milestones of the project, the critical interdependences between all contractors.
        iii. Project control and monitoring activities.
        iv. Requirement Management activities.
        v. Risk Management activities.
        vi. Quality Assurance activities.
    2. Define the communication method for reporting project status to NYCT.
    3. Establish the following:
        i. The activities and processes for Verification and Validation (V&V) of the Train Control System including:
            (a) Verification actions to incrementally confirm that the delivered subsystems and services will meet the requirements of these

Specifications.

(b) Validation actions to incrementally confirm that the behavior of the delivered Train Control subsystems and services will meet NYCT's needs.

ii. The activities and documentation requirements of systems integration activities necessary to support the Reliability, Availability, and Maintainability (RAM) Program, the Safety Program, and Safety Certification.

iii. The systems-level test plan to verify compliance of each subsystem, component, and service prior to running the system in Shadow Mode.

iv. An independent system-level test program to verify compliance with the Performance Requirements of Section 3.

2.4 Execution

2.4.1 General

a. The Contractor shall execute system integration functions for the scope of work within a structured process framework that incorporates the following:

2.4.1.1 Requirements Traceability Matrix (RTM) Management

a. The Contractor shall establish and manage an RTM process, using an NYCT approved RTM tool such as IBM RequisitePro™ or DOORSTM and its companion tools if necessary, for the management and traceability of the system level functional requirements specified in this contract. The Contractor may propose use of a different tool, however, the proposed tool shall be approved by NYCT.
b. The Contractor shall develop a Systems RTM Plan (as part of the Systems Integration Management Plan) that identifies the process of traceability, roles and responsibilities of NYCT and Contractor.
c. The Contractor shall identify all system level performance requirements, and systems integration requirements, and shall be responsible for their incorporation into the RTM process. The system level performance requirements and the systems integration requirements shall be linked to the appropriate system level functional requirements.
d. The Contractor shall identify the Train Control System's subsystem requirements related to systems level performance and functionality, the Contractor shall be responsible for their incorporation into the RTM process.
e. The Contractor shall identify and link the validation and verification activities for each phase of the project to the formal system requirements, including those in the phases of preliminary design, final design, design review, factory test, post installation test, systems level test, operational activation and pre-revenue test, and change management.
f. The Contractor shall establish parameters for the RTM attributes and linkages for RTM items that are needed in the RTM database for systems integration, such that it shall be possible to trace a system-level requirement down to the necessary subsystem level requirements and to trace from a subsystem level requirement up to all of the system level requirements it affects.
g. The Contractor shall establish attributes of the RTM to track verification and validation of all vital requirements throughout the design and test processes. Vital requirements shall be specifically identified.
h. The Contractor shall provide traceability of all necessary test plans, test procedures and test results to Contract requirements. The traceability should include all integration tests of software running in the host hardware, all re-test for new hardware or software releases, integration test within the subsystems, factory tests of functionality and interoperability

before shipment, post installation tests, and systems level on-site tests.

i. The Contractor shall prepare and submit periodic RTM reports to NYCT summarizing progress and concerns. The format and content of the reports shall be agreed with NYCT and modified as requested and required to meet the particular needs of the phase and status of the project.
j. The Contractor shall maintain the systems integration requirements of the RTM database throughout the life cycle of the project sending copies of the full database update to NYCT for all new configuration releases and shall provide full online access to the current database. Configuration releases of the database shall be coordinated with design, test and other submittals.
k. The Contractor shall deliver the complete database and database maintenance procedures to NYCT **at project completion**.

2.4.1.2 Project Coordination

a. The Contractor shall appoint a Project Manager who shall serve as a single point of contact for coordination of the Contract and to provide timely Contractor decisions and input to the project.
b. To ensure the efforts are coordinated at a system level, the Contractor shall participate in all project management and technical meetings with NYCT and stakeholders to ensure that systems level requirements are managed, verified and validated, throughout the lifecycle of the project.
c. The Contractor shall be responsible for documenting the decisions and action items related directly or indirectly to systems engineering and integration items.
d. The Contractor shall support liaison with other NYCT departments as requested by the Engineer.

2.4.1.3 Schedule Integration

a. The Contractor shall maintain a project schedule to facilitate coordination between various contracts, constraints and stakeholders that impact this Contract.
b. The Contractor shall assist NYCT in the management of the schedule to assess risk, plan pre-emptive delay avoidance, respond rapidly to slippage, and formulate recovery initiatives.
c. The Contractor shall be responsible for identifying all deliverables, and delivery dates, required to ensure that the subsystem equipment configuration shall achieve the overall project schedule and milestones of the entire Train Control System Project.
d. The Contractor shall propose a scheduling tool (e.g. Microsoft Projects, Primavera P6, or equivalent) for approval by the NYCT Program Manager.

2.4.1.4 Design Review Administration and Design Reviews

a. NYCT will coordinate and facilitate all system level design reviews.
b. The Contractor shall participate in system level design reviews to assure compliance with system level requirements and to ensure that all subsystems and services are correctly integrated.
c. The Contractor shall report all design concerns and deficiencies to NYCT as soon as the concern or deficiency has been identified and sufficient detail to provide a preliminary characterization of the problem has been generated.

2.4.1.5 Working Groups and Design Workshops

a. NYCT will schedule and administer a series of Working Group meetings with the Contractor to incrementally advance systems engineering and integration as a continuous process throughout the life cycle of the project. The primary objective will be to resolve design issues in advance of formal design review and test milestones.

b. The Contractor shall participate as requested in Working Groups with NYCT staff, Contractors, consultants to NYCT, and other nominated participants.

2.4.2 Design Review Process

a. During the evolution of the Project design, the Engineer will monitor the Contractors' progress on their respective scopes of work to determine compliance with the requirements of the respective contracts through design reviews and audits. Design reviews and audits shall be conducted jointly by the Engineer, the applicable Contractors, and other NYCT-designated parties. In all cases, approval by the Engineer shall not constitute relief from contractual obligations. Reviews shall be conducted incrementally, and, as a minimum, grouped for the major system elements. All ancillary and associated designs shall be included in the reviews of the major system elements. Each succeeding level of design review shall update the material from the previous review as well as advancing the design to the next level.
b. Design reviews shall be held to review system and subsystems designs for each location in the following major areas. Reviews can be combined for logically associated system elements and locations, and are subject to the approval of the Engineer.

2.4.3 Working Groups

a. Working Groups along with designated Chairs/co-Chairs will be established by NYCT to facilitate the timely and effective review/approval of technical submittals and requests for information. The Contractor shall participate in these working groups as applicable.
b. Within one month of Notice of Award, NYCT will establish a specific Systems Integration Working Group and initiate a series of monthly workshops, or their equivalent for this Working Group to discuss systems integration requirements and process for delivering the fully functional Train Control System. The Contractor shall participate, provide input to the agenda, help assign and track action items, record decisions, and initiate fast-track resolution of time-critical items.
c. The Working Group representatives will have the authority to speak for their respective NYCT departments on technical issues associated with that Working Group, and within the constraints of the Contract. Neither the Working Group chair nor any of the Working Group representatives are authorized to agree to any modifications to the Contract, which must be handled through the Engineer and in accordance with the appropriate Contract provisions.
d. Working to support the Contractor, one of the objectives of the Working Group is to ensure that the required content of a given submittal is understood and agreed before a document is formally submitted to the Engineer by the Contractor. The use of draft submittals is therefore encouraged.

2.4.4 Submittal Procedures

a. The Engineer will determine the detailed transmittal procedures for submittals and the procedures for correspondence to be used by the Contractor.
b. The Contractors shall reuse existing documentation provided under previous NYCT or MTAIT projects as much as possible. NYCT will endeavor to provide the Contractor with NYCT documentation to assist the Contractor whenever possible. However, NYCT cannot guarantee that all documentation requested by the Contractor will be available in a specific time frame or that it will be correct or complete. The Contractor shall use its own resources where required to survey, analyze, reverse engineer, etc. such information required for the contract that NYCT is not able to provide. The documentation submitted by the

Contractor shall be updated in the project format. Revisions shall be clearly identified (revision marks) to facilitate the review of the submittals.

c. Submittals shall consist of hard copies of drawings, specifications, listings, brochures, and catalog information. Unless specified otherwise in the Sections requiring the submittal, each Contractor shall supply two (2) hard copies of each submittal and an electronic version of all submittals on the Project SharePoint site. Project standards for electronic data shall be IBM PC-compatible applications, including:
    1. Text - Microsoft Word.
    2. Database - Microsoft Access.
    3. Spreadsheet - Microsoft Excel.

    The supply of the hard copy can be waived for documents transmitted to NYCT for review or approval during the course of the project. These documents will then be handled through the Program's SharePoint site. This waiver cannot apply to final versions, as-built, training, etc.

d. The Contractor shall schedule the release of submittals for NYCT's review in a manner consistent with the incremental design reviews specified in the Contractor's schedule and project management plans. The release of submittals for review shall be staggered, taking into account the number and size of documents for each subsystem or discipline, in order to allow the Authority to accomplish the turnaround of approvals and comments as follows:
    1. For non-drawing submittals of 200 pages or less, the Engineer will typically complete the review with a turnaround time of 14-days.
    2. Submittals larger than 200 pages and drawings, such as the System/Subsystem Design Description and other software submittals, may require more time for NYCT to thoroughly review.

e. The Contractor shall identify in the CDRLs those submittals that are estimated as larger than 200 pages. The Contractor and the Engineer shall determine as part of the CDRL approval, those submittals that may require additional time for NYCT review.

f. In order that there is sufficient time for the review process no submittals shall be submitted less than 60 days prior to their associated system/subsystem's planned design review milestone date.

3 SYSTEM PERFORMANCE

3.1 General

a. This section defines the system level performance requirements for the Train Control System. The Contractor shall be responsible for compliance with these system level and subsystem performance requirements. System-level performance requirements shall be allocated to individual subsystems of the Train Control System.
b. If the Contractor provides justification, NYCT may accept waiving some requirements in this section. If the Contractor's system does not comply with all specifications of this section, the Contractor shall identify each line item that cannot be satisfied by the Train Control System per the Gap Analysis (see Section 1.6). **Unless a written waiver is provided to the Contractor by the NYCT Program Manager, it shall not be assumed that any requirements of this section are waived**.

3.2 Jamaica Line

3.2.1 Performance Requirements

a. The Jamaica Line Project territory shall be within the limits of J2-596 and J2-682 on both tracks. Drawings are included as a part of the attachments.
b. The Jamaica Line will operate twenty-four (24) hours per day, seven (7) days per week.
c. The Train Control System shall meet or exceed the Performance Requirements detailed in this section.
d. Train Operations:
    1. Train Operations shall be in accordance with the functional requirements of Section 4.
    2. Specifically, ATP functions shall be implemented without unnecessarily constraining the minimum station to station run times and operating headways and shall provide for improved run-time and headway performance compared to current performance on the line.
    3. Unequipped trains will also operate the Jamaica Line.
e. Passenger trains will normally operate between the stations in both peak and off-peak periods. The Train Control System shall, however, support all permutations of service supported by the track configuration.
f. Run time:
    1. For a train operating in ATO mode, the Train Control System shall contribute no more than 3% to the theoretical minimum run time provided that the track configuration allows an optimal train speed.
    2. The headway and run times for equipped trains shall not be constrained by the AWS block design, and associated track circuit layout, when only equipped trains are operating on the line except when the Train Control System is required to comply with AWS functionality.
g. Design Headways
    1. The design headway is defined as the minimum un-interfered headway, where the speed profile of any given train is not affected by a preceding train, and where all trains perform at the maximum allowed speed, depending on the civil speed limits, and the acceleration and braking capabilities of the trains themselves.
    2. The design headway shall be calculated based upon normal operation of a preceding train not interfering with the performance of a following train.
    3. The above requirement applies to trains operating in ATO Mode. The Contractor

shall design the Train Operator interface so as to minimize operator response times when operating in ATPM mode. The maximum extension in headway when operating in ATPM shall be an increase of 5%. The maximum extension of run time when operating in ATPM shall be 5%. These extensions contribute to define the human to computer interface (train operator display) and specifically the maximum reaction time allowed to train operators.

4. The installed hardware and software provided supports the design headway.

h. Operating Headways
   1. Current operating headway at selected stations, known as timepoints, can be determined from Section 3.2.2.
   2. The operating (i.e. scheduled) headway will typically be greater than the design headway and will include an operating margin to permit recovery from system perturbations.
   3. The operating headway shall under no circumstance result in any degradation to the service operations that can be supported under the existing signal system.
   4. The Train Control System shall provide the closest feasible safe operating headways for equipped trains in both the normal and reverse directions, on all equipped track. The achievable design headway shall be determined by the time required for safe braking, station dwells and other physical parameters, plus a maximum allowance for all of the Train Control System's latencies and tolerances. For reference, a typical target figure for CBTC is 3s.
   5. Equipped trains for the Train Control System shall be able to operate between 0 and 55 mph in the entire UWB territory.
   6. With the Train Control System, the minimum practical scheduled throughput in the normal direction of travel on the Jamaica Line in ATO mode shall be targeted to be as follows:
      i. Southbound: 30 TPH.
      ii. Northbound: 30 TPH.
   7. The Train Control System shall support a reduction in headway (at the expense of increased trip times) when operating with an interfered headway.
      i. Interfered headway is the capacity that is achieved by the system where the speed profile of any train is affected by a preceding train such that a following train decelerates on the approach to a station and enters the station at reduced speed.
      ii. Trains operating under interfered capacity will experience reduced average operating speeds and increased trip time over a route as compared with trains operating under the conditions used to determine design capacity.
      iii. The interfered capacity of the system shall be at least 36 TPH.

i. System Capacity
   1. The hardware and software of the Train Control System shall support the design headway.

3.2.2 Current Performance Data

a. Operating fleet (For reference only):
   1. The fleet of revenue trains for the Jamaica Line is composed of R-179 and R-160 cars.
      i. Jamaica Line fleet will be deployed in 4-car operating units.
      ii. A revenue train operating on the Jamaica Line will consist of two operating units, the maximum revenue train length on the Jamaica Line shall not exceed 8-cars.
      iii. The Train Control System shall automatically determine train length and

shall inhibit operation in revenue service of trains with consist size exceeding 8-cars.

2. The revenue service fleet for the Jamaica Line will be composed of R-179 and R-160 cars such that:
    i. Each 4-car train will be nominally 240 feet in length.
    ii. Each 8-car train will be nominally 480 feet in length.

b. Train service
    1. Scheduled trains:

Table 3-1 Jamaica Line Project Station Stops

Station	Station Stop via Train Control
Parsons-Archer / Jamaica Center	X
Sutphin Boulevard / Archer Avenue	X
121st Street	X

    i. Other route paths may be necessary to simulate diversions and General Orders.
    2. Examples of permutations of service supported by the track configuration:
        i. It is possible to provide reverse running on both tracks between 121st Street and Parsons-Archer / Jamaica Center under a General Order.

3.2.3 Simulation Information

a. Territory description
    1. Simulations shall occur for the Jamaica J/Z line on the entire territory, all tracks, and all terminals.
    2. Train / platform length are nominally 480 feet.
b. Guaranteed Emergency Brake Rate (GEBR)
    1. The GEBR is the emergency brake rate used in the safe braking model after all system delays required for overspeed detection, vital logic processing and changing vital output states, for vital propulsion power cut off, emergency brake activation, brake cylinder pressure buildup have been completed including any delays imposed by the vehicle control system to limit the Jerk Rate. The GEBR is further adjusted for the effect of grades under the train at specific locations.
    2. The Proposers shall use a GEBR on level track of 1.8 mphps in the safe braking model calculations.
c. Dwell times
    1. The time from wheel stop to wheel start of a train berthing in a passenger station.
    2. A nominal dwell time of 30 seconds shall be used.
d. Replacement time
    1. The time required for one train stopped outside a station to move and replace the preceding train in the station berthing location.
    2. The replacement time shall be based on the following considerations:
        i. The following train is stopped, having advanced as far as permissible by the Safe Braking Model as implemented in the Proposer's train control system including any system latencies, uncertainties or buffer zone;
        ii. The stopped train moves as soon as permitted by the train control system, but not before the train berthed in the station has a movement authority to leave the station;

iii. train movement is at all times limited to the maximum speeds permitted by the Safe Braking Model;
iv. The train performance is limited to the propulsion capabilities and the service braking rate assumed for stations stops. The replacement time of the system shall not exceed 60 seconds.

e. Recovery time
   1. Recovery time is an additional allowance for perturbations from an ideal schedule.
   2. The capacity of the system shall be simulated including a recovery time of not less than 10 seconds.

f. Jamaica Project Alignment
   1. The simulation shall model the Jamaica Line alignment to include stations, grades and civil speed restrictions.
   2. The simulation shall model the performance capabilities of the Jamaica Line passenger trains (acceleration and service deceleration rates and jerks limits).
   3. The track to be modeled shall be the tracks described in 3.2.3.a Territory description.
   4. The simulation shall model all Train Control-related functions and parameters that have an impact on operational performance such as:
      i. Safe train separation assurance and interlocking interface functions of the I2S.
      ii. Train location parameters (both accuracy of measured end-of-train locations, and resolution of movement authority limits for a given train), including the frequency at which location reports and movement authorities are updated.
      iii. Train speed parameters, including both accuracy of speed measurement and resolution of speed limits established for a given train at a given location.
      iv. Communications delays, including nominal and worst-case transmission times of command/status messages between the Train Control System and the ATS, Zone Controllers, and trains as applicable.

      (Command/status messages to include, for example, messages related to movement authority updates and/or location report updates.)
      v. Equipment reaction times of the Train Control System, including maximum error accumulation for both wayside and carborne equipment, and for both ATO and ATPM modes as applicable.

      (CBTC equipment reaction times include, for example, the time required to establish new movement authority limits following location report updates, the time to establish new movement authority limits through an interlocking, and the time to determine a new ATP profile following movement authority update.)
      vi. System performance limitations of the Train Control System

      (e.g., the maximum number of trains that can be processed by the Train Control System within a given area of control).
      vii. AWS equipment reaction times including switch/route line-ups and equipment operational constraints.
      viii. ATS schedule adjustments and passenger/employee delays.
      ix. The automatic speed regulation algorithm in ATO mode of the Train Control System.
      x. Train operator reaction times in ATPM mode.

xi. Platform exit restriction function.
xii. Platform entry restriction function.

3.2.4 Submittals

a. Preliminary Performance Simulation Report
b. Final Performance Simulation Report
c. Safe Braking Model

3.3 Canarsie Line

3.3.1 Performance Requirements

a. The Canarsie Line Project territory shall confined between the limits of Q2-317 and Q2-428 on both tracks. Drawings have been included as a part of the attachments.
b. The Canarsie Line will operate twenty-four (24) hours per day, seven (7) days per week.
c. The Train Control System shall meet or exceed the Performance Requirements detailed in this section.
d. While the primary purpose of the Canarsie Line Project area will be to compare UWB speed and position data against the existing CBTC system, the Contractor shall also deploy the DCS subsystem of the Train Control System for remote health monitoring and access to log, if applicable. Note, the requirement of validating the UWB data against the CBTC system on the Canarsie line will not be considered for a Gap Analysis waiver.
e. Ultra-Wideband
    1. Location accuracy
        i. Stationary – 6 inches
        ii. In motion – 12 inches
    2. Location Update Frequency
        i. Nominally – 500 milliseconds
        ii. If the system design requires different location update frequencies for operating conditions, they should be identified in the design. Examples of different operating conditions that could apply include, but are not limited to:
            1. In motion vs Stationary
            2. Approaching Database Features:
                (a) Curves
                (b) Grade Changes
                (c) Switches
                (d) Home Signals
                (e) Stations
                (f) End of Line
    3. Acceptable Location delta between UWB positioning and surveyed CBTC markers (e.g. transponders)
        i. 12 inches.
    4. Speed Accuracy
        i. Nominally – 1 MPH
    5. Speed Update Frequency
        i. Nominally – 500 milliseconds
        ii. If the system design requires different speed update frequencies for operating conditions, they should be identified in the design. Examples of different operating conditions that could apply include, but are not limited to:

1. In motion vs Stationary
2. Approaching Database Features:
    (a) Curves
    (b) Grade Changes
    (c) Switches
    (d) Home Signals
    (e) Stations
    (f) End of Line

6. Acceptable speed delta between UWB and CBTC
    i. 1 MPH
7. Data throughput
    i. 1 Mbps
8. Data latency
    i. The Contractor shall specify the Maximum System Latency for the UWB design
        1. Before Operational Degradation
        2. Before Safety Response
9. Packet drop rate
    i. The Contractor shall specify the Maximum Packet Drop Rate for the UWB design
        1. Before Operational Degradation
        2. Before Safety Response

f. Data Communications System
    1. Data throughput
        i. Greater than or equal to 2.4Mbps
    2. Data latency
        i. Less than or equal to 50ms
    3. Packet drop rate
        i. Less than or equal to 10%

3.3.2 Simulation Information

a. As the Canarsie Line will be dedicated to the comparison of speed and positioning between the Train Control System and the existing CBTC system, no simulation is anticipated.

3.3.3 Submittals

a. UWB – CBTC Speed and Position Comparison Report

3.4 Execution

3.4.1 Performance Simulations

a. The Contractor shall determine the maximum merging point capacity:
    1. The Contractor shall calculate the maximum capacity achievable through all tracks at all stations for the Jamaica Line.
b. The Contractor shall submit a Performance Simulation Report including the following:
    1. A determination of the **theoretical minimum travel time** for a 10-car / 600 foot train on the Jamaica Line, using station dwells (wheel stop to wheel start) at each intermediate station as defined in Section 3.2.3, with train movements constrained

by train performance and track alignment characteristics only (i.e. the theoretical minimum travel time shall assume zero tolerances / reaction times within the Train Control System).

2. A determination of the **practical minimum travel time** for a 10-car / 600 foot train on the Jamaica Line, using station dwells (wheel stop to wheel start) at each intermediate station as defined in Section 3.2.3, with train movements constrained not only by the train performance and track alignment characteristics but with consideration of all relevant tolerances and reaction times of the Train Control System. This determination shall be performed both for trains operating in ATO mode and separately for trains operating in ATPM mode.
3. A determination of the **theoretical minimum design headway** for a 10-car / 600 foot train on the Jamaica Line, using station dwells at each intermediate station and each terminal station as defined in Section 3.2.3, with train movements constrained by train performance and track alignment characteristics only (i.e. the theoretical minimum design headway, shall assume zero tolerances / reaction times within the Train Control System).
4. A determination of the **practical minimum design headway** for a 10-car / 600 foot train on the Jamaica Line, using station dwells at each intermediate and terminal station as defined in Section 3.2.3, with train movements constrained not only by the train performance and track alignment characteristics but with consideration of all relevant tolerances and reaction times of the Train Control System. This determination shall be performed both for trains operating in ATO mode and separately for trains operating in ATPM mode.

c. The **theoretical minimum design headway** and **practical minimum design headway** determination shall be performed for following train operations:
   1. This determination shall be performed for train operations on the mainline tracks.
   2. This determination shall be performed both for trains operating in ATO mode and separately for trains operating in ATPM mode.
   3. This determination shall include non-revenue train movements to/from lay-up locations.
   4. Specifically, the network simulations shall include the following scenarios:
      i. AM peak period – Weekdays 7:00 am – 10:00 am.
      ii. PM peak period – Weekdays 4:30 pm – 8 pm.
   5. All different services as described in Section 3.2 or other more recent existing operating patterns indicated by NYCT. Contractor shall work with NYCT to incorporate any existing operating pattern changes on Jamaica Line prior to performing preliminary and final simulations.
d. The Contractor shall use RailSim for the simulations or an approved equivalent.

3.4.2 Timing and Sizing Document (TSAD)

a. The Contractor shall provide a Timing and Sizing Document, including calculations and supporting data and assumptions for review and approval by NYCT. The report shall demonstrate that the Contractor's Train Control System solution will achieve the performance requirements and how the requirements will be achieved by the Contractor's system architecture. The TSAD Document shall provide the timing and sizing analysis of the TCS System and its associated subsystem/devices for operational scenarios:
   1. Nominal
   2. Worst-Case
   3. Fault-detection/system reaction
   4. Failure detection/system reaction
   5. Communication system

6. Signal indication status to train(s)-train reaction
7. Track occupancy status to trains/train reaction
8. Other applicable operating scenarios
9. Availability limits due to system loading, i.e., communication limits, number of trains, number of wayside devices

b. The calculations shall state the maximum system capacity for wayside and DCS subsystem components (e.g. UWB Anchors, DCS Radio, ZC, etc.).

3.4.3 Safe Braking Model

a. The Contractor shall determine the safe braking model for the Train Control System, which shall be submitted to the Engineer for approval.
b. The safe braking model shall, as a minimum, include consideration of the following factors:
    1. Location uncertainty of lead train (including rollback tolerance).
    2. Location uncertainty of following train.
    3. Allowable overspeed permitted by the Train Control System.
    4. Maximum speed measurement error of the Train Control System.
    5. Train Control System reaction times and latencies.
c. The safe braking model shall also include consideration of the following train performance parameters:
    1. The maximum train speed shall be as defined as 55 MPH.
    2. The minimum and maximum train lengths shall be as defined in Section 3.2.2.
    3. The maximum train acceleration rate possible at the time an overspeed condition is detected by the Train Control System.
    4. Worst-case passenger train subsystem reaction time to disable the propulsion system following reaction to an overspeed condition by the Train Control System will be 0.65 seconds. Worst-case passenger train subsystem reaction time to begin to apply the emergency brakes following reaction to an overspeed condition by the Train Control System will be 1.15 seconds. Worst-case passenger train subsystem reaction time to fully apply the emergency brakes following reaction to an overspeed condition by the Train Control System will be 2.65 seconds.
    5. The Guaranteed Emergency Brake Rate to be used in the Train Control System's Safe Braking Model for the Jamaica Line shall be as defined in Section 3.2.3.

       The guaranteed emergency brake rate will be the minimum emergency brake rate achieved by a train on level tangent track under the range of environmental conditions, and worst-case credible latent brake equipment failure modes, which can be anticipated to exist for that train operating on the Jamaica Line. The guaranteed emergency brake rate will include consideration of maximum passenger load (plus snow and ice load as applicable), minimum anticipated adhesion levels, and maximum design tailwind.
d. The safe braking model shall also include consideration of the following alignment-related parameters:
    1. Civil speed limits.
    2. Grades.
    3. Interlocking Home Signals
    4. Track Switches
    5. End of Line
    6. Entry/Exit Test Territory Limits
e. The safe braking model shall also include consideration of operational-related requirements such as:
    1. The ability to berth at a station platform with a red home signal at the exit from the

station platform.

2. The ability to perform close-up maneuvers at pre-defined locations in order to reach stopping point with short buffer distance to the next danger point at limited speed and to meet performance requirements.

f. The Safe Braking Model shall include all requirements of Section 4.2.3.b.

4 FUNCTIONAL REQUIREMENTS

4.1 General Requirements

a. This section defines the functional requirements for the Train Control System. The system shall meet the following system characteristics:
    1. High-resolution train location determination, independent of track circuits, transponders, tachometers, and accelerometers.
    2. Continuous, high capacity, bidirectional train-to-wayside, intra-train (as required by the design), train-to-train communications (may be peer-to-peer or via wayside).
    3. Train-borne and wayside processors performing vital functions
b. The system shall be capable of supporting a variety of train configurations, including the following:
    1. Fixed-length unidirectional trains comprised of one or more basic operating units
    2. Fixed-length bidirectional trains comprised of one or more basic operating units
    3. Variable-length unidirectional trains
    4. Variable-length bidirectional trains
c. The system shall be capable of supporting a mixed fleet of trains, where specific trains, and/or classes of trains, have different performance characteristics.
    1. The system shall be capable of supporting a Mixed Mode operation with Unequipped Trains under AWS control.
    2. The system shall be capable of integrating with the AWS system controlling Unequipped Trains.
d. The Train Control System shall include the capability for providing ATP, ATO, and ATS functions.
e. ATP functions shall provide fail-safe protection against collisions, excessive speed, and other hazardous conditions.
f. ATP functions shall have precedence over both the ATO and ATS functions.
g. ATO functions shall control basic operations that would otherwise be performed by a train operator and shall do so within the protection limits imposed by ATP.
h. The Train Control System shall demonstrate a complete interface with an ATS system and an Solid State Interlocking (SSI) subsystem; the system interfaces shall be complaint with the following NYCT Interoperability Interface Specification (I2S) documents:
    1. I2S ATC-CBTC (except section 4)
    2. NYCT CBTC SSI Interface – Functional Specification
    3. NYCT CBTC SSI Interface – Protocol Specification
i. If the Contractor provides justification, NYCT may accept waiving some requirements in this section. If the Contractor's system does not comply with all specifications of this section, the Contractor shall identify each line item that cannot be satisfied by the Train Control System per the Gap Analysis (see Section 1.6). **Unless a written waiver is provided to the Contractor by the NYCT Program Manager, it shall not be assumed that any requirements of this section are waived**.

4.2 ATP Functions

4.2.1 General

a. All ATP functions shall be vital functions and shall be designed and implemented in accordance to Section 3.
b. The Train Control System shall be capable of providing bidirectional ATP.

4.2.2 Train Location / Train Speed Determination

a. Vital train location / train speed determination shall be a required ATP function for the Train Control System.
    1. The Train Control System shall establish the location, speed, and travel direction of each Train Control equipped train operating in the territory of the Train Control System.
    2. The Train Control System's train location determination shall safely and accurately establish the location of both the front and rear of the train.
    3. The Train Control System's train location determination function shall provide sufficient train location resolution and accuracy to support the performance and safety requirements of this Specification.
    4. The Train Control System's train location determination function shall be self-initializing and shall automatically detect and establish the location of each of the Train Control System's equipped train as it enters the territory of the Train Control System and on recovery from Train Control System equipment failures, without requiring manual input of train location or train length data.
    5. The Train Control System's train speed determination function shall provide sufficient speed measurement resolution and accuracy to support the performance and safety requirements of this Specification.
    6. The Train Control System shall compensate for the effects of measurement inaccuracies on train location and speed determination.
        i. Specifically, if the Train Control System's train location / speed determination function is dependent upon wheel rotation, the Train Control System shall correct for position errors induced by the slipping or sliding of wheels and shall correct for position errors caused by variation in wheel size due to wear, trueing, or replacement.
b. If secondary train location detection is implemented by the Contractor for data gathering during the pilot, an Auxiliary Wayside System may provide secondary train location determination to establish if a section of track is occupied by one or more trains, including trains not equipped with Carborne Train Control System equipment and/or trains with inoperative Carborne Train Control System equipment.
    1. It will not be necessary to determine the location of non-equipped trains, or trains with inoperative Carborne Train Control System equipment, to the same accuracy as Train Control System equipped trains.

4.2.3 Safe Train Separation

a. Safe train separation shall be a required ATP function for the Train Control System.
    1. Safe train separation shall be provided between all trains operating in UWB territory, whether or not the trains are UWB-equipped.
    2. The Train Control System shall provide safe train separation between UWB-equipped trains.
        i. Safe train separation shall be based upon the principle of an instantaneous (brick wall) stop of the preceding train.
    3. For mixed-mode operation, safe train separation shall be provided through an Auxiliary Wayside System and/or through strict adherence to operating procedures, as specified by NYCT.
    4. If secondary train location determination is provided through an AWS, then for a UWB-equipped train following a non-UWB-equipped train or a train with inoperative Carborne UWB equipment, The Train Control System shall limit the movement authority of the following train to the boundary of the section of track

occupied by the non-UWB-equipped or failed train.

5. If specified by NYCT, the Train Control System may further limit the movement authority to the route entry point of a route occupied by the non-UWB-equipped train or failed train.
6. The Train Control System's safe train separation function shall consist of the following:
    i. The calculation of the ATP profile (i.e., the profile of safe speed as a function of train location), derived from fixed ATP data (e.g., permanent speed limits) and variable ATP data (e.g., temporary speed limits and movement authority limit).
    ii. The supervision and enforcement of the ATP profile calculated by the Train Control System.
7. The ATP profile shall be governed by a safe braking model and shall ensure that under no circumstances (including failures) will the movement authority limit be exceeded by a UWB-equipped train.
8. The movement authority limit shall be the most restrictive of the following:
    i. The rear of a UWB-equipped train ahead (as determined by the system's train location function, with allowance for any location uncertainty.
    ii. The boundary of a section of track occupied by a non-UWB-equipped train or a train with inoperative Carborne UWB equipment (as determined by an auxiliary wayside system, if provided).
    iii. The end-of-track.
    iv. The entrance to an interlocking, when the route is not verified as aligned and locked.
    v. The boundary of a section of track with an opposing traffic direction established.
    vi. The boundary of a blocked track.
    vii. If specified by the authority having jurisdiction, the entrance to a highway grade crossing where warning devices are not confirmed to be operating.
    viii. The entrance to a route that is detected to be unsafe for train movement.
9. The Train Control System's safe train separation function shall support automatic close-up of trains and automatic coupling and uncoupling of trains in designated areas.
10. Facilities may be provided to bypass the Train Control System's safe train separation function to allow a train, under the control of a train operator, to travel beyond its movement authority limit (e.g., at a restricted speed), for failure recovery purposes.
11. Facilities may be provided to pull back (i.e., make more restrictive) a movement authority limit previously granted to a train.
    i. If the train were approaching or braking toward the original movement authority limit, the train may be in violation of the new ATP profile.
    ii. Under such circumstances, the Train Control System shall initiate an immediate brake application.
    iii. The brake application may be an immediate emergency brake application or a supervised service brake application.

b. A safe braking model shall be developed for each Train Control application.
    1. The safe braking model shall, as a minimum, include consideration of the following:
        i. Location uncertainty of lead train (including rollback tolerance)
        ii. Location uncertainty of following train
        iii. Train length
        iv. Train configuration
        v. Allowable overspeed permitted by the Train Control System

vi. Maximum Train Control System's speed measurement error
vii. Train Control System's reaction times and latencies
viii. Maximum train acceleration rate possible at the time an overspeed condition is detected by the Train Control System
ix. Worst-case reaction times to disable the propulsion system and apply the emergency brakes following detection of an overspeed condition by the Train Control System
x. Guaranteed emergency brake rate (GEBR)
xi. Grade

2. The GEBR shall be the minimum emergency brake rate achieved by a train on level tangent track under the range of environmental conditions and worst-case credible latent brake equipment failure modes, which can be anticipated to exist for that train in the specific application.
3. The GEBR shall be specified by the authority having jurisdiction and shall include consideration of maximum passenger load (plus snow and ice load if applicable), minimum anticipated adhesion levels, and maximum design tailwind.
4. The Train Control System shall have the capability to support multiple safe braking models to accommodate different train acceleration/braking rates for different classes and configurations of trains operating simultaneously within UWB territory and to accommodate automatic close-up and automatic coupling/uncoupling capabilities.
5. The Safe Braking Model shall include the capability to implement a Wet Rail Mode with modified parameters for conditions when lower than normal adhesion is present.
6. The Train Control System shall incorporate appropriate protection to ensure that the correct safe braking model is applied for a given train at a given location.
7. The Safe Braking Model shall comply with all requirements of Section 3.4.3.

4.2.4 Overspeed Protection and Brake Assurance

a. Overspeed protection shall be a required ATP function for the Train Control System.
   1. In establishing, supervising, and enforcing the ATP profile, as governed by the safe braking model, the Train Control System shall ensure that under no circumstances, including failures, will the train's actual speed exceed its safe speed.
   2. The safe speed shall be derived by considering the most restrictive of the following:
      i. The permanent speed limits on sections of track within the ATP profile.
      ii. Any temporary speed restrictions on sections of track within the ATP profile.
      iii. The speed limit associated with a Work Zone.
      iv. Any permanent speed restriction applicable to the particular class or configuration of train.
      v. Any speed restrictions enforced on the train because of train-borne failure conditions.
      vi. The maximum speed that would allow the train to stop safely prior to the limit of the train's movement authority or to slow down sufficiently to meet appropriate permanent or temporary speed restrictions upon entering that section of track.
   3. Speed limits and restrictions shall apply when any portion of the train is within the speed limit area.
   4. Enforcement of the calculated ATP profile shall be achieved by comparing the Train Control System's determined train speed with the ATP profile speed at the Train Control System's determined train location.

5. If the ATP profile speed at that location is exceeded, the Train Control System shall initiate an immediate brake application.
6. The brake application may be an immediate emergency brake application or a supervised service brake application.
    i. In the latter case, the Train Control System shall monitor the achieved brake rate to ensure an acceptable brake rate is achieved within a predetermined time frame; if not, it shall immediately apply the emergency brakes.
    ii. The safe braking model shall include appropriate allowances for reaction times associated with this brake assurance function.

4.2.5 Rollback Protection

a. Rollback protection shall be a required ATP function for the Train Control System.
    1. The Train Control System shall monitor actual train travel direction and shall compare measured travel direction with the Train Control System's established / commanded direction of traffic.
    2. Train motion against traffic for more than a specified rollback tolerance shall result in the Train Control System initiating an emergency brake application.

4.2.6 End-of-Track Protection

a. End-of-track protection shall be a required ATP function for the Train Control System configuration that permits the operation of trains up to, or in close proximity to, an end-of-track terminus.
    1. End-of-track protection shall be incorporated into, or function in conjunction with, overspeed protection to prevent trains from over-traveling the end-of-track or, if buffers are specified, to prevent trains from exceeding the design limits for impact with an end-of-track buffer.
    2. End-of-track protection design shall be based on the Safe Braking Model.

4.2.7 Parted Consist Protection and Coupling and Uncoupling of Trains

a. Where separate vehicles can be coupled together in a consist of two or more vehicles or units to form a train, the Train Control System shall have the capability of detecting and protecting parted trains.
    1. Parted consist protection shall be required regardless of whether the individual vehicles or units are considered to be permanently coupled or whether they are routinely uncoupled for maintenance or operational purposes.
b. The Train Control System shall also support operating requirements for coupling and uncoupling of trains, including automatic update of the consist length within the Train Control System.
    1. The Train Control System may assume a fixed, worst-case, maximum train length for a given class of trains operating in UWB territory, with a reliance on operating procedures to ensure this maximum train length is not exceeded.

4.2.8 Zero Speed Detection

a. Zero speed detection shall be a required ATP function for the Train Control System configuration and shall be in accordance with the requirements of 5.10 of IEEE Std 1475-1999.

4.2.9 Door Opening Control Protection Interlocks

a. Door open control protection interlocks shall be a required ATP function for the Train Control System.
    1. These interlocks, if provided, shall ensure that the following conditions are satisfied prior to enabling the opening of the train doors (and platform doors, if fitted):
        i. The train is “properly aligned” at a designated stopping point, where the designated stopping point and required tolerances shall be as specified by the authority having jurisdiction.
        ii. There is a platform (or other location specified by NYCT) on the side of the train for which the door opening is allowed.
        iii. Zero speed is detected.
        iv. The train is constrained against motion.
    2. Selective door open enable shall be possible for those applications where the train length exceeds the platform length.
    3. Local manual bypass of the preceding door open control protection interlocks shall be possible, for failure recovery purposes.

4.2.10 Departure Interlocks

a. Door open control protection interlocks shall be a required ATP function for the Train Control System.
    1. These interlocks, if provided, shall ensure that the following conditions are satisfied prior to enabling the opening of the train doors (and platform doors, if fitted):
        i. The train is “properly aligned” at a designated stopping point, where the designated stopping point and required tolerances shall be as specified by the authority having jurisdiction.
        ii. There is a platform (or other location specified by NYCT) on the side of the train for which the door opening is allowed.
        iii. Zero speed is detected.
        iv. The train is constrained against motion.
    2. Selective door open enable shall be possible for those applications where the train length exceeds the platform length.
    3. Local manual bypass of the preceding door open control protection interlocks shall be possible, for failure recovery purposes.

4.2.11 Emergency Braking

a. The train’s emergency brake system shall be capable of bringing the train to a stop within the assured stopping distance determined by the safe braking model.
    1. Specific criteria for resetting the emergency brakes to allow normal operation to resume shall be specified by NYCT.
        i. If conditions (as determined by ATP) are not correct for train movement, the emergency braking shall remain applied regardless of any reset signals or actions, except for a local manual bypass of the ATP functions for that train to permit manual train operation for failure recovery purposes.
        ii. Use of local bypass shall require strict adherence to operating procedures to ensure the safety of train movements.
    2. If correct ATP conditions exist after the emergency brakes have been reset, the train shall be permitted to move or continue to move; however, if the actual train speed again exceeds the ATP profile speed or a subsequent malfunction occurs, emergency braking shall be applied as before.

4.2.12 Route Interlocking

a. The Train Control System shall provide route interlocking functions equivalent to conventional interlocking practice to prevent train collisions and derailments.
    1. These functions shall include locking of the route in advance of the train entering the interlocking (time or approach locking) and once the train is in the interlocking (route locking).
    2. The switches shall also be locked when the track section containing the switch is occupied by a train (detector locking).
    3. Sectional release (of routes behind a train) may be provided where specified by NYCT.
    4. NOTE—The AREMA Communications & Signals Manual, Sections 2 and 16 [B2], provides examples of recommended practices for use in interlocking design.
    5. A movement authority shall not be advanced into an interlocking until the appropriate route is set and locked.
    6. Once a movement authority has been advanced through an interlocking, the affected route shall not be released and conflicting routes cleared unless either the train has travelled through and is verified clear of the interlocking or the movement authority is pulled back short of the interlocking and is in effect and the Train Control System has reported that the Safe Braking Distance of the train is short of the interlocking, or Approach Locking time applicable to speed of the maximum speed of the train and the characteristics of the guideway has expired.
    7. Where an auxiliary wayside system is specified, interlocking functions may be provided by separate interlocking equipment, which is based on train position established by a secondary train detection subsystem.
        i. In this case, the Train Control System shall interface to and may modify the conventional interlocking functions based on train position established by the Train Control System's train location determination function, to safely enable the enhanced performance capabilities of the Train Control System to be realized.
b. Where an AWS or separate interlocking is specified, the Train Control System shall interface to interlockings as follows:
    1. Time or approach locking shall apply, except in the event of a route being cancelled for an approaching UWB-equipped train (i.e., the movement authority is pulled back short of the interlocking and is in effect).
        i. In this case, if the train is greater than a safe braking distance from the entrance to the interlocking (as determined by the safe braking model) or the train stops prior to entering the interlocking, the route shall be released without running further time.
    2. Traffic locking may be overridden so that UWB-equipped trains may move in opposing directions within their respective movement authorities on the same track at the same time. The Train Control System shall ensure that UWB-equipped trains can only move in opposing directions when no Unequipped Trains are within the traffic section.
    3. Wayside signals with Trip Stops may be provided. The Train Control System may, when it is safe to do so, override the conventional aspects and control the Trip Stop to the Clear to cause the signal(s) to display CBTC aspect(s) (or equivalent) only to UWB-equipped trains.
c. In the event of a failure of the Train Control System's train location determination function, route locking shall remain in effect until the train is proven to be clear of the interlocking by the Train Control System (i.e., the train is subsequently determined to be clear of the interlocking limits), or through operating procedures, or a combination of both approaches.

1. In the event of a failure of the Train Control System's train location determination function in an interlocking where train location is also capable of being detected by means of a secondary system, Train Control System overrides of the interlocking functions may be released, provided route and other locking functions are maintained by the AWS so as to prevent the movement of a switch in front of and under the train until the train is proven to be clear of the interlocking.

d. In the event of a loss of switch indication once a movement authority has been issued through an interlocking, the Train Control System shall pull back the movement authority to the entrance of the interlocking.
    1. If a train is already within a safe braking distance of the switch, the Train Control System shall initiate an immediate brake application.

4.2.13 Traffic Direction Reversal Interlocks

a. Traffic direction reversal interlocks shall be a required ATP function for the Train Control System, in order to support reversal of train direction at terminal stations and to support intermediate turn backs and shuttle modes of operation.
    1. It shall not be possible to extend the movement authority for a train into a section of track where an opposing traffic direction has already been established.
    2. A reversal of traffic direction within a section of track shall not be possible unless
        i. All trains within that section of track are at zero speed and constrained against motion in the original traffic direction, and
        ii. The movement authorities for all trains outside of that section of track do not extend into the section and are constrained from being extended into the section in the original traffic direction.

4.2.14 Work Zone Protection

a. The Train Control System shall not grant movement authorities to trains to operate into out-of-service (blocked) tracks or through switches blocked in other than the required position and shall enforce restricted speeds on approach to and through defined work zones.
    1. The Train Control System may also include capabilities to preclude ATO mode of operation through a work zone.

4.2.15 Broken Rail Detection

a. The Train Control System shall interface to an auxiliary wayside system for purposes of receiving information regarding broken rail conditions to the extent that the AWS can detect such rail breaks.
    1. The Train Control System's reaction to a detected broken rail shall be as specified by NYCT.

4.2.16 Restricted Route Protections

a. The Train Control System shall include capabilities to prevent a train from entering a route that is unsafe for movement of that type of train due to mechanical, civil, electrical, or other predefined temporary or permanent conditions of the train or route, or through interfaces to intrusion detection devices, platform edge doors (where fitted), and/or other devices capable of detecting hazards that impact route integrity.

4.3 ATO Functions

4.3.1 General

a. The Train Control System shall, as a minimum, be capable of providing all of the ATO functions as defined in this subclause, to automatically operate trains in accordance with prescribed operating criteria within the safety constraints imposed by ATP.
b. The Train Control System's wayside-to-train and train-to-wayside data communications interface shall be sufficient to support all required ATO functions.

4.3.2 Automatic Speed Regulation

a. Automatic speed regulation shall be provided in both ATO and ATPM modes. The automatic speed regulation functionality for each mode shall be as specified below.
    1. ATO Automatic Speed Regulation
        i. The starting, stopping, and speed regulation of the train as it travels along the track shall be automatically controlled by the Train Control System so that the speed, acceleration, deceleration, and jerk rates are within specified passenger comfort limits (as defined by NYCT) and the train speed is below the overspeed limits imposed by ATP.
        ii. Station stopping accuracy shall be as specified by NYCT.
        iii. The Train Control System shall support multiple ATO speeds, acceleration, and service brake rates in accordance with the train operator (if present) or ATS inputs.
    2. ATPM Automatic Speed Regulation
        i. In ATPM the train is controlled manually by the Train Operator subject to the movement authority limits and overspeed protection. It shall be possible for the Train Operator to operate at any speed lower than the ATP speed or to stop the train. However, if the Train Operator attempts to operate the train above the ATP limit, the Train Control System shall automatically apply the Service Brakes to minimize ATP Speed Overshoots to avoid Emergency Brake applications.

4.3.3 Platform Berthing Control

a. The Train Control System shall be capable of implementing any of the following platform berthing control modes:
    1. Where the platform length is approximately equal to the train length, the Train Control System shall allow a train to enter a station platform only if there is sufficient room to fully berth or if the preceding train has a movement authority that shall allow it to fully leave the platform area and it has begun to move out of the station (i.e., within ATP constraints, train movement shall be controlled to minimize the likelihood of the train coming to a stop when only partially within the station platform limits).
    2. Where the platform length is longer than the train length, the Train Control System shall support multiple stopping positions within the platform area, as defined by NYCT.
    3. Where the platform length supports multiple train berthings, the Train Control System shall allow a train to enter a platform while another train already occupies an alternative berth.
    4. Where the platform length is shorter than the train length, the Train Control System shall support platform berthings consistent with the door opening control protection

interlocks.

4.3.4 Door Control

a. The Train Control System shall be capable of automatically controlling train doors during passenger boarding and discharging.
    1. As defined by NYCT, automatic door control may be limited to the following:
        i. Automatic door opening only (with or without passenger door open requests)
        ii. Automatic door closing only
        iii. Neither automatic door opening nor closing
    2. It shall be possible to manually disable the operation of any door set without affecting the automatic operation of other door sets.
    3. The amount of time the train is to remain in the station with doors open may be established by ATS and automatically controlled by ATO.
        i. While operating between stations in ATO, in the event of a loss of indication from the vehicle that all doors are closed and locked, the Train Control System shall apply a full-service brake until either the indication that all doors are closed and locked is recognized by the Train Control System or the train has come to a complete stop. It shall be possible for the Train Operator to continue in ATPM.

4.4 ATS Functions

4.4.1 General

a. The Train Control System shall be integrated with an I2S compliant (except section 4) ATS system. In addition to the I2S requirements for the ATS interface, the ATS functions shall be implemented as defined in this subclause.
b. The Train Control System's Data Communications network, inclusive of the wayside-to-train and train-to-wayside data communications interface, shall be sufficient to support the ATS functions and interface requirements as specified by in this specification and I2S.

4.4.2 ATS User Interface

a. Each ATS user interface shall display all information and implement all control actions as defined in this section.
b. Mandatory display data and user information inputs shall be in accordance with IEEE Std 1474.2-2003.
c. The ATS user shall be able to override any automated Train Control-related ATS functions.
d. Certain ATS functions (such as stopping a train en-route and the application and removal of temporary speed restrictions, switch/track blocking, or work zones) can potentially introduce system hazards and the specific implementation of these functions shall be considered in the hazard analyses required by Section 10. ATS functions are not required to be implemented in a fail-safe manner; however, the hazard analyses shall take into account, as a minimum, the probability of:
    1. Safety-related commands not being executed when initiated by an ATS user,
    2. The Train Control System prematurely removing safety-related commands initiated by an ATS user,
    3. The Train Control System executing safety-related commands that were not initiated by an ATS user,

4. Incorrect information being displayed by the Train Control System to the ATS user.

e. The hazard analyses shall give due consideration of the specific NYCT application and whether the trains are operated with or without crews.
f. Control action confirmation shall be provided for any safety-related user interfaces/inputs and functions whose inadvertent implementation could have an adverse operational impact.

4.4.3 Train Identification and Train Tracking

a. Each UWB-equipped train operating within UWB territory shall be assigned a train identification. This train identification shall indicate the type of train and other pertinent information about the train.
b. An ATS system shall have the capability to automatically track, maintain records of, and display on the ATS user interface the locations, identities, train schedule, and other pertinent data for all UWB-equipped trains operating in the UWB territory.
c. The front and rear position of trains shall be tracked based on Train Control System's train location reports, and the train location shall be displayed on the ATS user interface.
d. Variations in train length may be displayed either proportionally or as a standard-length icon supplemented by textual train length data.

4.4.4 Train Routing

a. An ATS system shall have the capability to permit UWB-equipped trains operating in UWB territory to be manually and automatically routed based on the Train Control System's train location reports and in accordance with the train service data, predefined routing rules, and any ATS user-directed service strategy.
b. Where applicable to the specific track configuration, automatic routing shall facilitate the proper merging and diverging of trains at junctions, turn back of trains, the movement of trains from/to storage areas, and the rerouting of trains in response to service disruptions and/or planned outages.
c. Train routes shall be indicated on the ATS user interface and may also be indicated to the train operator on their displays, as specified by NYCT.
d. Movement Authority Limits (MAL) shall be capable of being displayed on the ATS user interface, and any uncommanded reductions of authority limits shall be alarmed.
    1. The MAL shall also be indicated to the train operator on their displays.

4.4.5 Automatic Train Regulation

4.4.5.1 Schedule/Headway Regulation

a. An ATS system may have the capability to automatically monitor and regulate the performance of UWB-equipped trains operating in UWB territory, in relation to schedule and/or headway adherence.
b. An ATS system shall include an automatic dispatching function (based on train identities, the Train Control System's train location reports, scheduled and actual headways between trains, and service strategies implemented by authorized ATS users).
c. Schedule and headway regulation for UWB-equipped trains shall be by means of dwell time variance (including train holds) and may also be by control of run times between stations (e.g., through adjustments to train acceleration and service brake rates, and speeds), as specified by NYCT.
d. The desired station departure time and desired speed profile between stations shall be indicated to the train operators on their displays and, when operating in ATO mode, shall be implemented automatically by the Train Control System using the automatic speed

regulation function of Section 4.3.2.

e. An ATS system may provide the capability to adjust the train service braking profiles for UWB-equipped trains (e.g., in response to wet rail conditions).
    1. The Train Control System shall coordinate implementation of requested changes in service braking profiles to avoid conditions that would result in an emergency brake application.

4.4.5.2 Junction Management

a. The ATS system shall include automatic train regulation functions, based on the Train Control System's train location reports, to facilitate appropriate train meets (such as transfers between local and express tracks, and at the merge point between different lines) in order to minimize overall system delays.

4.4.5.3 Energy Optimization

a. The ATS system shall have the capability to implement energy optimization algorithms for UWB-equipped trains through the real-time control and coordination of train acceleration, train coasting, and train braking.
b. The priority given to energy optimization versus schedule/headway regulation shall be as specified by NYCT.

4.4.6 Station Stop Functions

4.4.6.1 Stop Train at Next Station

a. An ATS system shall include the means to direct a single UWB-equipped train or a group of UWB-equipped trains to stop at the next station, even if the train is scheduled to bypass that station.
    1. The Train Control System shall indicate the ATS train stop information to the train operator display.

4.4.6.2 Hold Train at Station

a. The ATS system shall include facilities to hold (and subsequently release) a UWB-equipped train at a station.
    1. The Train Control System shall indicate the train hold information to the train operator displays and prevent a UWB-equipped train from departing the station in ATO mode.

4.4.6.3 Skip Station Stop

a. The ATS system shall include facilities to direct a UWB-equipped train or group of UWB-equipped trains to pass through a station or group of stations without stopping.
    1. The Train Control System shall indicate the skip station information to the train operator display.

4.4.6.4 Door Control Inhibit

a. The ATS system shall include facilities to inhibit (and subsequently permit) the Train Control System's control of the train doors, in accordance with Section 4.3.4.

4.4.7 Restricting Train Operations

a. The application and removal of the following functions can potentially introduce system hazards and the specific implementation of these functions shall be considered in the hazard analyses required by Section 10.

4.4.7.1 Stopping a Train En Route

a. The ATS system shall provide a means to stop a single UWB-equipped train or group of UWB-equipped trains immediately.
    1. The Train Control System shall initiate an immediate brake application on the designated trains and notify the train operator via the display.

4.4.7.2 Temporary Speed Restrictions

a. The ATS system shall include facilities to impose (and remove) temporary speed restrictions for UWB-equipped trains operating on any section of track in UWB territory.

4.4.7.3 Switch/Track Blocking

a. The ATS system shall include facilities to block (and subsequently unblock) a switch, an exit signal, a route entry point, or a section of track within UWB territory.
b. The Train Control System shall prohibit UWB-equipped trains from receiving movement authorities over blocked switches not aligned in the required position or into routes and/or sections of track that have been blocked.

4.4.7.4 Work Zones

a. The ATS system shall include facilities to establish (and subsequently remove) temporary work zones for the protection of work crews and work trains.
b. The Train Control System shall enforce restricted speeds on approach to and through defined work zones.
c. Information indicating that the restriction is due to a work zone shall be displayed to the train operator display, and the Train Control System may preclude ATO mode of operation through a work zone.
d. The ATS system shall also provide methods of visually and audibly indicating the approach and direction of trains along the wayside to warn on-track roadway workers in areas where visibility is restricted.

4.4.8 Passenger Information System Interfaces

a. The ATS system shall interface with wayside and/or train-borne passenger information systems to trigger automatic passenger information messages, such as train arrival information, based on the Train Control System's train location reports.
b. Train-borne passenger information system interfaces shall be in accordance with IEEE Std 1477-1998.

4.4.9 Fault Reporting

4.4.9.1 Train Control System Fault Reporting

a. Failures and out-of-tolerance conditions detected by, or input to, the Train Control System that can impact the on-time performance of the transit system or result in some other loss of specific Train Control functionality shall be automatically indicated on the ATS user interface display.
b. Any alarms shall be categorized and prioritized into critical and noncritical alarms and logged. All critical alarms shall require acknowledgment.

4.4.9.2 Train Fault Reporting

a. Carborne equipment of the Train Control System shall include interfaces to Carborne subsystems for the purposes of communicating train health data to the wayside for display on the ATS user interface displays, as specified by NYCT.

5 DATA COMMUNICATIONS SYSTEM (DCS)

5.1 General Requirements

5.1.1 General

a. This section defines the requirements for the Train Control System's DCS Network to be designed, assembled, furnished, and tested by the Contractor.
b. The DCS Network shall consist of:
    1. A wayside network for communication between wayside elements of the Train Control System for the Project Lines;
    2. Network Management System for wayside network.

5.1.2 Scope of Work

a. Perform any and all necessary site surveys, communications environment studies, analyses, and tests required to support the design, installation, testing, and commissioning of the DCS network.
b. Design and develop a complete DCS network able to support the Train Control System's functional and performance requirements of this Specification.
c. Furnish all labor, materials, tools and equipment, and perform all operations necessary to design, build, ship, receive, unload, store, and test the DCS network as required and specified herein. The DCS network shall include all interface equipment, communications routing equipment, backbone wayside equipment, and other system elements necessary to implement a complete end-to-end data communications network for the Train Control System on:
    1. The Project Line territories.
    2. Transition areas for supporting entry & exit into UWB limits on the Project Lines (refer to Sections 1 and 3)
d. Test the Ethernet DCS network in accordance with applicable requirements of Section 9.
e. The Contractor is responsible for design, furnish, test, commission the DCS network meets all the requirements as specified in this Specification. The Contractor shall provide all necessary engineering support services, installation inspection services and acceptance of installed DCS network equipment.

5.1.3 Codes, Standards, and Specifications

a. Codes, standards and specifications referenced in this section are to be the latest edition in effect at the time of Contract Award unless otherwise noted, and are considered to be a part of this section as applicable.
    1. AREMA Communications and Signaling Manual of Recommended Practices, part 11.4.5 (Electrostatic Discharge Protection) and part 9.1.1 (Design Criteria for Lead Acid Battery).
    2. Cenelec 50159:2010, Railway applications - Communication, signaling and processing systems - Safety-related communication in transmission systems.

5.1.4 Submittals

a. Prepare and submit the following documents for the review and approval by NYCT as required at each phase of the project:
b. At PDR: Preliminary DCS Network Design Report which shall address (as a minimum) the

following issues:

1. FCC equipment certification
2. Optical link budget analysis (which includes all possible losses from test points, splices, etc. and distances of all lengths of cable used)
3. A complete description of DCS Network design (including hardware and software), and all subsystem interfaces. This description shall include the capacity of each communications link or interface, an estimate of the expected peak load on each link or interface and a preliminary allocation of the DCS requirements to functional subsystem elements. This description shall also include a summary of features incorporated into the network design that shall reduce the risk of the occurrence of broadcast storms (i.e. such as port limiting on network switches and proper training for personnel responsible for network installation and configuration).
4. Description of the master plan for testing subsystem elements of the DCS network to include the items to test.
5. Connections for power for all wayside equipment (including equipment for the NMS) and estimates for power consumption.
6. The level of DCS network redundancy required in order to comply with Section 8 despite the presence of network device failures. Evidence must be provided that shows that the DCS network does not contain any single point of failure.
7. Provide an DCS Network diagram which shows lines to represent network connectivity of each node and all IP-based network hardware, including desktops, servers, printers, hubs, switches, IP addresses and routers.
8. Provide a consolidated set of Design Criteria for the DCS network that forms the basis of design. Design criteria shall include all constraints that the DCS Network imposes on the major subsystems, (UWB Radios, ZCs), Solid State Interlockings (SSI) and ATS.
9. Provide an installation plan for all elements of the DCS Network.
10. Complete definition of data transmission requirements (i.e. data throughput, latency) of all interface devices.
11. Performance characteristics of individual LRUs including timing, testability, sizing, throughput, memory requirements that support previous analysis of DCS network performance.
12. Complete equipment and cable layout drawings and interface information for all wayside elements.
13. Catalog cut sheets and equipment specification sheets for all Contractor supplied DCS network equipment.
14. Analysis that shows how the overall DCS design satisfies the requirements for Cenelec 50159:2010 and mitigates all threats described in this standard.

c. At FDR: Submit the Final DCS Network Design Report addressing (as a minimum) the following issues:

1. A complete and final description of the DCS Network showing interfaces to all other systems and subsystems.
2. Layout drawings showing final location of all equipment and cabling on the wayside.
3. Submit detailed DCS network equipment test plans and procedures in accordance with Section 9 for approval by NYCT, that address (as a minimum) the following:
    i. Communications and interface tests between adjacent zone controllers via dedicated fiber optic cables.
    ii. Optical loss/attenuation tests to confirm optical link budget estimates provide earlier.
    iii. Network convergence times of 250 msec or less.
    iv. Evidence of tests on interference susceptibility/immunity of the Ethernet

DCS Network in accordance with Section 6.

4. Submit all Factory Acceptance Test (FAT) reports for DCS related equipment.

5.2 Products

a. Supply the complete DCS Network and all necessary equipment which meets the requirements of, and is capable of performing the functionality defined in these Specifications. The DCS Network shall include all necessary data communications equipment, software, wiring, and cabling required to interconnect the wayside subsystems.
b. The Ethernet DCS Network shall include:
    1. Communications hardware, software, cabling, and other devices as required to interface in the Project Line territories and Health Check Statuses with the following items:
        i. All field equipment i.e. ruggedized wayside switches that support Modbus protocol.
        ii. Remote ATS workstations located in the Project Line territory. The contractor, following proper survey, will provide the type of connection to the remote ATS workstation(s).
    2. The Contractor shall survey the Project Lines and verify that any available existing power is sufficient for the Wayside / DCS equipment being furnished in this Program.
        i. If the Contractor determines that the existing Power is not sufficient, NYCT will provide access to existing 120v / 60hz power from a Station. If any additional power is required for the wayside equipment, the Contractor shall design and furnish all materials, filtering, and conditioning equipment for the new Wayside power.
        ii. If additional power is required, NYCT or a third party will conduct the installation.
    3. Communications hardware, software, cabling, and other devices as required to interface between Zone Controllers (if applicable) and other distributed wayside equipment.
    4. All mounting hardware, brackets, cases, racks, cabinets or other items required for DCS Network assembly / installation.
    5. The Contractor shall design, furnish, install, test and commission power rack or cabinet that connects to the room UPS power source, and supplies the control voltage and energy required by the DCS Network equipment.
    6. The DCS Network shall utilize redundant Ethernet switches and routers that utilizes industry standard, non-proprietary protocols that supports all NYCT network communication types (SONET, COE, MODBUS) unless otherwise approved by the NYCT Program Manager.
c. The DCS Network shall be of a modular design that will support replacement of one LRU without significant impact on other aspects of the system design or operation.
d. The DCS Network shall interface internally and externally with other devices and systems.
e. The following apply to provisions of the DCS Network:
    1. All solid-state equipment furnished shall be protected, as a package, from lightning discharges, electrostatic discharge, power line surges, and electromagnetic interference in an approved manner. Furnish and install of approved types of EMI filters and surge suppressors.
    2. All solid-state devices shall be of heavy duty, industrial or commercial types. All furnished solid-state devices shall be commercially available from at least two manufacturers.

3. All printed circuit boards that connect by means of connectors shall be keyed to prevent them from being incorrectly inserted in the sockets.
4. All printed circuit boards shall have conformal coatings to protect against dust, humidity, etc.
5. There shall be no permanent external data communications connections to the DCS Network. Temporary external data communications connections may be permitted only during the testing and commissioning phases but must be protected by an NYCT approved firewall and completely and irrevocably removed once testing is complete.
6. Redundant DCS equipment shall be installed within two physically separate DCS cabinets, or if space constraints require, in one cabinet as approved by the Engineer. The DCS Contractor shall house in its DCS cabinet all DCS radio equipment and shall provide reserved space, circuit breakers and all necessary furnishing needed for the DCS radio integration in the DCS cabinet.
7. All data communications equipment furnished shall continue to function during, and shall not be damaged by, switching of primary power by the automatic transfer panels.
8. The DCS Network shall demonstrate acceptable reliability and availability as defined in Section 8. Specifically, no failure of two field or wayside elements shall result in a complete DCS network failure and no single DCS Network cable failure shall lead to an outage of RF coverage and/or data communications in any location.
9. The DCS Network shall be capable of self-monitoring and reporting down to the lowest replaceable card/board/module for all network elements on the wayside.
10. All fiber optic cables used will have 50% spare capacity.
11. All single mode and multimode fiber optic cables used (included jumpers) must be identified using a color scheme and cable tags.
12. All wire and cables shall comply with the NYCT wire and cable requirements identified in Section 13.2.

5.3 Execution

a. The Contractor shall supervise the installation of the DCS network.
b. All cabinets, enclosures housing electronic equipment shall be provided with adequate protection against electrostatic discharge during installation and maintenance of equipment in accordance with AREMA Communications and Signal Manual of Recommended Practices, part 11.4.5.
c. Test and commission the Ethernet DCS network in accordance with the requirements of Section 9 of this specification.
d. The Contractor shall coordinate with NYCT for the purposes of establishing, furnishing, and maintaining appropriate levels of DCS Network security.
e. The Contractor shall provide DCS Network and computer security that complies with Cenelec 50159:2010.
f. The Contractor shall furnish and install all the necessary DCS network interface to the ATS workstations located on the Project Line territory.
g. The design of the Project Lines DCS Networks shall not result in degradation of network redundancy and performance of any existing DCS radio or and DCS network.
h. The deployment, test and commissioning of a new DCS Network equipment shall have no operational impact on the existing DCS radio equipment and DCS network.
i. If the design required fiber optic, the Contract shall design for two physically separate fiber optic cables (36 single mode fibers in each cable) on either side of the track as part of the design of the Project Lines DCS Networks.

6 ENVIRONMENTAL REQUIREMENTS

6.1 General Requirements

6.1.1 General

a. This section defines the Environmental and Electromagnetic Compatibility (EMC) requirements for all Train Control equipment provided under this Specification.
b. Train Control equipment is defined as all carborne, wayside, and DCS equipment being provided by the Contractor to comprise a fully functioning Train Control System as defined by this Specification.
c. The test requirements specified in this section shall also serve as criteria for equipment design.
d. Where any conflict exists between the requirements of this section and any other section of this Specification, the more severe requirement shall be followed. The contractor shall request clarification through formal correspondence where any ambiguity exists.
e. If the Contractor provides justification, NYCT may accept waiving some requirements in this section. If the Contractor's system does not comply with all specifications of this section, the Contractor shall identify each line item that cannot be satisfied by the Train Control System per the Gap Analysis (see Section 1.6). **Unless a written waiver is provided to the Contractor by the NYCT Program Manager, it shall not be assumed that any requirements of this section are waived**.

6.1.2 Scope of Work

a. The Contractor shall demonstrate through rigorous analysis and test, as described in this section, that the Train Control System will meet all the Environmental and EMC requirements of this section.

6.1.3 Codes, Standards, and Specifications

a. Codes, standards, and specifications referenced in this Specification are to be the latest edition in effect at the time of contract award unless otherwise noted, and are considered to be a part of this Specification as applicable:
    1. American Railway Engineering and Maintenance Association (AREMA) – Communications & Signals Manual of Recommended Practices, Part 11.5.1-Recommended Environmental Requirements for Electrical and Electronic Railroad Signal System Equipment.
    2. Military Standards MIL-STD-810 – Environmental Test Method Guidelines.
    3. Institute of Electrical and Electronic Engineers (IEEE) – IEEE 1478 Environmental Conditions for Transit Rail Car Electronic Equipment.
    4. American Society for Testing & Materials, ASTM-B-117, Standard Practice for Operating Salt Spray (Fog) Testing Apparatus.
    5. American Society for Testing & Materials, ASTM-B-368, Standard Method for Copper-Accelerated Acetic Acid-Salt Spray (Fog) Testing (CASS Test).
    6. EN 50121-2, "Railway Applications – Electromagnetic Compatibility, Part 2: Emission of the whole railway to the outside world". (IEC Equivalent: IEC 62236 Part 2).
    7. EN 50121-3-1, "Railway Applications – Electromagnetic Compatibility, Part 3-1: Rolling stock – Train and complete vehicle". (IEC Equivalent: IEC 62236 Part 3-1)
    8. EN 50121-3-2, "Railway Applications – Electromagnetic Compatibility, Part 3-2: Rolling stock – Apparatus". (IEC Equivalent: IEC 62236 Part 3-2)

9. EN 50121-4, “Railway Applications – Electromagnetic Compatibility, Part 4: Emission and Immunity of the Signaling and Telecommunications apparatus”. (IEC Equivalent: IEC 62236 Part 4)
10. IEC 61000-1-2, Electromagnetic Compatibility; Part 1-2: General – Methodology for the achievement of the functional safety of electrical and electronic equipment with regard to electromagnetic phenomena.
11. FCC Regulations, Code of Federal Regulations (CFR), title 47, part 15.
12. MTA/NYCT AC Train EMC Standard.
13. IEC 60571 Electronic Equipment used on Rail Vehicles.

6.1.4 Submittals

a. The Contractor shall prepare and submit the following to the Engineer for approval:
    1. List of all Train Control equipment being supplied under this section and the corresponding proposed qualification method for each item listed.
    2. Environmental Test Plan.
    3. Environmental Test Procedures.
    4. Environmental Survey Test Plan.
    5. Environmental Site Survey Report.
    6. Environmental Test Report.
    7. EMC Control Plan.
    8. EMC Design Report.
    9. EMC Test Plan.
    10. EMC Site Survey Test Procedure.
    11. EMC Site Survey Report.
    12. EMC Signaling Compatibility Analysis.
    13. EMC Final Field Test Procedure.
    14. EMC Final Field Test Report.
    15. EMC Safety Analysis.

6.1.5 Environmental & EMC Testing Requirements

a. All Equipment furnished shall comply with the environmental requirements specified in Table 6-1 and Table 6-2 and the EMC requirements specified in this section.
b. The Environmental and EMC acceptance tests may be waived by the Engineer provided one of the following conditions are met:
    1. The equipment has been previously tested and certified compliant by a qualified test laboratory to the Environmental and EMC requirements specified in this contract or,
    2. The equipment has been successfully operating on NYCT property in a similar environment to that of this contract for more than five years without damage or performance degradation.
c. Before the Environmental and EMC Test Plans are submitted for review, the Contractor shall submit to the Engineer a list of all Train Control equipment being supplied under this Specification and a waiver request for any equipment on that list for which the Contractor is seeking to waive any portion of the Environmental or EMC testing. A separate waiver request shall be submitted for each piece of equipment. Each waiver request shall contain the following information:
    1. Detailed description of the equipment in question for this contract,
    2. Detailed description of the equipment previously qualified including all modifications or changes to the previously qualified equipment with an analysis of the impact of those modification or changes to the test results.

3. All major design differences between the previously tested equipment and the equipment being provided. The information provided shall be of sufficient detail such that the Engineer can confidently determine the similarity of the two pieces of equipment.
4. Contract name and number under which qualification tests have been performed.
5. List of the tests the contractor is seeking to waive.
6. Certified test data, including a description of the test setup, for all of the testing required by this section.

d. Equipment that has been previously tested on NYCT property and certified but has undergone hardware modifications shall be required to undergo all environmental testing.
e. All environmental testing shall be performed while equipment is operational and set up identical to the actual field installation and the operating environment. Where it is not practical to have the equipment under test operating throughout the entire test, functional tests shall be performed before and after the testing. Such details shall be outlined in the specific test procedures.
f. All testing shall be performed either at the Contractor's facilities or by an independent testing laboratory. The facilities or testing laboratory shall be accredited by either the National Institute of Standards and Technology or the American Association for Laboratory Accreditation. The test laboratory shall be ISO 9001 certified.
g. The Contractor shall submit Environmental and EMC Test Plans to the Engineer for approval. The Test Plans shall include information on the test lab to be used, the test personnel, the test schedule, test standards, test levels, test equipment, and failure criteria. Sample test report sheets shall be included in the test plans.
h. The Contractor shall submit Environmental and EMC detailed Test Procedures to the Engineer for review and approval. The test procedures shall detail the specific test setup for each test to be performed on a piece of equipment. The tests standards, test levels, detailed equipment setup, mode of operation during testing, and failure criteria shall be detailed. The detailed test procedures shall include diagrams showing the exact arrangement of the equipment for each test. This shall include the detailed mounting arrangement, including all brackets, associated mounting hardware, and sensor placement for the shock and vibration testing. The test procedures shall also outline specific mode of operation for the equipment under tests as well as the failure criteria. Test procedures shall be submitted at least 30 days prior to conducting the tests.
i. The Contractor shall submit certified test reports to the Engineer for review and approval for each piece of equipment tested within 30 days of completion of the test. The test reports shall include all test setup information including equipment calibration reports. The reports shall also include the pass/fail results for all tests. Any deviation from the test procedure shall be reported. All test failures shall be reported as well as resolutions.
j. If any failures are observed during the laboratory testing, the testing shall be stopped immediately and the Engineer shall be notified. The Contractor shall analyze the failure and implement a corrective action plan. The failed test shall be rerun with the corrective action(s) implemented. This process shall be repeated until the test has passed. The Engineer has the right to request retesting of any previously passed tests if the design change will affect those tests. Any design changes required to pass the test shall be reported to the Engineer for review and incorporated into the final design upon review and approval from the Engineer. All failed tests and implemented changes shall be recorded in the test report.
k. Environmental and EMC Site Surveys shall be conducted on the Project Lines as required in Sections 6.2.5 and 6.3.6.
l. Equipment used in these tests shall not be used in service. However, it should be refurbished and used as training aid.

6.2 Environmental Requirements

6.2.1 Classes of Environment

a. The Train Control System's equipment shall operate in a wide range of environments, from severe to benign. A severe environment is one in which no controls or conditioning is applied. A benign environment is one in which the ambient conditions are closely controlled at a predetermined level. In order to adequately specify the appropriate operating range for each piece of equipment used, the environments have been subdivided into the following eight (8) categories:
    1. Class A: Roadbed - All equipment directly attached to track components such as rails, ties, or mounted between the ties, within striking distance of debris falling from or attached to a train.
    2. Class B: Wayside Outdoors - All equipment located within 20 ft of track centerline, but not directly on the track bed.
    3. Class C: Wayside Signal Enclosures - All equipment installed in equipment cases, which provide basic shelter from rain and snow. No heating, air conditioning, and humidity control is provided.
    4. Class D: Wayside Control Rooms - All equipment installed in relay rooms or large enclosures, which provide basic shelter from rain and snow. Also, heating, air conditioning, and humidity control is provided.
    5. Class E: Computer Rooms - All equipment located in benign environment in Central Control and Tower Rooms.
    6. Vehicle Interior - All equipment mounted in the enclosed interior spaces of the vehicle. This category of environmental conditions is defined as E4 and E5 in IEEE standard 1478.
    7. Vehicle Exterior, Roof Mounted and Underfloor Mounted - All equipment mounted on space outside the enclosed areas of the vehicle, which is exclusive of direct contact with the rails ("sprung") (e.g., radio antennas). This category of environmental conditions is defined as E3 in IEEE standard 1478.
    8. Vehicle Exterior, Truck Mounted - All equipment mounted on "unsprung" components of the vehicle (e.g., trucks, wheels, and axles). This category of environmental conditions is defined as E1 and E2 in IEEE standard 1478

6.2.2 Parameters for Environmental Tests

a. Table 6-1 and Table 6-2 summarize the parameters for the environmental tests to be conducted by the Contractor. The tables are based on AREMA Part 11.5.1 and IEEE 1478. Test methodology used to demonstrate equipment capability to meet these environmental requirements shall be according to this Specification, the Contractor's qualification test plan, and the procedures contained in MIL-STD-pdr810.

Table 6-1 Vehicle Environmental Requirements

Parameter	Condition	Interior E4/E5	Exterior Body Mounted E3a/E3b	Vehicle Exterior Truck Mounted E2	Vehicle Exterior Axle Mounted E1
Temperature (°C)					
Relative Humidity					
Vibration					
Mechanical Shock					
Abrasive Environment					

Table source: IEEE 1478
** Parameter values are modified from IEEE 1478 Standards*

Table 6-2 Wayside Environmental Requirements

Parameter	Condition	Class A (Roadbed)	Class B (Wayside Outdoors)	Class C (Wayside Signal Enclosures)	Class D (Wayside Control Room)	Class E (Computer Room)
Temperature (°C)	Operation Max. Min.	 +70° -20°	 +70° -20°	 +70° -20°	 +55° -20°	 +25° +20°
	Storage Max. Min.	 +85° -30° *	 +85° -30° *	 +85 -30° *	 +85° -30° *	 +50° -15°
Humidity (Non-condensing)	Operating Max. Min.	95% 0%	95% 0%	95% 0%	95% 0%	45% 40%
	Storage Max. Min.	95% 0%	95% 0%	95% 0%	95% 0%	95% 5%
Vibration	5 - 20 Hz 20 - 200 Hz	0.2" p-p 4.2 g p	0.1" p-p 2.0 g p	0.07" p-p 1.5 g p	0.05" p-p 1.0 g p	0.05" p-p 1.0 g p
Mechanical Shock (11ms)	Shipping	10 g p	10 g p	10 g p	10 g p	10 g p
	Operating	10 g p	10 g p	10 g p	10 g p	-
Abrasive Environment	Salt Fog Rain Sand Dust/ Metallic Dust	Yes	Yes	No	No	No

Table source: AREMA C&S Manual Part 11.5.1
** Parameter values are modified from AREMA C&S Manual Part 11.5.1*

6.2.3 Environmental Test Sequence

a. The Contractor shall sequentially perform all the Environmental tests described in Section 5 of this Specification on one sample lot of Train Control equipment to the order specified below.
b. All equipment to be qualified for use as Train Control (wayside and carborne equipment) shall pass all environmental acceptance tests described in Section 5 of this Specification in the following sequence:
    1. Sinusoidal resonance vibration test.
    2. Sinusoidal Vibration test.
    3. Random Vibration test.
    4. Mechanical Shock test.
    5. High Temperature test.
    6. Low Temperature test.
    7. Rain test.
    8. Metal Dust test.
    9. Humidity test.
    10. Salt Fog test.
c. All Environmental testing shall be performed on a production level sample of the equipment. The equipment shall be functioning during the testing as it will be in actual service unless otherwise noted. The equipment shall be arranged for testing as it will be arranged in the field in actual service. All equipment that will be interfacing with NYCT's existing infrastructure or trains shall be included in the arrangement for the shock and vibration testing including all poles, brackets, isolators, and mounting hardware. Test arrangements shall be detailed in the test procedures and approved by the Engineer before testing begins.
d. The combined aggressive effect of humidity soak prior to the salt fog testing may cause undue environmental stress on electronic equipment. Therefore, salt fog testing may be performed on a separate sample lot from the rest of the environmental tests.
e. When carborne Train Control equipment is required by the Contract, samples of

production level carborne Train Control equipment shall be tested at the lowest and highest specified operating temperatures expected to be experienced by the equipment during normal operation. The equipment is expected to be turned on and to operate within these operating temperatures. The sample size shall at a minimum be two (2) complete production level sets of Carborne Train Control equipment to undergo the entire sequence of Environmental tests as specified above.

f. In case of failure of equipment during any of the tests, the interruption of the tests shall be administered as per guidelines in the MIL-STD-810. Any process of interruption of tests or alteration of sequence of tests or substitution of equipment shall be presented in the Environmental Test Plan in accordance with MIL-STD-810 and shall be approved by the Engineer prior to commencement of testing.

6.2.4 Detailed Environmental Test Requirements

a. Temperature
    1. The specified storage temperatures are the lowest and highest ambient temperatures expected to be experienced by equipment during storage or exposure to climatic extremes with power off. The equipment is not expected to be capable of operating at these temperatures, but to survive them without damage.
    2. The specified operating temperatures are the lowest and highest ambient temperatures expected to be experienced by the equipment during normal operation. The equipment is expected to be turned on and to operate within these operating temperatures.
    3. The equipment shall be fully operational within nominal boot up time as accepted for all Train Control subsystem equipment after initial turn on.
    4. The extreme temperature testing shall be performed on production Train Control units, without the use of forced air-cooling fans, or heaters.
    5. The Train Control equipment shall perform as required in the Specifications over the specified temperature range when tested. Testing shall include high and low temperature testing while under operating conditions.
    6. The Train Control equipment under test shall function per the Specifications without failure after storage temperature tests, and during and after operational tests.
    7. After testing, the Train Control equipment under test shall also meet the failure requirements of MIL-STD-810 Section 5.14.
    8. The Train Control equipment under test shall be subjected to operational high temperature testing as specified by MIL-STD-810 Test Method 501.5 Procedure II. The duration of the test shall be 72-hours and the temperature shall be as specified in Table 6-1 and Table 6-2. Equipment shall be turned on and fully operational (including displays) within the nominal boot up time as accepted for all Train Control subsystem equipment at the specified temperature. No external cooling may be utilized to pass this requirement.
    9. The Train Control equipment under test shall be subjected to operational low temperature testing as specified by MIL-STD-810 Test Method 502.5 Procedure II. The duration of the test shall be 8-hours and the temperature shall be as specified in Table 6-1 and Table 6-2. Equipment shall be turned on and fully operational (including displays) within the nominal boot up time as accepted for all Train Control subsystem equipment at the specified temperature. No external heating may be utilized to pass this requirement. Internal heater strips or other means, which are a permanent part of the system design, may be used.

b. Humidity
    1. The Train Control equipment under test shall be operated and stored without

damage and without degradation at the specified ambient relative humidity. The specified humidity is for an ambient operating temperature of 30°C and storage temperature of 60°C. The equipment shall perform as required in the Specifications following exposure to the specified temperatures and humidity extremes when tested in the context of Test Method 507.5, Procedure I – Induced (Storage & Transit) of MIL-STD-810.

2. The Train Control equipment under test shall function per the Specifications without failure after humidity tests and also meet the failure requirements of MIL-STD-810 Section 5.14.

c. Vibration
   1. The Train Control System's equipment shall be designed and manufactured to withstand the specified vibration encountered in all shipping, mounting, and operating modes without damage to the equipment.
      i. Vehicle (Test method per IEEE 1478):
         (a) To verify that the equipment can withstand the operating environment vibration tests shall be performed according to IEC 61373 as defined in Table 6-1.
      ii. Wayside (Test Method per MIL-STD-810):
         (a) Vibration tests shall be performed according to the standards contained in Test Method 514.6 of MIL-STD-810 (3 axis cycled vibration test) and to the levels indicated in Table 6-1 and Table 6-2. The Train Control equipment shall operate satisfactorily when subjected to sinusoidal vibration in the frequency range of 5 to 200 Hz applied along each of three mutually perpendicular axes for a period of four hours per axis.
         (b) The Train Control equipment under test shall function per the Specifications without failure after sinusoidal vibration testing. After testing, the equipment under test shall also meet the failure requirements of MIL-STD-810 Section 5.14.
         (c) Random vibration tests shall be performed according to the standards contained in Procedure I, Test Method 514.6 of MIL-STD-810. The Train Control equipment shall be subjected to random vibration with the power spectral density as shown in Figure 1, applied along each of the three mutually perpendicular axes for a period of four hours per axis.
         (d) The Train Control equipment under test shall function per the Specifications without failure during and after random vibration testing. After testing, the equipment under test shall also meet the failure requirements of MIL-STD-810 Section 5.14.

d. Mechanical Shock
   1. Vehicle (Test method per IEEE 1478):
      i. Equipment shall withstand the Table 6-1 shock conditions without damage, degradation, or abnormal operation.
   2. Wayside (Test method per MIL-STD-810)
      i. The Train Control equipment shall be designed and manufactured to withstand the specified shock and transient vibration encountered in shipping and operation. The equipment shall be capable of withstanding shock pulses of the shape and tolerance shown in Figure 2 when applied along each of three mutually perpendicular axes both in the positive and negative directions.
      ii. The Train Control equipment under test shall function per the Specifications without failure after being subjected to the specified mechanical extremes

per Test Method 516.6, Procedure I of MIL-STD-810 (3 axis shock pulse test). The equipment under test shall also meet the failure requirements of MIL-STD-810 Section 5.14 after testing.

e. Salt Fog
    1. The Train Control equipment that is exposed to the outdoor elements shall be capable of operating in, and suitable protected from heavy salt spray. The salt fog test shall be performed to the standards contained in Test Method 509.5 of MIL-STD-810. A 5% salt concentration (by weight) shall be used. The test solution shall be prepared as specified in ASTM-B-117 and acetic acid shall be injected as specified in ASTM-B-368. The equipment shall be capable of passing the Salt Fog Test when tested in the context of Test Method 509.5 of MIL-STD-810.
    2. The Train Control equipment under test shall function per the Specifications without failure after being subjected to the specified salt fog testing. The equipment under test shall also meet the failure requirements of MIL-STD-810, Section 5.14.

f. Rain
    1. The Train Control equipment that is exposed to the outdoor elements shall be capable of operating in rain, and suitably waterproofed to withstand rainfall at a minimum rate of 13 cm/hour and an accompanying wind rate of 18 m/sec. The equipment shall perform as required in the Specifications when tested in the context of Test Method 506.5, Procedure I of MIL-STD-810.
    2. The Train Control equipment under test shall function per the Specifications without failure after being subjected to the specified rain testing. The equipment under test shall also meet the failure requirements of MIL-STD-810, Section 5.14.

g. Metal Dust
    1. The Train Control equipment that is exposed to the outdoor elements shall be capable of withstanding the metal dust particles penetration in sizes from 1 to 650 microns in diameter. The equipment shall be capable of passing the Metal Test when tested in the context of Test Method 510.5 of MIL-STD-810 using metal dust instead of sand
    2. The Blowing Metal Dust testing procedures, as specified in Test Method 510.5 of MIL-STD-810, shall be performed on Train Control equipment intended for use in vehicles, wayside outdoors, and trackside equipment categories. The dust composition used as test media for this test shall be product PNF-50 (-30M) and manufactured by Ametek, Specialty Metal Products, P.O. Box 427 Route 519 Eighty-Four, PA 15330. The metal dust concentration shall be maintained at 0.3 g/m3. The air velocity shall be 8.9 m/s. The test shall be run for a duration of 6 hours at 23°C (1.5 hours per side) and 6 hours at the specified high operating temperature of the equipment. The Train Control equipment under test shall function per the Specifications without failure after being subjected to the specified sand and dust testing. The equipment under test shall also meet the failure requirements of MIL-STD-810, Section 5.14.

h. Contaminants
    1. For all categories of environment (except for Class D and E), the equipment shall be capable of resisting the effects of contaminants, which may penetrate into the equipment. The equipment shall function in the presence of high-pressure water, the below listed contaminants, and any other corrosives, where appropriate, without experiencing degradation in performance and reliability.
    2. The following is a list of possible contaminants:
        i. Iron/ Steel dust.
        ii. Oil vapor.
        iii. Oxides of nitrogen.
        iv. Ozone.

v. Carbon dust.
vi. Copper dust.
vii. Hair.
viii. Loose paper.
ix. Common cleaning solutions.

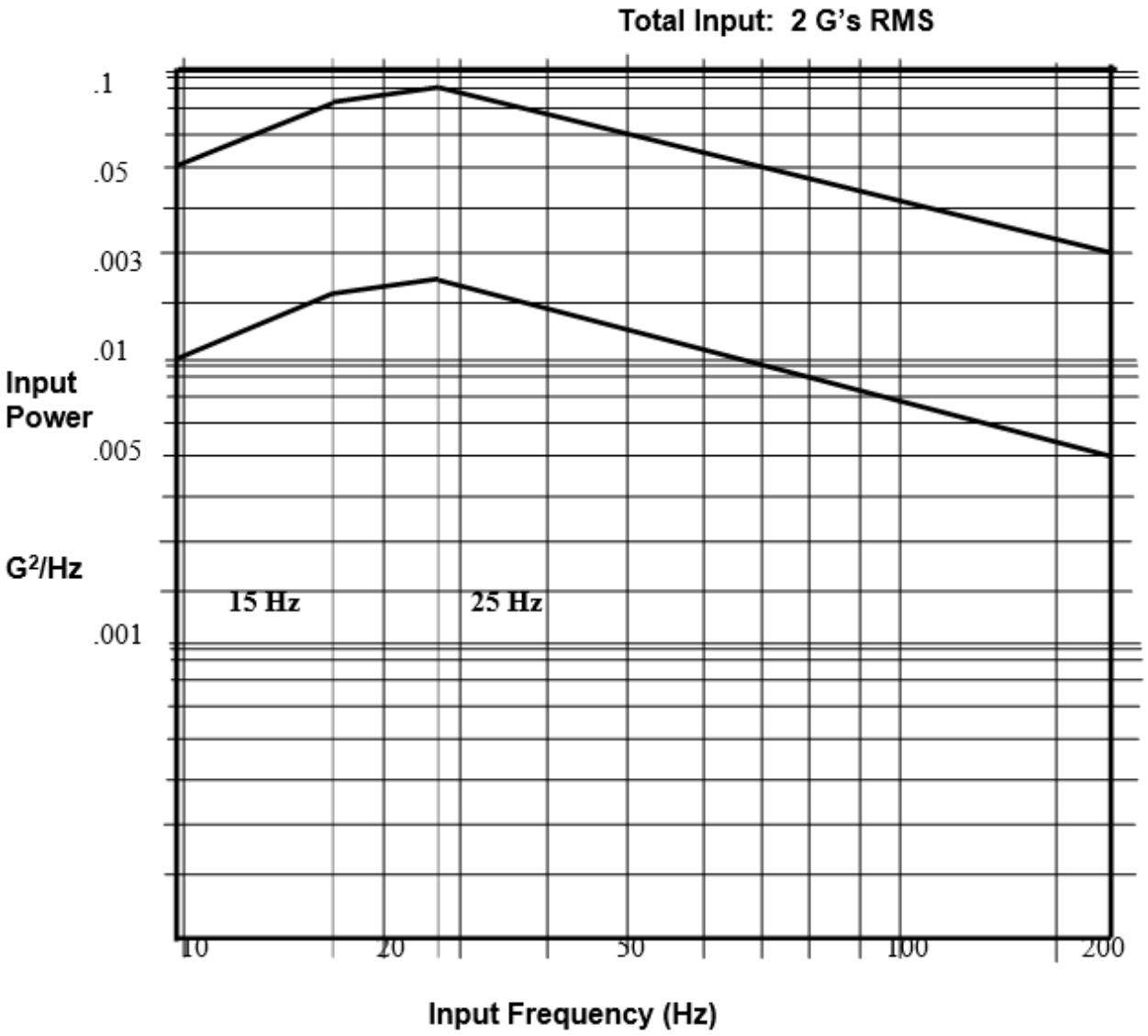


Figure 1 Power Spectral Density Graph for Random Vibration Testing

(Only applicable to wayside subsystems)
[Figure source: AREMA C&S Manual Part 11.5.1]

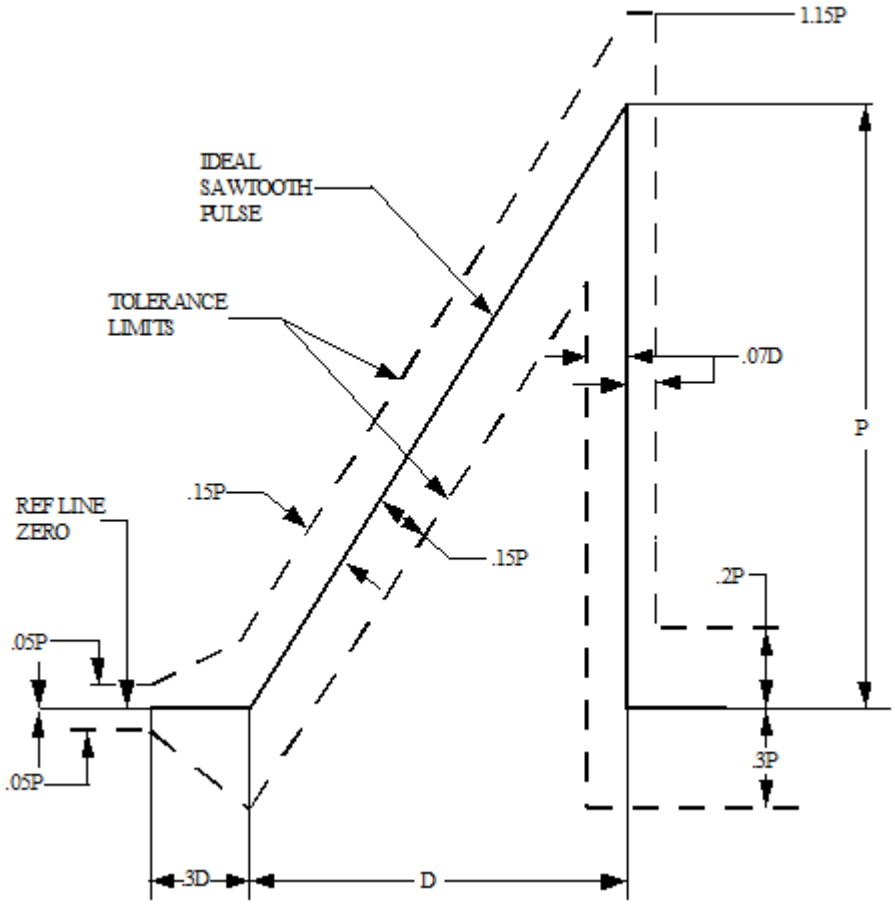


Figure 2 Shock Pulse and its Tolerance Limits

[Figure source: AREMA C&S Manual Part 11.5.1]

6.2.5 Environmental Site Surveys

a. The Contractor shall determine and report on the environment of the Project Lines where the Train Control equipment will be installed to verify that the Train Control System will operate as desired in the equipment's installed location(s). Site surveys shall be conducted at locations where equipment is to be installed to determine the maximum environmental levels present. Relay rooms and other indoor locations (if applicable) shall be assessed for temperature and humidity conditions. Elevated structures shall be assessed for shock and vibration conditions.
b. The Contractor shall conduct all necessary tests and site surveys of the environment of the Project Lines to determine the temperature and shock and vibrations levels present at the locations the Train Control equipment will be installed.
c. The Site Surveys shall cover an adequate quantity of field locations such that the worst-case limits can be determined.
d. The Environmental Site Survey Test Procedure shall be submitted to the Engineer 30 days after issuance of the Notice to Proceed.
e. The Environmental Site Survey Test Procedure shall include details relate to scheduling, personnel needed, equipment to be used, locations to be tested, and tests to be conducted.
f. The Environmental Site Survey Test Report shall be submitted and approved by the Engineer at PDR.
g. The Environmental Site Survey Test Report shall include a comparison of the ambient

levels found at each location to the equipment limits described in Table 6-2. The report shall demonstrate through analysis that all Train Control equipment has been designed and tested to operate as intended under the measured field conditions at the locations where it is to be installed with adequate safety margins. If ambient conditions at a location exceed the design limits of the equipment to be installed at that location, the report shall present recommended modifications to the location and/or to the equipment such that the equipment will be able to operate as intended in that location.

h. The Contractor shall implement the required modification(s) to the location and/or the equipment as agreed to by the Engineer.

6.3 Electromagnetic Compatibility (EMC) Requirements

6.3.1 General Requirements

a. The Train Control System shall be electromagnetically compatible within itself, with other equipment provided by the Contractor, with all Trains in operation at NYCT, with NYCT communications systems, with other NYCT electronic equipment, and with all electronic equipment operating adjacent to NYCT's property, as specified elsewhere within this Specification.
b. The Contractor shall analyze its systems and wiring design and the environments into which these elements will be placed and shall develop a design that to the maximum extent possible is inherently free of interfering electromagnetic emissions and immune to electromagnetic susceptibility. The design shall consider isolation, shielding, grounding, bonding, wiring methods and routing and any other aspects of the proposed installation in order to minimize the potential for electromagnetic interference.
c. The Contractor shall conduct a program which achieves and documents the EMC. The Contractor shall apply the EMC program requirements to all subsystems and suppliers. The Contractor shall ensure that all equipment, both individually and together, complies with the EMC requirements in all modes of operation including failure modes. The Contractor shall ensure that all Train Control equipment complies with the EMC requirements, in all possible operation modes, including all allowed modes of degraded performance and failure modes. The Contractor shall work with NYCT and its suppliers to resolve any EMC problems, as they relate to the Train Control system and their operation, discovered during execution of this Contract.
d. The Train Control System electromagnetic emissions shall also comply with applicable portions of FCC Regulations, including those related to FCC OET Bulletin 65 regarding human exposure to radiofrequency electromagnetic fields.
e. The laboratory testing of various subsystems is required as a guide during the design phase to ensure a high probability of EMC compliance for the complete Train Control System. Successful testing on a subsystem level does not ensure EMC compliance. Final approval of EMC compliance shall be based on testing of the complete Train Control System, under worst case conditions on the actual NYCT environment.
f. All values stated in this in this section (including those mentioned in the codes, standards cited below) shall be interpreted as peak values and not average values.

6.3.2 Scope of Work

a. The Contractor shall execute the following activities:
    1. Conduct and document a program in which the Train Control System achieves EMC while providing safe and reliable operation in all specified functions and modes.
    2. Apply the EMC program requirements to all subsystems and sub-contractors within

the Contractor's scope.

3. Ensure that all equipment provided, taken individually and together, complies with the EMC requirements of these Specifications, in normal, degraded, and emergency operating and maintenance modes.
4. Demonstrate to the satisfaction of the Engineer that the systems or equipment furnished and installed will not interfere with any existing systems or equipment.
5. Work with NYCT and its other equipment suppliers to resolve any EMC problems discovered during execution of this Contract.

6.3.3 Definitions

a. Electromagnetic Compatibility (EMC) is defined as the ability of the Train Control System and its subsystems to operate satisfactorily in the electromagnetic environment of NYCT. This means that the Train Control System shall operate without malfunction and shall not cause other equipment and systems within the NYCT environment to malfunction.
b. Electromagnetic Interference (EMI) is defined as electromagnetic signals generated by the Train Control System and/or its subsystems which degrades the proper operation of systems external to the Train Control System, such as the communications system, signaling system, carborne system or any wayside devices, as well as equipment co-located within NYCT's right of way, but not owned by NYCT

6.3.4 EMC Program Requirements

a. All Train Control equipment shall meet the following requirements:
    1. Operate within the performance requirements specified herein without any degradation of performance, malfunctions, unacceptable and undesirable responses, or damages, caused by radiated or conducted electromagnetic signals, noise transients or spikes existing or introduced by radio equipment at the locations where the equipment shall be installed and operated.
    2. Not generate electromagnetic signals, noise, transients or spikes that interfere with the operation of other equipment.
    3. Comply in all respects to FCC Regulations defined in CFR Title 47, part 15 for incidental, intentional and unintentional radiators including digital devices and FCC OET Bulletin 65 regarding human exposure to radiofrequency electromagnetic fields.
b. EMC shall be part of the basic design of the equipment to be furnished and installed. The application of electromagnetic control components including but not limited to: filtering, shielding, bonding and grounding shall be an integral part of the equipment.
c. Due to the presence of strong magnetic fields no Cathode Ray Tube (CRT) technology is permitted. Only Liquid Crystal Display (LCD) technology is acceptable.
d. The requirements in evaluating EMC shall include, but not be limited to the following:
    1. Degradation Criteria. Degradation criteria shall be established by the Contractor for each system/equipment and approved by the Engineer. These criteria shall be used to define and evaluate malfunctions, unacceptable and undesirable responses. When available, the results of system/equipment laboratory interference tests shall be used in establishing or defining the criteria.
    2. Safety Margins. Safety margins shall be established for systems/equipment. Existing test points shall be used, use of special equipment manufacturers or circuit breakouts shall be minimized. Unless otherwise specified in the Contract, safety margins less than 6 dB shall not be used. When safety margins have been established and approved for systems/equipment the inputs, outputs or other test points shall be monitored on a continuous basis and reports of monitoring

submitted to the Engineer.

3. Instrumentation. Approved equipment intended for use with the system shall be used to monitor systems/equipment and provide data records.
4. Acceptance Criteria. Compliance with these Specifications shall have been achieved when compatible operation, including any approved safety margins, is demonstrated without unacceptable responses or malfunctions.
5. Equipment affecting vital functions shall either not be affected or shall be made to fail safe when portable radio transmitters/receivers are operated in the vicinity of the equipment when the equipment case is open.

e. If the Contractor's EMI/EMC control program is not being performed to the satisfaction of the Engineer, NYCT may direct that the Contractor assign one or more full time EMI/EMC Engineer(s) dedicated solely to this project at no additional cost or expense to the Contracting Party or the Authority.
f. Safety and functionality parameters shall be established and approved by NYCT for all Factory and Field System Testing.

6.3.5 EMC Control Plan

a. The Contractor shall submit an EMC Control Plan prior to PDR. The EMC Control Plan shall document the process of EMC Management, outlining the criteria to be met and the methods used by the Contractor to meet the specified requirements and achieve EMC. The EMC Control Plan shall contain the following:
    1. Organizational responsibilities that clearly shows the direct reporting relationship between the EMI/EMC Engineer and the Systems Integrator so as to achieve and document compliance with EMI/EMC requirements. The objective is to ensure adequate authority is vested in EMI/EMC Engineer so as to resolve problems at the earliest opportunity.
    2. The name, address and relevant certification of any EMI/EMC Test Laboratory or organization that the Contractor has or is proposing to use.
    3. EMI/EMC Engineer Qualifications. Emphasis is required on the cross-discipline and independent nature of the EMI/EMC Engineer, showing that they can effectively influence the design when EMC aspects are at variance with other constraints. The EMI/EMC Engineer shall have a minimum of 5 years of qualified experience in the field of EMI and EMC, including but not limited to: preparation of EMI control plans, EMI test plans, performing EMI testing, preparation of reports and shall have thorough knowledge of EMI standards. Specific duties of the EMI/EMC Engineer shall include the following:
        i. Prepare all control plans, test procedures, on-site test reports, supervise all tests, review all design and installation work and coordinate all EMI/EMC work.
        ii. Work from the time of commencement of the design work until such time as the work has been completed, accepted and placed into operation.
    4. A schedule of EMC document submissions, audits, tasks and milestones shall be included.
    5. A summary of EMC requirements passed to sub-contractors by the Contractor.
    6. An EMC Cable Management strategy.
    7. Details of the installation guidelines, cable classification and segregation system used to achieve systems EMC.
    8. Approach for determining the EMC environment, and organization of the EMC Environment Report.
    9. Approach for analysis of EMC design characteristics, emissions, susceptibility, and margin of Train Control equipment, and organization of the EMC Design Report.

10. Approach for analysis of EMC safety impacts, and organization of the EMC Safety Analysis.
11. Frequency matrix showing clock and other operating frequencies of all equipment.

b. The EMC Control Plan shall be updated whenever there are major changes to any part of the design that relates to EMI/EMC.

6.3.6 EMC Site Surveys

a. The Contractor shall conduct a comprehensive study to determine and furnish a report on the NYCT EMI/EMC environment for the Train Control System. The Contractor shall adequately determine the EMI/EMC environment, so that the Contractor can ensure that the Train Control System emissions do not interfere with other NYCT and neighboring equipment, and so the Contractor can ensure that the safe and reliable operation of the Train Control System is not adversely affected by emissions of the NYCT EMI/EMC environment. The EMC Site Surveys shall cover an adequate quantity of field locations such that the worst-case limits can be determined.
b. The Contractor shall conduct all necessary tests and site surveys of the Project Line EMI/EMC environment to determine the emission levels and susceptibility levels of NYCT equipment which could interact with the Train Control System.
c. Specifically, the EMC Site Survey Test Report shall include sections covering but not limited to:
    1. Train Emissions: Where Carborne Train Control equipment is required by the Contract, the Train Emissions section shall identify train emissions related to carborne and wayside Train Control System and AWS equipment, for trains presently in operation on the Project Lines. Train worst-case emissions including operation of any or all train equipment alone or in combination, and in normal, abnormal, failure, and emergency conditions shall be considered.
    2. Train and Complete Vehicle: Where carborne Train Control equipment is required by the Contract, radiated emission shall be measured in accordance with the procedures contained in “Railway Applications – Electromagnetic Compatibility, Part 3-1: Rolling Stock – Train and complete Vehicle, EN 50121-3-1”. Test shall be performed with the train in static and dynamic mode.
    3. Railway Emissions: Emissions shall be measured in accordance with the procedures contained in “Railway Applications – Electromagnetic Compatibility, EN 50121-2: Emissions of Whole railway to the outside world”.
    4. Carborne subsystem: Where carborne Train Control equipment is required by the Contract, carborne emissions and susceptibility shall be measured in accordance with the procedures contained in “Railway Applications – Electromagnetic Compatibility, Part 3-2: Rolling Stock – Apparatus, EN 50121-3-2.
    5. Environment at equipment Locations: The Contractor shall determine ambient operating environment at all equipment locations and furnish a report on the ambient conditions that apply to the Tain Control equipment installation locations. Determination of the RF ambient shall include:
        i. New and existing NYCT and New York metropolitan area Public Safety communications systems.
        ii. Cellular and PCS systems.
        iii. Wireless LAN devices.
d. Particular attention shall be paid to the pass band of the Train Control equipment and the surrounding frequencies. The Contractor shall propose, for approval by the Engineer, a suitable frequency range for test. Such equipment could include On-Board and Wayside Radios, Antenna Systems (Active or Passive), Radio Frequency (RF) Distribution Systems, Repeaters, Regenerators, or any other device that would be susceptible to RF

interference. The purpose of this testing is to characterize the environment so that the Contractor can show by design, analysis, and test, that at least a 6dB margin is maintained at all times. All tests shall measure H-Field and E-Field.

e. The EMC Site Survey Test Report may emphasize operating frequencies which correspond to operating frequencies of the Train Control equipment and other critical frequencies to the extent those frequencies are documented in the Contractor's EMC Design Report.
f. The EMC Site Survey Test Procedure shall be submitted to the Engineer 30 days after Notice to Proceed.
g. The EMC Site Survey Test Procedure shall include details relate to scheduling, personnel needed, equipment to be used, any train movements required, locations to be tested and tests to be conducted.
h. The EMC Site Survey Test Report shall be submitted and approved by the Engineer at PDR.
i. The Site Survey Test Report shall include a comparison of the ambient levels found at each location and the CENELEC standard EMC limits. Recommend specific modifications to the emissions and susceptibility limits in the CENELEC standards as required to for compatibility with the ambient EMI levels.

6.3.7 EMC Design Report

a. The Contractor shall furnish a Report on the EMC design characteristics of the Train Control equipment.
b. The Report shall discuss all EMI/EMC design methods and techniques utilized to ensure EMC compliance at the system, subsystem, and individual equipment level, and describe operation of all subsystems as part of the overall Train Control System.
c. The EMC Design Report shall include, but not be limited, to the following sections:
    1. EMC Equipment Identification: The EMC Design Report Equipment Identification section shall identify all Train Control equipment with significant emissions or susceptibility with respect to the NYCT EMC environment.
    2. All EMI/EMC documentation shall be identified together with all EMI/EMC specifications that are to be used in the design and validation.
    3. An analysis of any corrosion threats, issues and mitigations.
    4. Maintenance requirements needed to maintain the system's immunity to EMI and preserve its EMC.
    5. Intended installation location and identify which parts of the system are contained within an equipment room, which are external and estimated separation distances.
    6. EMC equipment characteristics: For identified Train Control equipment, the EMC Design Report equipment characteristics section shall provide a complete description, statement, and analysis of equipment operating parameters and characteristics related to emission and immunity, including but not limited to operating frequencies, sensitivity levels, circuit configurations and impedances, modulation, coding, error detection, and emission levels. The information in the section shall fully describe all design aspects related to EMC, including protections against interference such as message coding and checking.
        i. For equipment in which EMC performance could be affected by changes to configuration or parameters of the software or firmware, provide complete documentation of the software or firmware, and an approved configuration control record for the delivered and tested software or firmware version.
        ii. The EMC Design Report shall include a grounding plan which states the Contractor's grounding approach and implementation. The plan shall

include system grounds, safety grounding, power grounding, applications of single point grounding, applications of multipoint grounding, applications of hybrid grounding, use of ground planes, rack grounding, equipment grounding, cable shield grounding, and circuit grounding. A grounding diagram shall be used to show the grounding topology.

iii. The EMC Design Report shall include a cable routing plan which states the cable routing approach and implementation. The plan shall separate signals and electromagnetic noise from high level signal circuits and power circuits and equipment from coupling into low level circuits. The plan shall include cable routing on messenger and in precast channel, within rooms and enclosures and on racks.

iv. The EMC Design Report shall include details of filter characteristic and component values of power line filters. If filter pins are to be employed in the design, the attenuation and peak rating characteristic shall be included. A description of construction materials employed in the design shall be given. Bonding surfaces shall be identified, together with details of any surface treatment used to achieve compliance.

v. The EMC Design Report shall contain details of mechanical design as related to EMC. Materials shall be described, as well as procedures and methods to be used for purposes of attenuating electromagnetic emissions and reducing susceptibilities of equipment to the specified electromagnetic threats. A description shall be given for internal shielding and filtering methods used to achieve compliance. Mechanical drawings shall be used to identify the locations and physical characteristic of possible apertures, electrical connectors and panel mounted components, and design details of RFI gaskets.

6.3.8 EMC Test Requirements

a. All EMC testing shall be performed on a production level sample of the equipment. The equipment shall be functioning during the testing as it will be in actual service. The equipment shall be arranged for testing as it will be arranged in the field in actual service. When so determined by the Engineer, portions of the existing systems which will be in close proximity to the installed Train Control System components shall be simulated in the test environment so that a more direct measurement of interference or coupling with the existing systems can be performed. The detailed test procedures shall include diagrams showing the exact configuration for each piece of equipment. The test procedures shall also outline specific mode of operation for the equipment under tests as well as the failure criteria.
b. Where any EMI levels are observed during the EMC Site Surveys that exceed the levels described in the sections below, the levels observed during the Environmental test shall apply.
c. When carborne Train Control equipment is required by the Contract, carborne equipment shall comply with the requirements of EN 50121-3-2.
d. Wayside communications equipment shall comply with the requirements of EN 50121-4.

6.3.9 EMC Signaling Compatibility Analysis

a. The EMC Signaling Compatibility Analysis shall demonstrate that the Train Control System will operate as intended in the NYCT operating environment and that it will not cause degradation of performance, under normal and credible failure conditions to any pre-existing system or third party assets.

b. The analysis shall include all operating frequencies from DC to 10 GHz. For frequencies not covered by the IEC 50121 series of standards the Contractor shall propose other test methods and standards to the Engineer for approval.
c. The EMC Signaling Compatibility Analysis shall be submitted to the Engineer for review and approval after all field and laboratory EMI/EMC testing has been completed. The purpose of the analysis is to show that the measured environmental and equipment emissions are within the tolerances of the measured equipment susceptibility for all Train Control equipment, with the required margins taken into account.
d. Equipment Susceptibility: The Equipment susceptibility section shall provide a documented analysis of the susceptibility of the identified Train Control System with respect to the NYCT electromagnetic environment. For each identified piece of Train Control equipment with significant susceptibility, the Equipment Susceptibility section shall provide an analysis with:
    1. Level and type of signal to which the identified equipment is EMI-susceptible.
    2. Worst-case and typical predicted level of the signal in the NYCT environment, from the EMC Site Survey Test Report.
    3. Contractor's proposed worst-case margin against disruption of safe and reliable operation of the identified Train Control System by the NYCT EMC environment. Where appropriate, the section may include statistical or signal analysis to describe system-level protections against interference.
e. Equipment Emissions: The Equipment Emissions section shall provide a documented analysis of the emission of the identified Train Control Systems with respect to the NYCT electromagnetic Environment. For each identified piece of Train Control equipment with significant emissions, the Emissions section shall provide an analysis with:
    1. Worst-case and typical level and type of emission for each piece of identified equipment.
    2. Identification of NYCT environment items which may be affected by an emission from the Train Control equipment, such as train or other two-way radio services.
    3. Predicted susceptibility level of the environment item which may be affected by the Train Control equipment.
    4. Contractor's proposed worst-case margin against disruption of the environment item by the identified Train Control equipment. Where appropriate, the section may include statistical or signal analysis to describe system-level protections against interference.
    5. The Emissions section shall include but not be limited to an analysis of the RF Data Link and the Train Control System's Wayside-to-central Data Link. Worst case radiated emissions shall include variable RF propagation characteristics.
f. Induced Voltages: The Contractor shall ensure and demonstrate with evidence that any cables supplied under the Contract other than power cables used by the System are properly shielded, grounded and terminated to prevent noise and/or electric shock.
g. Operation Requirements: The Operating Requirements section shall provide the Contractor's statement of operating or maintenance restrictions to control susceptibility and/or emissions, such as keeping equipment covers closed when operating portable radios, or keeping radios off near certain equipment.
h. Internal Interface EMC: The internal interface EMC section shall state and detail the Contractor's selected standard for achieving EMC at interfaces between modules and elements which make up the Train Control System. The Contractor may select a standard published by a standard-making body, e.g. IEEE-STD-1100, EN 300 253, or may select a proven project standard created by the Contractor and approved by NYCT.

6.3.10 Final Field EMC Testing

a. The Contractor shall develop an EMC test strategy (plan) to demonstrate compliance of the Train Control System to the requirements of EN 50121, and section 3.4 of the MTA/NYCT AC Train EMC Standard.
b. After all installation work is complete, the Contractor shall perform required Final Field EMC Tests in accordance with the EN 50121 series of standards, section 3.4 of the MTA/NYCT AC Train EMC Standard and this section.
c. The Final Field EMC test performed by the Contractor shall be witnessed by the Engineer and shall demonstrate EMC between all subsystems and/or equipment (both vital and non-vital) during all modes of operation while the subsystems and/or equipment are individually or collectively operated. Final Field EMC tests shall be completed and approved by the Engineer prior to the request for a ”Bulletin” for taking equipment into service.
d. The Contractor shall execute testing as per the guidelines of FCC OET Bulletin 65 regarding human exposure to radiofrequency electromagnetic fields.
e. The Contractor shall execute the following steps:
    1. Establish procedures for the Final Field EMC tests: For each item, prepare a Test Plan, in which the Contractor will quantitatively demonstrate that the item achieves the margin identified in the EMC Design Report worst case conditions. At a minimum, the Test Plan shall include the following sections: Introduction, Schedule, Equipment Configuration Under Test, Test Track, Test Equipment Configuration and Calibration, Test Runs, Test Methods, Test Data Collection Procedures, and Test Report Format. Each Test Plan shall include the following:
        i. Test conditions and procedures for all electronic and electrical systems/ equipment installed in or associated with the system and equipment under test.
        ii. Modes of operation and monitoring points for each system and equipment.
        iii. Methods to be used to select critical circuits to be monitored for compliance with the degradation and safety margin.
        iv. Procedures used for developing failure criteria and limits.
        v. Evaluation and degradation criteria for each system and equipment.
        vi. Use of approved results from laboratory interference tests on systems and equipment.
        vii. Details concerning frequency ranges, channels, and combinations to be specifically tested such as image frequencies, intermediate frequencies, local oscillator, and transmitter fundamental and harmonically related frequencies. Systems susceptibility criteria identified during laboratory testing shall be included.
        viii. Tests with a portable radio/cellular telephone operating at VHF, UHF and common cellular frequencies as follows: 160 MHz, 460 MHz, 800 MHz, 915 MHz, 1.9 GHz, 2.4 GHz and 5.8 GHz. This test would be performed with the portable radio/cellular telephone in transmit mode within 6 inches of Train Control equipment with cabinet doors open and closed.
        ix. The sequence for operating systems/equipment during tests.
        x. Adjustment and settings of variable controls.
        xi. Methods and procedures for data readout and analysis.
        xii. Calibration schedules and description of instrumentation for measuring electrical, electronic, video, and mechanical outputs of equipment and systems to be monitored during the testing.
        xiii. Personnel required for the Contractor and NYCT.
    2. Perform tests: For each identified item, perform and document the test per the

approved test procedures. Coordinate in advance with NYCT for access to, control of, and safe operation of NYCT staff, track, trains, equipment, and facilities.

3. Test Report: For each tested item, prepare a Final Field EMC Test Report which shall document the results of the follow:
    i. At a minimum, each test report shall include the following sections: Introduction, Schedule, Equipment Configuration Under Test, Test Track, Test Equipment Configuration and Calibration, Test Runs, Test Methods, Test Data Collection Procedures.
    ii. Analyze the results of each Final Field EMC test and determine if the equipment as built is suitable for deployment in the NYCT environment. A margin of at least 12 dB shall be maintained in vital circuits and 6 dB on all non-vital microprocessor-based equipment. Techniques for minimizing the effects of unfavorable tests results, or analysis showing the test results will not result in degradation in the safety, reliability, or performance of the system shall be submitted. The Engineer will have unilateral authority to approve the design recommendations or analysis submitted. If the Contractor recommended solution is not approved, the Contractor must identify a suitable design to meet the requirements specified herein at no additional cost to NYCT, and shall submit the modified design for approval, with test results which show the design meets the requirements.
    iii. As part of each Final Field EMC test report, the Contractor shall prepare a compliance matrix to record test results from individual equipment/systems in the presence of other equipment/systems.
4. Approval: The Engineer will be the sole approving authority for Final Field EMC Test Reports submitted by the Contractor. The Engineer will approve the Contractor's Final Field EMC Test Reports and equipment if the Contractor has demonstrated satisfactory Train Control operation in worst case operating modes with approved margins.

6.3.11 EMC Safety Analysis

a. The Contractor shall furnish an EMC Safety Analysis Report. This report shall include a comprehensive study demonstrating that all EMI related risks and potential hazards that may adversely affect the functionality of the Train Control System or Vehicle Control Systems, have been identified and mitigated. This report shall be submitted to NYCT for approval.
b. The EMC Safety Analysis shall include an assessment of the potential threat of electromagnetic disturbances to the Train Control System and Vehicle Control Systems. This should take into account the intended electromagnetic environment.
c. The EMC Safety Analysis report shall include an assessment of the safety impact to the Train Control System and Vehicle Control Systems and corrective actions to achieve desired safety integrity level. The report shall include provision to prevent EMC hazards due to changes in software or firmware parameters.
d. The EMC Safety Analysis report shall include an assessment of the Train Control System emissions and its impact on neighboring equipment.
e. The EMC Safety Analysis report shall address all operating hazards which cause EMI impacts, such as using a portable radio near an open equipment locker, and documentation that residual hazards are compatible with NYCT safety requirements.
f. The EMC Safety Analysis report shall address the relationship of the Train Control System and AWS EMC program to other EMC programs, including new technology vehicle procurements.
g. To facilitate this exercise, the Contractor shall refer to the IEC 61000-1-2,

"Electromagnetic Compatibility – Part 1-2: General – Methodology for the achievement of functional safety of electrical and electronic equipment with regard to electromagnetic phenomena"

h. The EMC Safety analysis report shall be compatible with the Contractor's System Safety Program.

7 SOFTWARE REQUIREMENTS

7.1 General Requirements

a. This section defines the software requirements for the Train Control System.

7.1.1 General

a. The Contractor is expected to develop a comprehensive program for the development of software that complies with all requirements of this Specification. It is envisioned that each subsystem supplier (i.e. Contractor) will provide their own set of software documentation.
b. Where the Contractor has a software development process in place that meets the intent of these requirements but is not in complete compliance, the Contractor must document and provide the specific details of the process they intend to use, for Engineer approval within the Software Development Plan (SDP). The Contractor must not proceed with the implementation of any process or plan prior to Engineer approval; if the Contractor elects to do so, it will be at their own risk.
c. The software requirements specified herein shall be applicable to all Contractor, subcontractor and Original Equipment Manufacturers (OEMs) that are responsible for delivering software products for each subsystem. All required software documentation shall describe the processes that will be followed by the Contractor, subcontractors, and OEMs.
d. If the Contractor provides justification, NYCT may accept waiving some requirements in this section. If the Contractor's system does not comply with all specifications of this section, the Contractor shall identify each line item that cannot be satisfied by the Train Control System per the Gap Analysis (see Section 1.6). **Unless a written waiver is provided to the Contractor by the NYCT Program Manager, it shall not be assumed that any requirements of this section are waived**.

7.1.2 Scope of Work

a. The Contractor shall furnish all tested software required for each subsystem, including central, and wayside subsystems, as required by the contract.
b. The Contractor shall furnish all documentation associated with each software subsystem.

7.1.3 Codes, Standards, and Specifications

a. Codes, Standards and Specifications are to be the latest edition in effect at the time of Contract Award, unless otherwise noted, and are considered to be a part of this Specification as applicable.
    1. IEEE Standard 1558, "Standard for Software Documentation for Rail Equipment and Systems".
    2. Software Engineering Institute (SEI), "Standard CMMI Appraisal Method for Process Improvement (SCAMPISM Version 1.1)".
    3. ANSI/IEEE STD 1028, "IEEE Standard for Software Reviews", The Institute of Electrical and Electronics Engineers.
    4. IEEE Standard 1003, "IEEE Standard for Information Technology - Portable Operating System Interface (POSIX)".
    5. IEEE Standard 1008, "IEEE Standard for Software Unit Testing".
    6. IEEE Standard 1228, "IEEE Standard for Software Safety Plans".
    7. International Engineering Consortium document IEC 61508, "Functional Safety of

Electrical / Electronic / Programmable Electronic Safety-related Systems."

7.1.4 Definitions

a. Commercial-off-the-shelf (COTS) Software:
    1. Software purchased by the Contractor that is commercially available to the public.
        i. Example: COTS software includes but is not limited to operating systems, compilers, business applications (such as word-processing, e-mail) and other such applications as offered by firms such as Microsoft, Lotus, IBM, Novell, etc. used without modification. These items have been referred to as "Shrink-wrapped Software" items.
    2. Software products have at least one year of established service and industry use. The product has a usage base of twenty microprocessor-based systems in areas other than transportation. Multiple copies of a product in one system are considered the same usage.
    3. Is available for a target hardware environment or device such that the installation for the intended function is user-friendly, such that it requires little or no configuration (e.g. "plug-and-play") and integrates with elements (which may be supplied by other vendors) for control of components that are not part of the intended function.
        i. Example: a commercially available word-processing application, used on a specific operating system that interfaces with drivers supplied by other parties for control of specific hardware devices (e.g., printers, displays, disk controllers).
    4. For software development tools only, is strictly standardized and widely used by programmers not associated with the originator of the tool.
        i. Example: Requisite Pro – Information and requirements management CASE Tool.
b. Standard Software shall:
    1. Have an application platform with an Open Systems Application Program Interface, as defined per IEEE STD 1003.
    2. Have been service proven in a transit property or related application for over three years.
    3. Have been developed using an industry accepted software development methodology following a documented process, as approved by NYCT.
    4. Have documentation that exists and was created to an Engineer-accepted standard and is sufficient to meet the requirements of this Contract.
    5. Have been purchased from third-parties or is Contractor-developed internally as a base for all projects. Standard software fully satisfies the requirements of the Specification without modification for the NYCT and has been approved for use by the Engineer.
        i. Examples include operating system for Zone Controller software developed for previous NYCT CBTC applications, software development utilities, software diagnostic programs, network managers, and window managers.
c. Custom Software:
    1. New software developed specifically to respond to the requirements of this Specification.
    2. Modifications to COTS or Standard software developed specifically to respond to the requirements of this Specification.
d. Vital Software:
    1. For the purposes of this Contract, vital software shall be defined as software that

is not COTS software, which is safety critical. Vital software shall be limited to those software modules that are specifically identified by the Contractor as such and acknowledged by the Engineer as such.

e. Non-Vital Software:
    1. For the purposes of this Contract, non-vital software shall be defined as all software, which is not safety critical. Non-vital software shall be identified by the Contractor as such and acknowledged by the Engineer as such.
f. Configuration Data:
    1. For the purposes of this Contract, configuration data is data that is used to populate the system databases. Configuration data includes items such as system parameters, operational data (i.e. operator data, vehicle data, alignment data), simulation data, and test data.

7.1.5 Submittals

a. The Contractor shall provide software documentation in accordance with the specific industry standards identified herein. All documents shall conform to the format and content specified in the applicable standard(s) (including guides and recommended practices) unless prior approval has been given by NYCT. Submittals may be combined only with NYCT's approval. If a section of the applicable standard does not apply, the Contractor shall identify the required section, mark it "not applicable", and provide justification to the satisfaction of the NYCT Program Manager.
b. The Contractor shall identify all software documentation that shall be provided in fulfillment of Contract requirements that is not in conformance to the specified (or alternate Engineer approved) standard, including pre-existing documentation developed to a different standard. The Contractor shall provide, within the SDP, a description of non-conforming documentation to be used, the plan to ensure completeness and comprehensiveness for the subsystem (including assurance that no non-Train Control features or design will be included in the documentation delivered), a copy of the standard the documentation was developed to, and justification for submission as part of the subsystem. The Contractor shall not deliver any non-conforming software document without prior approval from the NYCT Program Manager. The Contractor shall be solely responsible for demonstrating, to the satisfaction of NYCT, that all Contract requirements are met through these non-conforming documents.
c. All software documentation shall be controlled under a Software Configuration Management System. All software documentation as required herein shall be updated and maintained by the Contractor throughout all phases of software development through Project Completion.
d. Software documentation shall either be submitted for review and approval by NYCT, shall be submitted for information, or shall be subject to review and audit as follows:
    1. Documentation that is submitted for review and approval shall be submitted in accordance with the timeframes identified within the Submittal Schedule. Changes to the approved deliverables shall result in the deliverable being resubmitted with the modifications (i.e. additions/deletions/modification) clearly marked.
    2. Documentation that is submitted for information only shall be submitted according to the timeframes identified within this section. Documentation that is submitted for information only is typically in the form of reports or information that needs to be conveyed to NYCT. The content of the documentation is not subject to a review and approval cycle. In the event the Engineer has reason to believe the content of the documentation is inaccurate or is incomplete, the Engineer will provide comments to the Contractor. The content of the documentation shall be resubmitted within 30 days of receipt of the comments.

3. Documentation that is subject to review and audit shall not be submitted unless requested by the NYCT Program Manager. Upon request of a document by the NYCT Program Manager, the Contractor shall submit the requested document within 15 days of receipt of the request. (Note that this requirement of 15 days is for the submittal of existing documentation only). The Engineer may elect to provide comments on sections of the requested document or the document in total. The Contractor shall respond to all comments made by the Engineer within 30 days of receipt of the comments.

e. A comprehensive detailed list of all latest firmware and software installed in the field as well at the remote office location, shall be submitted 30 days prior to in service.
f. The following documents, which are subject to review and approval by the Engineer in accordance with the Submittal List.
    1. Software Project Management Plan (SPMP)
    2. Software Development Plan (SDP)
    3. Software Configuration Management Plan (SCMP)
    4. Software Verification and Validation Plan (SVVP)
    5. Software Quality Assurance Plan (SQAP)
    6. Software Requirements Specification (SRS)
    7. Software Test Plan (STP)
g. The following documents shall be submitted for information only:
    1. Metric reports
    2. Software Version Description (SVD)
    3. Software Configuration Item List (SCIL)
    4. Firmware and Software Installation List
    5. Software Test Procedures
    6. Software Test Report
    7. Software Verification and Validation Report (SVVR)
    8. Software Change Report
    9. Software Design Description (SDD)
    10. Database Design Description (DBDD)
h. The following documents are subject to review and audit by NYCT:
    1. Firmware Design Description
    2. Software Development Folder (SDF)
    3. Software Problem Report

7.2 Products

a. The Contractor shall furnish, install, and test all executable software, firmware and associated source code.
b. The Contractor shall furnish all software deliverables as defined in Section 7.1.4.

7.3 Execution

7.3.1 Software Standardization

a. All user displays, documentation and operational text shall be in the English Language (United States).
b. In order to facilitate the maintainability and enhancement of the Train Control System and subsystems, the Train Control subsystem software provided by the Contractor, the OEMs, and all third-party software suppliers participating in this project, shall comply with industry-accepted and NYCT software standards identified herein. These standards shall be documented and submitted in the SDP for NYCT's approval. NYCT may reject any

software that does not conform to these standards. Compliance with industry and NYCT standards shall not release the Contractor from the contractual obligations to satisfy the functional, performance, reliability, availability, scalability, expandability, and other requirements of these Specifications.

c. The Contractor shall use NYCT preferred COTS products (e.g. operating system software, database management systems, E-Mail software) unless the Contractor obtains prior approval from NYCT for alternative software products. Approval may be granted for alternatives that are better suited to the characteristics of the Contractor's standard system and have superior performance and cost advantages over NYCT's standards, provided that the Contractor can validate that they satisfy the specified requirements.

7.3.2 Software Development Methodology

a. A defined software development methodology that fully complies with IEEE Standard 1558, Standard for Software Documentation for Rail Equipment and Systems. The Contractor shall produce software documentation in accordance with Procurement Type 5 as defined in IEEE Std 1558. The format and content of the software documentation defined herein shall be developed in accordance with IEEE Std 1558 and shall include any additional requirements as specified within this section. The Contractor shall submit software documentation in accordance with the requirements defined in this section.
b. The Contractor shall produce and enforce a comprehensive software development process that includes methodologies for all Train Control subsystem software utilizing the specified standards as applicable. The software development processes, activities, documentation, and software requirements as specified within this Specification, shall apply to the Contractor, all subcontractors and any other developing organizations providing software for the Train Control subsystems. The Contractor shall document the software development methodology within the SDP.

7.3.3 Software Products

a. The Contractor shall categorize Vital software as either Standard software or Custom software. The Contractor shall categorize Non-vital software as COTS software, Standard software, or Custom software.
b. The Contractor shall provide software documentation for all delivered software products including Vital software and Non-vital software.
c. Commercial off the shelf (COTS) Software:
    1. It is desired that all COTS products be integrated into the Train Control System without modification. The modification of existing COTS software to meet Train Control subsystem software requirements, including but not limited to applications, operating systems, and network services and utilities, shall require approval of the Engineer. Modified COTS software, delivered as part of the Train Control System, shall be categorized as Custom software and shall be subject to the requirements defined within this section.
    2. All software documentation shall address the integration of COTS software into the Train Control System including startup/shutdown of COTS applications, data exchange with COTS applications and testing of COTS applications.
d. Standard Software:
    1. Standard software may be provided for both Vital and Non-vital software systems.
    2. For Standard software integrated into the Train Control System, the Contractor shall demonstrate, to the satisfaction of the Engineer, that a software development life cycle, equivalent to that defined in this section was followed. The SDP shall define whether the same or equivalent software development, software

management, configuration management, software Verification and Validation, and software quality assurance processes were followed for standard software as is required in these Specifications.

3. For each Standard software product that is to be integrated into the Train Control System, the Contractor shall identify (in the SDP) the standard software documents that meet the CDRL requirements specified in this section. NYCT may elect to audit the Standard software documents for conformance to software requirements. In the case that the Engineer finds the Standard software documents to be inadequate or lacking in detail, the NYCT Program Manager may require supplemental documentation be provided by the Contractor. At the direction of the NYCT Program Manager, the Contractor shall provide additional documentation.

e. Custom Software:
   1. Custom software may be provided for both Vital and Non-vital software systems.
   2. For Custom software and modifications to COTS or Standard software developed specifically to respond to the requirements of this Specification, the Contractor shall ensure that all software documentation identified within this section describes the design, development and testing of the Custom software.

7.3.4 Software Development and Management Tools

a. The SDP shall define all proposed software development, implementation, testing, prototyping, management and CASE tools that they intend to use during all phases of development of the Train Control System software. The latest version of all tools shall be utilized for the Train Control System unless approval of the NYCT Program Manager is given.
b. Software Configuration Management and Version Control Tools:
   1. The Contractor shall use a software configuration management/version control tool to provide and enforce comprehensive software configuration management and version control for all software configuration items (SCIs) as defined in the approved SCMP. The configuration management/version control tool shall be implemented within 30 days of NTP. The Contractor's use of an automated software configuration management/version control tool is required, starting in the Integrated Testing phase.
   2. All software development artifacts to be controlled under the configuration management/version control tool shall be baselined as defined in the approved SCMP. All Standard software being reused for the Train Control System, either with or without modification shall be placed under configuration management within 30 days of NTP. Software program files, test plans, procedures, test cases, data files, and test script drivers shall be controlled using the configuration management tool prior to initiating software testing.
   3. All Train Control System documentation shall be baselined into the configuration management/version control tool prior to submission to NYCT for review.

7.3.5 Software Audits and Inspections

a. Software audits and/or inspections may be either at the software development site or will be "desktop audits" of delivered documentation at NYCT, at the discretion of NYCT. Software audits/inspections will not apply to software development facilities supplying unmodified COTS software products. Software audits/ inspections will apply to all software development facilities, including all Contractor and subcontractors, providing Custom software. The Engineer and/or the Engineer's representatives shall be able to interview

any member of the Contractor's Train Control team (including subcontractor staff) during the audits and inspections. The Contractor will be notified 15 days prior to and audit and/or inspection. Audits and/or inspections may occur during any phase of the Contract.

b. The Engineer or the Engineer's representative(s) (including consultants) shall be allowed access to the Contractor's facilities or any facility at which the Train Control System software development is being performed, for the purposes of inspections and audits. The Engineer's representatives shall be allowed to review, audit and verify the functional implementation of the Train Control System software development informally in conjunction with scheduled project meetings at the Contractor's facilities. This shall include inspection of software development folders. Reviews/audits may be conducted by NYCT during the implementation phase.
c. NYCT will document the results of each audit in an Audit Findings Report and present it to the Contractor for resolution. The Audit Findings Report will be provided even if an audit results in no findings. The Contractor shall acknowledge receipt of the Audit Findings Report in writing within 5 working days of its receipt. Each finding in the Audit Findings Report will be classified as either: a) Critical, b) Major or c) Minor and shall be managed by the Contractor as a variance. Critical is defined as a defect or requirement nonconformance that may impact safety and/or cause financial losses. Major is defined as a defect or requirement nonconformance that may adversely impact performance and/or operation of the system. Minor is a defect or requirement nonconformance that will allow the system to operate without adverse effect on the operation of the system.
d. The Contractor shall provide a Corrective Action Plan to the Engineer in response to all received Audit Finding Reports that contain variances. The Contractor shall provide the Corrective Action Plan within 10 working days of receipt of the Audit Findings Report. The Corrective Action Plan shall identify the planned actions and schedule of actions to address and close all variances identified in the Audit Finding Report.

7.3.6 Software Planning and Management

a. Software Project Management Plan:
    1. The Contractor shall develop and submit a Software Project Management Plan (SPMP) that defines the technical and managerial processes or activities necessary to satisfy the software project requirements. The SPMP shall be developed in accordance with IEEE Std 1558, Procurement Type 5. The SPMP shall be the controlling document for managing the Train Control System software development.
    2. The SPMP shall define the staff that will be supporting the Train Control System development including names, expertise, duration of assignment, and percent allocation to the project. The SPMP shall address expertise requirements for each lifecycle phase, development team structure, organizational structure and Contractor interfaces with the Engineer.
    3. The SPMP shall define the role of the Contractor with respect to interfacing to the Engineer, including interface meetings, deliverable submittals and comment resolution.
    4. The SPMP shall describe the approach to be followed for providing the Engineer or authorized Engineer representative access to developer and subcontractor facilities for review of software products and activities. The SPMP shall define the software schedules and associated software milestones. The activities and milestones on the software schedule shall directly relate to activities on the project master schedule, thus integrating software, system, hardware, and subcontractor / Contractor development activities.
    5. The SPMP shall include a Software Development Plan that defines the Train

Control System software processes to be used to develop, test, and deploy the Train Control System. The Contractor may elect to submit the SDP separately from the SPMP. The SDP shall define the software development methods to be used for each phase of software development, including descriptions of the manual, automated tools and procedures to be used in support of these methods.

6. The SDP shall define the software review, audit, walkthrough and inspection types to be applied during software development; the procedures associated with each review, audit, walkthrough, and inspection; and the type to be applied for each software development life-cycle activity.
7. The SDP shall define the process to be implemented to assure the correctness and completeness of all test systems, simulators, and other custom support tools. The SDP shall define the process to validate all support tools implemented as part of the Train Control System, including those tools provided in support of development, test, or maintenance.
8. Standards for documentation of source code shall be provided in the SDP. If the use of multiple programming languages is pre-approved by the Engineer, then the Contractor shall provide the standard or the name of the standard for each programming language to be used.
9. The SDP shall define the procedures and guidelines for establishing, controlling, and maintaining the software development environment. The SDP shall address the software development environment (including working, control, and build), software test environment, and software maintenance environment.
10. The SDP shall define the software process details for unit, module, integration, acceptance, and system testing, including the methodology and guidelines for preparing for, performing, revising, retesting, and analysis and recording of test results.
11. Changes to the approved SPMP and/or SDP shall result in the SPMP and/or SDP to be resubmitted.

b. Software Configuration Item List:
    1. The Contractor shall prepare, deliver, and maintain a detailed inventory of all software configuration items (SCIs) in a Software Configuration Item List (SCIL). The SCIL shall include all documentation and all software maintained under the Train Control System Software Configuration Management System necessary for the development, design, and execution of the Train Control System, including Vital software, Non-vital software, and Configuration Data. A firmware Configuration Item (CI) is managed during development as an SCI. A firmware CI once installed in hardware is managed as a hardware CI.
    2. As the Train Control System software development progresses, the lowest level to which the software is defined during that phase shall be the level to which the software inventory is documented. The SCIL shall document the evolution or changes that occur to each SCI. The Contractor shall update the SCIL as each SCI changes, throughout the Contract period.
    3. Each SCI shall include a software classification as follows:
        i. Vital software – Standard or Custom
        ii. Non-vital software – COTS, Standard or Custom
        iii. Configuration data
        iv. Custom software shall be further defined as new software, modified COTS software (for Non-vital) or modified Standard software. The Contractor may propose alternate classifications, however final category designation is subject to Engineer approval.
    4. The SCIL shall identify for each SCI:
        i. Configuration Item identifier, version identifier, release identifier, and

manufacturer;
ii. Identification of all subcomponents, data files, configuration files, and other relevant items;
iii. Functional description and purpose within the Train Control System;
iv. Identification of whether the SCI is applicative software; meaning part of a functional implementation or service software; meaning it is related to an operating system function
v. Cross-reference to pertinent Contractor documents;
vi. Software classification (for COTS software, provide the name of the product);
vii. Development history of SCI, including description of all versions, changes, and status, including:
(a) Origination of Standard or Custom software;
(b) Current development status, specific to each software lifecycle phase;
(c) Reuse estimate/actuals;
(d) Guidelines for use, restrictions and specific procedures or modifications.

c. Software Configuration Management Plan:
1. The Software Configuration Management Plan shall define the procedures for software configuration management including SCIL management, software version control, software change control and software build management. The SCMP shall be developed in accordance IEEE Std 1558, Procurement Type 5. The SCMP shall include guidelines for the use of the configuration management/version control tool as well as the procedures for controlling the files during development. These guidelines shall address the structure of working directories, impose limitations on multiple program copies, and identify the criteria for retrieving and storing versions to control.
2. The SCMP shall include the following:
i. The Contractor's approach to managing all software items documented in the SCIL.
ii. Methods and facilities used to maintain, store, secure and document controlled versions of the identified software developed as well as externally acquired COTS products.
iii. Transitioning of the software configuration management system and program to NYCT.
iv. Content requirements, format and the approval cycle of Configuration Management reports shall be included in the SCMP. Report formats shall be consistent and tool-independent.
3. The Contractor shall document modifications to software design artifacts subsequent to the Final Design Review milestone within a Software Change Report. The Software Change Report shall be kept current, reflecting all agreed upon changes to the baselined software design artifacts. The content of the Software Change Report shall include the following:
i. Changes to baselined software requirements (e.g. changes to the Software Requirements Specification).
ii. Changes to baselined software design (e.g. changes to the Software Design Document, which includes database documentation and the Interface Design Document).
iii. Changes to baselined code.
iv. Changes to baselined databases.
v. Revisions to COTS products.

vi. All programming corrections and modifications resulting from field testing shall be documented and listed as failures with solutions.
vii. The SCMP shall describe the content of the Software Change Report and the frequency of generation of the report.

4. The SCMP shall describe the content of the Software Change Report and the frequency of generation of the report.

d. Software Verification and Validation:
   1. The Contractor shall document the approach for software verification and validation in a Software Verification and Validation Plan (SVVP). The SVVP shall be developed in accordance IEEE Std 1558, Procurement Type 5.
   2. See Section 10 for a description of the requirements for a System/Software Verification and Validation Plan.
   3. The Contractor shall verify all Train Control System software required under the Contract in accordance with the Engineer approved SVVP and shall provide the required documentation under the SVVP to demonstrate conformance to the satisfaction of the Engineer.
   4. The SVVP shall define the content and format for all outputs and reports to be provided as part of the Software Verification and Validation Report (SVVR). The Contractor shall document software verification and validation results in a SVVR.
   5. The SVVR shall document the technical quality of each software product and the software development process. The SVVR shall include the following:
      i. Description of V&V tasks performed
      ii. Summary of task results
      iii. Summary of anomalies and resolution
      iv. Assessment of software quality
      v. Identification and assessment of technical and management risks
      vi. Recommendations

e. Metrics:
   1. The Contractor shall collect software metric data throughout the life of the Contract and shall produce Software Engineering Metric Reports. Software Engineering Metric Reports shall be submitted to the Engineer monthly beginning at PDR through FDR. Software Engineering Metric Reports shall be submitted to the Engineer monthly beginning with Software Implementation through System Acceptance. The following software metric data shall be collected:
      i. Software requirements analysis metrics (e.g. requirements volatility metric);
      ii. Software design metrics (e.g. design volatility metric);
      iii. Software size (source lines of code, new, used with no modifications, used with modifications, etc.);
      iv. Computer resources metrics (e.g. target processor throughput utilization, target memory utilization, data bus throughput utilization) planned versus actual;
      v. Number of Software Change Reports;
      vi. Internal product review metrics (within the Contractor/subcontractor organization);
      vii. Test metrics (e.g. number of defects generated as a result of unit, module, integration, factory, and system tests);
      viii. Work or effort planned versus work or effort performed to date;
      ix. Software budget planned versus expended to date;
      x. Resource allocation planned, versus resource allocation applied to date;
      xi. Planned size for each SCI, versus the current estimate or actual size;
      xii. A count of the total number of software variances, problems, or errors

detected to date. The total software variances categorized at each severity class shall be identified.

f. Software Quality Assurance Plan:
    1. The Contractor shall develop and document the approach for performing effective software quality assurance and for identifying individuals responsible for performing software quality assurance activities in a Software Quality Assurance Plan (SQAP). The SQAP shall be developed in accordance IEEE Std 1558, Procurement Type 5. The SQAP shall be applicable to all software and firmware developed specifically for the Train Control System and SSI subsystem provided in response to this Specification.
    2. The SQAP shall address both scheduled and unscheduled audits of software development processes, by the Contractor's internal quality assurance organization, and shall include a process for resolution/tracking of any defects identified by this audit. The SQAP shall describe how the results of internal development reviews and audits are recorded and resolved.
    3. The SQAP shall describe how non-conformance is identified and the methods that are used for tracking and resolving non-conformance issues. Note that non-conformances shall include software development process problems, as well as software product anomalies.
    4. The SQAP shall include the plan for reporting the Contractor's and subcontractor's software quality assurance activities. Software quality assurance activities shall include software process compliance evaluations and software product reviews. Contractor shall ensure that the SQAP will be adopted and followed by the subcontractor.
g. The Contractor shall provide a Software Safety Plan that conforms to IEEE Std. 1228, IEEE Standard for Software Safety Plans. See Section 10 for the Software Safety Plan requirements.

7.3.7 Software Requirements Definition

a. Software Requirements Specification:
    1. The Contractor shall develop and submit a Software Requirements Specification (SRS) for each Train Control subsystem. The SRS shall be developed in accordance IEEE Std 1558, Procurement Type 5. The SRS shall address each Train Control subsystem software requirement defined within this Specification and allocated to software within the Requirements Traceability Matrix (RTM). All software requirements shall be fully analyzed and documented in the SRS. The SRS shall be kept up-to-date throughout the life of the project and shall reflect all Engineer-approved changes to the software requirements.
    2. The SRS shall include graphic representations of software functions (such as data flow diagrams), which conform to the requirement analysis methodology defined in the approved SDP. The graphic representations are intended to assist the Engineer in understanding the functional descriptions of the software items and the hierarchy of the software functions. Data definitions and database requirements shall be defined in the SRS. Graphical representation of the data hierarchy shall be provided and a complete data dictionary shall be generated for all SRS data.

7.3.8 Software Design

a. Software Design Description:
    1. The Contractor shall develop Software Design Description (SDD) documentation. The SDD shall be developed in accordance IEEE Std 1558, Procurement Type 5. The SDD shall be submitted to NYCT in accordance with these milestones. The Contractor shall ensure that all requirements for the SCI are allocated to its software components. The Contractor shall provide both textual and graphical descriptions according to the Engineer approved development methodology described in the SDP.
    2. For the PDR, the Contractor shall transform the software requirements for each SCI into a software architecture that describes the top-level structure and identifies the software components. The SDD documentation for PDR shall include the following:
        i. A description of the hierarchy and structure of the software including decomposition to modules or components, data decomposition, external interface and message and inter-process communications.
        ii. Provide the software component definitions including algorithms and data structures, input and output descriptions, static relationships to other software components or units, and reuse identification.
        iii. A description of the internal and system databases used by the software, including a description of all inputs required and outputs produced by each software module.
        iv. Detailed program specifications for each component shall be provided describing the software component concept of execution, including data flow and control flow.
        v. Resource and design limitations such as maximum quantity of data items, which can be processed, shall be identified.
    3. For the FDR, the Contractor shall develop a detailed design for each software component defined as part of the software architecture. The software components shall be refined into lower levels containing software units that can be coded, compiled, and tested. The Contractor shall refine the design that was presented at PDR and update the SDD documentation for FDR. A formal baseline of all software design artifacts shall be created and placed under configuration management upon completion and Engineer approval of the Final Design Review milestone. No changes shall be made to baselined software design artifacts unless prior approval is given by the Engineer.
b. Database Design Description:
    1. The Contractor shall develop Database Design Description (DBDD) documentation. The DBDD shall be developed in accordance IEEE Std 1558, Procurement Type 5. The DBDD documents shall reflect a level of design that is consistent with the PDR and the FDR project milestones. The Contractor shall ensure that all requirements for the SCI are allocated to the appropriate database elements. The Contractor shall provide both textual and graphical descriptions according to the Engineer approved development methodology described in the SDP.
    2. The DBDD shall describe the structure and content of the Train Control System databases; provide descriptions and procedures for creating and maintaining the databases, and documentation on the preparation of database data. The DBDD shall define the individual elements (files, records, fields, and tables) of each sub-database and describe the interrelationships to elements of different sub-databases. A comprehensive description of the structures that integrate the

individual database elements shall be provided in the DBDD, using both text and diagrams to show the interrelationships of these elements.

3. The database design and associated DBDD documents shall be advanced to a level that is consistent with the SDD for the PDR milestone and shall be further advanced in accordance with the software detailed design for FDR.

c. Firmware Design Description:
    1. If the Contractor implements certain functions in firmware, that is software which is stored in memory chips that hold their content when the power is turned off (e.g., EPROMs and EEPROMs), that implementation shall be documented in a Firmware Design Description document. The Firmware Design Description document shall include justification for the firmware implementation. All software planning documents (e.g. SCMP, SDP, SVVP) shall include a description of how firmware will be managed by the Contractor.

7.3.9 Software Implementation

a. The Contractor shall develop software source code for all software units defined as part of the software design. The Contractor shall implement the Train Control System databases and shall populate the databases with Train Control System data. The Contractor shall implement all code and databases using the methods, techniques, and guidelines defined in the approved SDP. The Contractor shall only deliver software executables consisting of software modules applicable to the Train Control System implementation.
b. The Contractor shall deliver software verification and validation results in an updated SVVR for software implementation activities, 20 days after the software implementation activity.
c. At the end of the software implementation, prior to the beginning of software testing, the Contractor shall place all Train Control System software and databases under configuration management representing the developmental baseline. Changes to this developmental baseline shall be recorded using the Software Change Report in order to provide early metrics to the Engineer on the quality of the software being developed.
d. Software Development Folders:
    1. The Contractor and all subcontractors developing software for each Train Control subsystem shall establish and maintain software development folders (SDF) for each software component or SCI, as defined in the approved SDP. For each software element or unit identified during development, a folder shall be utilized to maintain a current status of the development of the software unit. The SDF shall be available for quality audit or for inspection by the Engineer or Engineer's representatives.
    2. The Contractor shall define the content of the SDF within the SDP. At a minimum each SDF shall include:
        i. Configuration change status and change metrics collected;
        ii. Signoff sheet for approval of each section following formal contract milestone completion;
        iii. A change log recording changes to sections after signoff;
        iv. Schedule and status of the SCI covered by the SDF;
        v. Reference to associated requirements, design descriptions, test plans, test procedures and test results;
        vi. Problem reports associated with the SCI;
        vii. All (formal and informal) design review, audit, inspection and walkthrough materials prepared, resulting outputs, and follow-up including correspondence;

viii. Notes the developer, tester, or other team member identifies as possibly being of use at a later date.

7.3.10 Software Testing

a. The Contractor shall develop and submit a Software Test Plan (STP) that describes the overall software developmental test processes including the responsibilities of individuals and the documentation of the test results. The STP shall address unit level, component and software integration testing. The STP shall be developed in accordance IEEE Standard 1558, Procurement Type 5. In addition, the STP shall conform to the latest edition of IEEE Standard 1008, Standard for Software Unit Testing.
b. The Contractor shall develop test procedures and test reports for software integration testing. The test procedures and test reports shall adhere to the content requirements as specified in Section 9 Inspection and Test. The test procedures and test reports shall adhere to the submittal timeframes as specified in Section 9 Inspection and Test. The software test procedure documentation shall provide a complete and comprehensive test of all the software requirements and functionality allocated to each SCI. The Contractor shall ensure that each Train Control subsystem software requirement defined within this Specification and allocated to software within the RTM has been addressed within the software test procedures. The RTM shall provide mapping for each software requirement to the associated test procedure(s). The development of test procedures shall address the following test requirements:
    1. Complete exercising of the software component logic;
    2. Testing the full range of inputs against expected outputs;
    3. Stressing the software unit at the limits of its requirements;
    4. Test scenarios that will expose errors, omissions, and unexpected results.
c. The Contractor shall document all software testing as defined under the approved Train Control System SVVP and STP. Configuration change status and change metrics collected during the software test phase shall be included and maintained in the SDF. Upon successful completion of each stage of software testing all results and test documentation shall be updated to the SDF.
d. The Contractor shall perform complete and comprehensive testing of all Train Control System software during all phases of development. During implementation of the software, the Contractor shall perform testing of each software unit or lowest level component. Following completion of software unit testing, module level tests shall be performed and then software integration testing. All software testing shall be fully documented and maintained by the Contractor.
e. Should any software inspections or tests indicate that specific software or documentation does not meet the specified requirements, the appropriate item(s) shall be repaired, replaced, upgraded, or added, by the Contractor at no additional cost to the Engineer prior to proceeding to the next phase of development. The Contractor shall document all deficiencies. All tests necessary to verify the effectiveness of the corrective action shall be repeated after correction of a deficiency.
f. Software testing shall be automated and modular as far as practicable, in order to facilitate regression testing.
g. The Contractor shall perform the following types of software tests:
    1. Unit level.
    2. Unit/Component integration (Module test).
    3. Software Configuration Item (SCI) Level (Software Integration Test).
h. Following satisfactory completion of all software testing and Engineer approval, formal factory and site tests shall be performed as defined in Section 9 Inspection and Test.
i. Software Unit Testing:

1. The Contractor shall perform comprehensive testing of each software unit or lowest level component. The Contractor shall perform the following types of Verification and Validation (V&V) checks on each software unit:
2. Peer reviews (for example: code walkthroughs, inspections, etc.);
3. Static analysis (for example: consistency checks, data flow analysis, loop tests, type checking, range testing (lower limit nominal, upper limit), etc.);
4. Formal analysis (for example: proof of correctness, symbolic execution, etc.).

j. Software Component Testing:
   1. The Contractor shall test each software component or logical set of software units using test tools including software test drivers, test data, test stubs, and simulators necessary to verify that each software unit is functioning properly. The Contractor shall automate the software component testing, using software test tools utilizing both “Black Box” and “White Box” techniques. The Contractor shall comply with the guidelines delineated in the most current issue of IEEE Standard 1008 Standard for Software Unit Testing in planning and documenting the software module testing.

k. Software Integration Testing:
   1. After completion of component testing, each software system (logical set of modules) shall be integration tested on the target hardware. This software integration testing shall include execution of the software test procedures using software test tools and test data necessary to simulate interface and communication with other software systems, hardware, devices, and external equipment.
   2. During software integration testing, simulation tools shall be utilized that allow for the testing of the software system in a real time, scenario scripted, modelled environment. The test simulator shall include a user-friendly interface that provides the capability to develop and define scenarios; store scenarios for later execution; and control scenario execution. All test simulators and test tools shall be independent of the Train Control System software and shall not include software identical to the software under test.
   3. All problems identified during software integration testing shall be logged in the Software Problem Report document. Problem reports shall include project name, originator, problem number, problem name, software element or document affected, origination date, category and priority, description, analyst assigned to the problem, date assigned, date completed, analysis time, recommended solution, impacts, problem status, approval of solution, follow-up actions, corrector, correction date, version where corrected, correction time, description of solution implemented.

l. The Contractor shall deliver software verification and validation results in an updated SVVR for software test phase activities, 20 days after the software test phase activity.

m. Software Test Results:
   1. Upon completion of software integration testing, test results shall be analyzed by the Contractor and documented in a Software Test Report. The Software Test Report shall include an overall assessment of the software tested and shall document the results of the tests performed, including:
      i. The completion status of each test procedure performed;
      ii. Summary of Software Problem Reports produced.
   2. The Software Test Report shall include a test log for the Test Procedure. The test log shall describe the following:
      i. The date(s), time(s), and location(s) of the tests performed;
      ii. Identification of individual(s) who participated in the testing, including witnesses.

iii. Modifications to the hardware and software configurations used for the testing;
iv. Modifications to test files and data to support testing including changes made to scripts, test stubs, input files, and scenarios.

7.3.11 Transfer to Operation

a. All requirements for performing factory testing and site testing are described in Section 9 Inspection and Test. The Contractor shall perform a complete regeneration of the Train Control System software under test in the target environment, immediately prior to the start of factory testing.
b. Upon completion of each software test as defined herein and every factory and field test as defined in Section 9, the Contractor shall update and submit the following:
    1. Software configuration item list;
    2. Software Test Report and
    3. Software Change Reports
c. The Contractor shall provide Software Version Description (SVD) document for each release of software for installation at the customer site. The SVD shall be developed in accordance IEEE Std 1558, Procurement Type 5. The SVD shall be generated in conjunction with each version of Train Control subsystem software created. The SVD shall identify and describe the new software version, shall summarize all Software Change Reports associated with the new version of software and shall describe all installation instructions. The SVD shall be submitted to NYCT, for all software releases, upon the start of Factory Acceptance Testing through Project Completion.
d. The Contractor shall provide a Software Acceptance-For-Test Form for each release of software for installation at the customer site. The Contractor's Safety Manager shall sign-off on each vital software release by signing the Software Acceptance-For-Test Form. The Software Acceptance-For-Test form shall include the signature of the Contractor staff member that verified that the software release has been fully tested and is ready to be installed at the Contractor site. The Software Acceptance-For-Test form shall include the signature of the Contractor staff member that verified that that the delivered software files match those described in the SVD.

7.3.12 Support Software for Application Functions

a. CBTC-ATS Operating System:
    1. The Operating System software shall comply with the evolving set of Portable Operating System Interfaces (POSIX) standards (i.e., IEEE Standards 1003.0, 1003.1, 1003.2, etc.). The operating system shall be event driven and respond to demands for service resulting from an event in the system or from a user request. The operating system shall assign resources and shall process simultaneous events according to both dynamically assigned priority levels and those priority levels fixed by user definition. The operating system shall include facilities for scheduling the sequence of program operation that are not based on priority (such as time-based or program dependent sequences). The operating system shall schedule programs to run periodically at any interval.
    2. Non-periodic programs shall be scheduled by time and date. Starting times shall be specified with a resolution of one second. Online facilities to add to and delete programs from the list of periodic and scheduled programs shall be provided. The scheduling facility shall provide for scheduling a program to run on another processor and scheduling a program requested by another processor. The scheduling of periodic programs shall be automatically corrected for manual and

automatic adjustments of time.

3. The operating system shall be able to dedicate portions of main memory to specific programs or data and constrain the maximum amount of main memory used by specific programs or data. The operating system shall support optimization schemes/programs to efficiently utilize memory including, but not limited to, memory managers, cache and cache managers. The operating system shall support on line access to all system services by System users from multiple programmer terminals and workstations interfaced locally and over all attached networks.
4. An access security scheme shall be provided to confirm a user's authorization before the user may request any system service, software utility or application program. As a minimum, the user shall be required to enter a user identification and password. The operating system shall include features to restrict:
    i. The services, utilities and programs that the user may execute;
    ii. The data (files) that the user may access; and
    iii. The data access permissions (such as read, write, and modify permissions).

b. Zone Controllers/Wayside Subsystems Operating System:
    1. The operating system for zone controllers or other wayside subsystems shall satisfy all industry-accepted requirements for processing of safety-critical data, and shall be certified by the Contractor to be suitable for vital applications. The Engineer shall have to right to verify and approve the operating system for vital processing.
c. Train Onboard Subsystem Operating System:
    1. The operating system for carborne controller or other vital carborne subsystems shall satisfy all industry-accepted requirements for processing of safety-critical data, and shall be certified by the Contractor to be suitable for vital applications. The Engineer shall have to right to verify and approve the operating system for vital processing.
d. Windowing System:
    1. Window system software shall be provided with the Train Control System and SSI System ATS workstations. The window system shall conform to the standards contained in the X Consortium's Inter-Client Communications Conventions Manual (ICCCM, Version 2.0 – 1994 or latest issue) or other equivalent, widely used window system, which is approved by NYCT. The window system shall work with the graphical user interface provided by the Contractor.
e. Programming Languages:
    1. Unless prior Engineer approval is obtained, the Train Control System software shall be built using one high-level language (e.g. Ada, C, C++, Java, Visual Basic). Any high-level language used in the implementation of Train Control application software shall comply with the industry standards and NYCT standards pertaining to the language.
    2. Unless prior Engineer approval is obtained, the Contractor shall not use proprietary (i.e., not commercially and widely used outside of the developing organization) programming languages as part of the Train Control System. Unless prior Engineer approval is obtained, the Contractor shall not use assembler languages or other low-level languages.
    3. Unless prior Engineer approval is obtained, automated code generation output from the CASE development tool must conform to the same standard programming language requirements listed in this Specification.
    4. Libraries for each programming language shall contain non-proprietary standard subroutines and functions that can be merged with programs or called during

program execution. Proprietary subroutines may be used by the Contractor upon approval by the Engineer. All libraries used to produce the Train Control System shall be provided.

5. The programming language(s) used to implement the Train Control System shall include facilities to request all required system services.

8 RELIABILITY, AVAILABILITY, AND MAINTAINABILITY (RAM) REQUIREMENTS

8.1 General Requirements

8.1.1 General

a. The ability of the Train Control System to perform required functions under typical operating and faulted conditions (e.g. hardware and software failure) is of paramount importance to NYCT. This section defines general requirements and specific tasks as they pertain to the reliability, availability and maintainability program, product development, production, initial deployment, demonstration, and Shadow Mode phases of the Train Control System and its equipment. This section also defines requirements for availability, reliability and maintainability demonstration tests, and submittal of analyses and predictions to demonstrate compliance with RAM requirements.
b. If the Contractor provides justification, NYCT may accept waiving some requirements in this section. If the Contractor's system does not comply with all specifications of this section, the Contractor shall identify each line item that cannot be satisfied by the Train Control System per the Gap Analysis (see Section 1.6). **Unless a written waiver is provided to the Contractor by the NYCT Program Manager, it shall not be assumed that any requirements of this section are waived.**

8.1.2 Definitions

a. Availability (A) – A measure of the degree to which a system can remain in an operable state and perform its intended functions under specified operating conditions and given time interval. The availability of a system is a function of how often failures occur (Mean Time Between Functional Failures (MTBFF)), how quickly failures can be isolated and repaired (Mean Time to Repair (MTTR)), and how long logistics support delays contribute to the down time (Mean Repair Travel Time (MRTT)), expressed as the following:

$$A = \frac{MTBFF}{MTBFF + MTTR + MRTT}$$

b. Accessibility – A measure of a relative ease of admission to the various areas of a system for the purpose of operations or maintenance.
c. Certification, Safety – A collective set of activities undertaken to prepare, review, and certify that a supplied system meets all stated requirements.
d. Corrective Maintenance Time (CMT) – A total amount of active time taken to troubleshoot and isolate a fault or failure, remove and replace/ repair faulty item(s), and perform functional checks to verify operational readiness status.
e. Environment – The aggregate of all external and internal conditions such as temperature, humidity, electric and magnetic fields, shock and vibration, etc.) either naturally or artificially made, that influence the form, performance or survival of the system.
f. Fault – An event defined as an immediate cause of failure instigated by maladjustment, misalignment, defect, error, or similar.
g. Failure – An event, or inoperable state, in which system, or any item or part of a system, does not, or would not, perform as specified or designed.
h. Failure Analysis – Post failure event activity involving logical and systematic examination of a failed system, its construction, application, and documentation to identify failure mode, failure mechanism and causes.

i. Failure, Catastrophic – A failure that causes a complete loss of a system.
j. Failure, Critical – A failure, or combination of failures, that prevents a system, or any of its key elements, from performing a specified task.
k. Failure, Chargeable – A relevant failure, or combination of failures, that require repair or replacement of system's components, software revision or upgrade, including intermittent, unverified or software anomalies type failures.
l. Failure, Intermittent – A failure which occurs for a limited time interval, followed by system's recovery and ability to perform within specified limits without a need for remedial action.
m. Failure, Rate – The frequency at which a product fails within a given time interval.
n. Failure, Repair – Part of corrective maintenance in which manual action is performed on failed item.
o. Failure, Relevant – An independent failure which results in a loss of function of an item caused by any of the following:
    1. A fault in the item, or its resident software, while operating within its design and environmental specification limits.
    2. Improper operation, maintenance, or testing of the item as a result of Contractor supplied documentation.
p. Failure, Non-Relevant – Any failure condition of an item not included in the definition of Relevant Failure above, such as the following:
    1. A failure caused by malfunctions of other equipment.
    2. A failure caused by human error, except as noted above for a relevant failure.
    3. A failure caused by operating a system outside of its design or environmental specification limits.
q. Mean Time Between Failures (MTBF) – The MTBF of an item is the ratio of the total operating time, t, accumulated by the total population of identical items, to the total number of relevant failures, F, occurring within the population of identical items during time t. The MTBF for hardware components, subsystems, and systems shall be calculated in general conformance to applicable sections of MIL-HDBK-217F. The MTBF is expressed quantitatively by the following equation:

$$MTBF = \frac{t}{F(t)}$$

r. Mean Distance Between Failures (MDBF) – The MDBF of a car class is the ratio of the total operating distance accumulated by the total population of the cars in the class (d) to the total number of functional failures (FF) which result in a train delay. MDBF is expressed quantitatively by the following equation:

$$MDBF = \frac{d}{FF}$$

s. Mean Time To Repair (MTTR) – The MTTR is the ratio of the total active corrective maintenance time, Tcm, expended during a given time interval, t, for the total proportion of identical items to the total number of relevant failures, F, requiring corrective maintenance which occur within the population of items during the same time. MTTR is expressed quantitatively as follows:

$$MTTR = \frac{T_{cm}(t)}{F(t)}$$

t. Mean Time Between Functional Failures (MTBFF) – The mean time between failures that cause the Train Control System or an individual subsystem to cease to perform its intended function. If redundancy or other techniques are used to continue to provide the complete system/subsystem functionality after a failure of an individual component occurs, then the failure shall not be counted as a functional failure. The MTBFF of an item is the ratio of the total operating time, t, accumulated by the total population of identical items, to the total number of functional failures, FF, occurring within the population of identical items during time t. MTBFF is expressed quantitatively by the following equation:

$$MTBFF = \frac{t}{FF(t)}$$

u. Mean Repair Travel Time (MRTT) – The mean time between the time that a failure occurs and the time that a technician arrives at the site of the failure. For this project, MRTT shall be 1.0 hour.
v. Mean Distance Between System Component Failure (MDBSCF) – The MDBSCF of a system is the ratio of the total operating distance, d, accumulated by the total population of cars in the car class to the total number of chargeable relevant failures, F, occurring for that population of components within each specified system of the cars in the class during the time t. It is expressed by the following equation,

$$MDBSCF = \frac{d}{F}$$

w. Maintenance – the combination of all technical and administrative actions, including supervisions, intended to retain a product in, or restore it to, a state in which it can perform a required action.
x. Maintenance, Preventive – A maintenance carried out at pre-determined intervals or according to prescribed criteria, intended to reduce the probability of failures or degradation of the functioning of an item.
y. RAM Program – A documented set of time scheduled activities, resources and events serving to implement an organized structure, responsibilities, procedures, activities, capabilities, and resources that jointly ensure that a system will comply with given contractual requirements.
z. Train Delay – An incident causing a revenue train to be: a) more than five (5) minutes late of its scheduled arrival at destination terminal, b) canceled (either at its original terminal or en route), or c) rerouted

8.1.3 Scope of Work

a. The Contractor shall provide a Train Control System design which, under normal operating conditions, achieves high level of availability, low failure rate and ensures ease of maintenance, and minimizes maintenance interventions.
b. The Contractor shall ensure that the Train Control System supplied under the Contract features the necessary levels of redundancy, and complies with the system assurance requirements defined in this Section.
c. Failure to achieve the reliability, availability or maintainability requirements shall result in modification to system, subsystem, or component design, modification to maintenance manuals, or other action as necessary at no additional cost to NYCT.

8.1.3.1 RAM Design

a. The Contractor shall furnish, maintain and implement a Reliability, Availability, and Maintainability Program Plan (RAMPP). The RAMPP shall describe how compliance to this Specification will be achieved.
b. The Contractor shall devise a system for effective management and control of the RAMPP to assure compliance with contractual requirements.
c. The Contractor shall monitor and report status of each RAMPP task against the plan and schedule, utilizing the reporting system as agreed upon by the Engineer.
d. At the minimum, the RAMPP shall include the following:
    1. Availability Design, Analysis and Predictions for the Train Control System
    2. Availability Design, Analysis and Predictions for the Train Control System's subsystems.
    3. Reliability Design, Analysis and Predictions for the Train Control System's subsystems.
    4. Maintainability Design, Analysis and Predictions for the Train Control System's subsystems.
e. The Contractor shall develop the RAMPP in accordance with the applicable provisions of most recent version of the European Standard EN-50126, and submit it to NYCT for review and approval. The final version of the RAMPP shall be delivered to NYCT as part of acceptance of system design.
f. The RAMPP shall contain, as a minimum, the following information:
    1. Clearly defined program objectives as it pertains to Reliability, Availability and Maintainability articles of this specification.
    2. The methodology and equations used to predict compliance with the specified requirements.
    3. The organization and personnel responsible for management of program.
    4. Management and Quality Controls to ensure that program plan is adhered to, and a description of how compliance shall be assured by the Contractor and its subcontractor and equipment suppliers.
    5. Techniques for allocation of quantitative requirements to lower level functional elements of subsystems, and to the piece part level.
    6. Provision for source selection, first article inspection, and surveillance of subcontractor's reliability and maintainability activities.
    7. Procedures and controls (including piece part selection and screening, manufacturing process controls, procurement controls, and test procedures) to be utilized during production to assure achievement of reliability and maintainability requirements.
    8. Procedures to determine the efficacy of the built-in diagnostic functionality in the Train Control System design, both hardware and software.
    9. Provisions for a closed loop data collection system for gathering, analyzing, recording and reporting of all failures which occur during the factory and on-site testing activities prior to acceptance.
    10. The recording, analysis and reporting of failures shall differentiate between a design or workmanship type to those related to errors in handling, transporting, storing, and operating of the Train Control System.
    11. The failure investigation and reporting system shall include necessary provisions to ensure that detected problems are investigated in a timely manner, and promptly addressed with appropriate corrective actions to reduce or prevent repetition of failures.
    12. Failure report form, as approved by the Engineer.

8.1.3.2 System Availability Analysis and Predictions

a. The Contractor shall furnish an Availability Analysis Report (AAR) for the Train Control System, maintain and supply most recent revisions as part of the Design Review activities, as appropriate.
b. The analysis work shall be based on the availability block diagram, with clearly defined MTBFF, MDBF, and MTTR of the Train Control System's components.
c. The ARR shall describe relevant historical, statistical, and experimental basis for the analysis. All assumptions, such as level of training of maintenance personnel, availability of spare parts, maintenance response time, and preventative maintenance for each device, shall be listed.
d. The Contractor shall allocate Availability and Reliability targets (MTBFF and MTBF) to each subsystem components as required to meet the requirements defined at the system and subsystem levels in Section 8.2.2.
e. The predicted MTBFF, MTBF, MDBF, and MDBSCF figures will be revised and finalized based on results of subsystems' Reliability Calculation and Availability Analysis reports (Ref. **Error! Reference source not found.** and **Error! Reference source not found.**).

8.1.3.3 Subsystems Availability Analysis and Predictions

a. The Contractor shall furnish a detailed Availability Analysis Repot (AAR) for each of the Train Control System's subsystems, for review and approval by the Engineer.
b. The subsystem ARRs shall include availability calculations and prediction details as appropriate, to substantiate design of pertinent equipment.
c. The analysis work shall be based on the availability block diagrams with clearly defined estimates for MTBFF, or MDBF, and Availability, including the following:
    1. Predicted reliability of each component (see Reliability Design, Analysis and Predictions).
    2. Equipment Architecture and its functionalities (e.g. redundancy management).
    3. Estimates for Mean Time To Repair (MTTR) of each component.
    4. Any required preventive maintenance.

8.1.3.4 Subsystems Reliability Design, Analysis and Predictions

a. The Contractor shall furnish a detailed Reliability Analysis Report (RAR), for each of the Train Control System's subsystems.
b. The subsystem RARs shall include reliability analysis and predictions details as appropriate, to substantiate equipment design.
c. The Reliability Calculations shall be provided for approval as a preliminary version, as part of the Preliminary Design Review process. The Contractor shall revise and update the preliminary version based on NYCT feedback, as part of the Final Design Review process. The reliability requirements of Section 8.2.2 shall be allocated to lower tier levels of the hardware and/or software as the design progresses.
d. At the minimum, the subsystem RARs shall include the following:
    1. Subsystem definitions and related assumptions.
    2. Subsystem reliability breakdown figures.
    3. Component failure rates (or MTBF) assumed in the calculations and assumption basis.
    4. The reliability calculations and allocations shall be approved by the Engineer prior to release of the design for manufacturing.
    5. An analysis of computed results demonstrating compliance to the Contract requirements.
    6. A data used for reliability calculations shall be based on manufacturer supplied field data, or an actual data/ RAM analysis from a mature reference project by similarity, or on a reliability database figures from EIREDA, NPRD-95, IEEE 500-

1984, FMD-97, or EN 61709; or extrapolation from RAM data from similar system only if none of the above is available.

8.1.3.5 Maintainability Design, Analysis and Predictions

a. The Contractor shall furnish a Maintainability Analysis Report (MAR), for each subsystem, for review and approval by the Engineer.
b. The subsystem MAR shall include maintainability analysis and prediction details as appropriate, to substantiate the equipment design.
c. The Maintainability Calculations shall be provided for approval as a preliminary version to support the Preliminary Design Review process. The Contractor shall revise and update the preliminary version based on the Engineer's feedback, as part of the Final Design Review process. The requirements of Section 8.2.3 shall be allocated to lower tier levels of the hardware as the design progresses.
d. At the minimum, the subsystem MAR shall include the following:
    1. Subsystem definitions and related assumptions.
    2. Subsystem maintainability breakdown figures.
    3. Component maintainability rates (or MTBF) assumed in the calculations and assumption basis.
    4. The maintainability calculations and allocations shall be reviewed by the Engineer prior to release of the design for manufacturing.
    5. An analysis of computed results demonstrating compliance to the Contract requirements.

8.1.4 Codes, Standards, and Specifications

a. Codes, standards and specifications referenced in this section shall be the latest edition in effect at the time of Contract Award unless otherwise noted, and are considered to be a part of this section as applicable.
    1. MIL-HDBK 217F, Reliability Prediction of Electronic Equipment.
    2. EN 50126: Railway applications - The specification and demonstration of Reliability, Availability, Maintainability and Safety (RAMS).
    3. IEEE 1474.1: CBTC Performance & Functional Requirements.
    4. MIL-STD 785B, Reliability Program for Systems and Equipment Development and Production.

8.1.5 Submittals

a. Submittals are identified throughout this section and are summarized in Section 12.
b. The Contractor shall submit a Failure Analysis Report (FAR) within 30 calendar days following any hardware failure. The FAR shall provide a detailed analysis of a failure down to the component level.
c. The Contractor shall regularly monitor and review failure events for patterns and/or downward performance trends which may adversely impact the specified MTBF limits, inform and submit a Corrective Action Plan to the Engineer within 15 calendar days upon initial observations of such events.

8.2 Products

8.2.1 General Product System Assurance Requirements

a. The Train Control System shall be designed so that the failure of any single component, processor, or device shall not render the system unavailable or a critical function non-operative.
b. The Contractor shall use redundancy to meet the overall availability requirements stated in this section, as required.
c. The Contractor shall monitor the system performance during the Shadow Mode testing phase of the project to ensure the systems Reliability and Availability are consistent with the predictive calculations. Any inconsistencies shall be identified to NYCT.

8.2.2 Availability, Reliability, and Maintainability Requirements

a. System Availability Requirements
    1. The Train Control System shall be designed to have a total availability of 99.86% for the Project configuration.
    2. The Availability of the Train Control System shall be such that no more than one (1) unplanned subsystem shutdown (such as Zone Controller “section Out of Service”, or similar critical failure, inhibits Train Control operation for longer than 10 minutes, exclusive of repair time), occurs during the Shade Mode testing phase.
    3. Shutdown or other critical failures which result from causes that are not the responsibility of the Contractor will not be counted towards the Availability demonstration metrics.
b. Subsystem Availability and Reliability Requirements
    1. Each furnished piece of equipment shall be designed for a maximum reliability, such that it will be able to perform its specified functions under the stated operating conditions. Reliability of each piece of equipment shall be measured based upon relevant failures of the equipment. Mean Time Between Failure (MTBF) of the equipment shall be calculated in conformance with applicable sections of MIL-HDBK-217 or another approved standard. Components and materials shall be selected, and standards of quality control and test procedures employed, to assure the lowest possible failure rates consistent with NYCT Standards.
        i. The Train Control equipment shall be designed for a minimum service life expectancy of 30 years.
        ii. When furnished under the scope of the Contract for the Project Lines, the Carborne Train Control Equipment fitted on a multi-car Unit (e.g. 4-car, 5-car, 6-car, as applicable), including redundant equipment (Train Control processors, radio, positioning subsystem, displays, power supplies and interface equipment) shall be designed to meet the reliability target of 75,000 miles MDBSCF; Carborne DCS for 150,000 miles; and an overall MDBF of no less than 300,000 miles.
        iii. Each Zone Controller (ZC) (if applicable) shall be designed to have a MTBFF of no less than 100,000 hours. ZC unit shall have a MTBF of no less than 10,000 hours.
        iv. Radio Communication System (Wayside Data Communication Link, and Carborne when applicable), provided by others, associated with ZC area shall conform to the following requirements:
            (a) At any point of the line, the Radio Communication System consisting of the Wayside Radio Units (WRU), Wayside Transmission Units (WTU) and Antennas that ensures the radio link

between the wayside equipment and the carborne equipment of a single train, shall be designed to have a MTBFF of no less than 100,000 hours.

(b) Each Wayside Transmission Unit (WTU), shall be designed to have a MTBF of no less than 10,000 hours.

(c) Each WRU and antenna(s) shall be designed to have a MTBF of no less than 10,000 hours.

(d) The loss of one Wayside radio on a cell should not affect the operation of any cell downstream.

(e) Each radio board or component shall report its health status to the diagnostic PC and ATS. The failures should be diagnosed down to board level of the WRU's.

v. The DCS Wayside Network shall conform to the following requirements:

(a) The DCS Wayside Network shall be fully redundant and capable of automatic reconfiguration upon detection of a single failure without disrupting the operations or safety critical functions.

(b) In case of a double failure of a DCS Wayside Network component(s) (switch or router), the network shall not completely shut down and it must provide at the minimum, a partial coverage of the line. This design and the consequence of a double failure must be reviewed and approved by the Engineer before the FDR.

(c) The entire DCS wayside network shall have a MTBFF of no less than 1,000,000 hours.

(d) Each DCS equipment unit (router, switch, modem, power supply) shall be designed to have a MTBF of no less than 100,000 hours.

(e) Each DCS equipment unit single failure shall be capable of being detected down to each board or component level automatically by a Network Management System.

vi. As the ATS subsystem is expected to be simulated and compliant with I2S, no reliability or availability requirements are being imposed for the ATS subsystem. If the Contractor furnishes an ATS subsystem that has not been certified for use on NYCT, the Contractor shall ensure that the proposed ATS is capable of meeting a design for a MTBF of no less than 15,000 hours.

8.2.3 Maintainability Requirements

a. The Contractor shall employ modular design principle featuring replaceable subassemblies according to their logical function, and minimize a need for use of maintenance tool to the greatest extent possible.
b. Components or subassemblies requiring frequent removal shall feature plug-in capabilities, and be adequality identified, secured, and keyed to prevent misapplication.
c. Components requiring frequent removal, repair or replacement, shall be readily accessible and maintainable without the need for use of special tools or equipment.
d. In general, equipment or components requiring periodic replacement, or identified as mission or safety critical items, shall be located where removal and replacement can be easily accomplished. A failure mode and effect analysis shall be used to aid in prioritizing the location of such equipment.
e. To the extent possible, a design of mission critical subsystems and equipment shall allow for an on-line replacement of hardware segments such as LLRUs, without disrupting the operations or safety critical functions, or introducing a disruption or hazardous condition during the on-line, or off-line modification, replacement or verification. For example, a

Wayside Radio Unit having “A” and “B” replicas, shall allow removal of a “faulty, or passive” radio (“A” or “B”) from its respective card cage, without interrupting the “healthy, or active” one, and/or communication link between the Carborne and WTU.

f. The system design shall employ a built-in diagnostic capacity accessible by Portable Test Equipment (PTE) or remote diagnostics too, capable of providing a comprehensive and thorough information to aid field maintainers troubleshoot and identify faults down to the level of LRU.
g. Train Control equipment shall be designed to automatically detect board installation errors made by field maintainers.
h. The system design shall minimize system re-test after board replacement.
i. The Mean Time To Repair (MTTR) a failed piece of Train Control equipment shall be no more than 30 minutes. The overall MTTR shall include a total time needed to complete on-site diagnostics, replacement of affected components, and validation of the repaired equipment, subsystem, or system.
j. Once the system is in Shadow Mode testing, the NYCT’s Centralized Electronic Shop (CES) will facilitate repairs of electronic boards/components; the actual repair shall be accomplished either by the Contractor, NYCT, or by an approved third party.
k. Where required by the Scope of Work for the Contract, Department of Car Equipment (DCE) personnel will support maintenance of the Carborne Train Control equipment at designated car shop.
l. Wayside Train Controller equipment including Zone Controllers, DCS radio equipment (including fiber cables of the Wayside Network), antennas, transponders, interlockings, signals, trip stops, and switch machines will be maintained by Maintenance of Way (MOW), signals section.

9 INSPECTION AND TESTING

9.1 General Requirements

9.1.1 General

a. This section includes requirements for inspection and testing of the Train Control, DCS, and ATS systems, henceforth referred to as the Train Control System.
b. All materials and equipment furnished and all work performed under these Specifications shall be inspected and tested. Should any inspections or tests indicate that specific hardware, software, or documentation do not meet the specified requirements, the impacted items shall be repaired, replaced, upgraded, or modified as necessary to correct the noted deficiencies by the Contractor at no additional cost to NYCT. After correction of a deficiency, all tests necessary to verify the effectiveness of the corrective action shall be repeated. In the event that changes and/or modifications are made during, or resulting from testing, the Engineer has sole authority to determine any and all inspections/tests that the Contractor shall repeat and/or additional inspections/tests that shall be performed.
c. If the Contractor is furnishing an SSI and/or ATS subsystem which has already been tested and certified for use on NYCT, the Contractor can propose limiting testing to functions that require an action or a reaction from the Train Control System and PICO/Inspection testing of the subsystem.
d. If the Contractor is installing an SSI and/or ATS subsystem which has not been tested or certified for use on NYCT, all requirements of this section shall apply to all functions of the subsystem.
e. If the Contractor provides justification, NYCT may accept waiving some requirements in this section. If the Contractor's system does not comply with all specifications of this section, the Contractor shall identify each line item that cannot be satisfied by the Train Control System per the Gap Analysis (see Section 1.6). **Unless a written waiver is provided to the Contractor by the NYCT Program Manager, it shall not be assumed that any requirements of this section are waived**.

9.1.2 Scope of Work

a. The Contractor shall develop, organize and implement a test program that tests and verifies that the Train Control System meets all functional, Reliability, Availability, Maintainability and Safety (RAMS) and performance requirements as per the Specification.
b. The Contractor shall perform the following inspections and tests for all Train Control System equipment and subsystems at a minimum:
    1. Post Installation Inspections/Check Out.
    2. Field/ Site Tests.
    3. Shadow Mode Phasing Tests.
c. The Contractor is not required to test all functions of Section 4 on the site. Some tests can be demonstrated in the Contractor's Factory environment. The Contractor's Test Program shall include a matrix which identifies which tests will be performed on the site and which will be performed in the Factory, this matrix shall be subject to approval by NYCT. However, all Post Installation Inspections/Check Out and Shadow Mode Phasing tests must be performed on the site.
d. Prior to starting any tests on-site or off-site in factory, The Contractor shall perform a Test Readiness Review (TRR), which shall be reviewed by NYCT.
e. Inspection and testing shall be compliant with the requirements of ISO-9001, clauses 4.10 "Inspection and Testing" and 4.11 "Control of Inspection Measuring and Test Equipment"

and align with the 'V' diagram illustrated below (Figure 3).

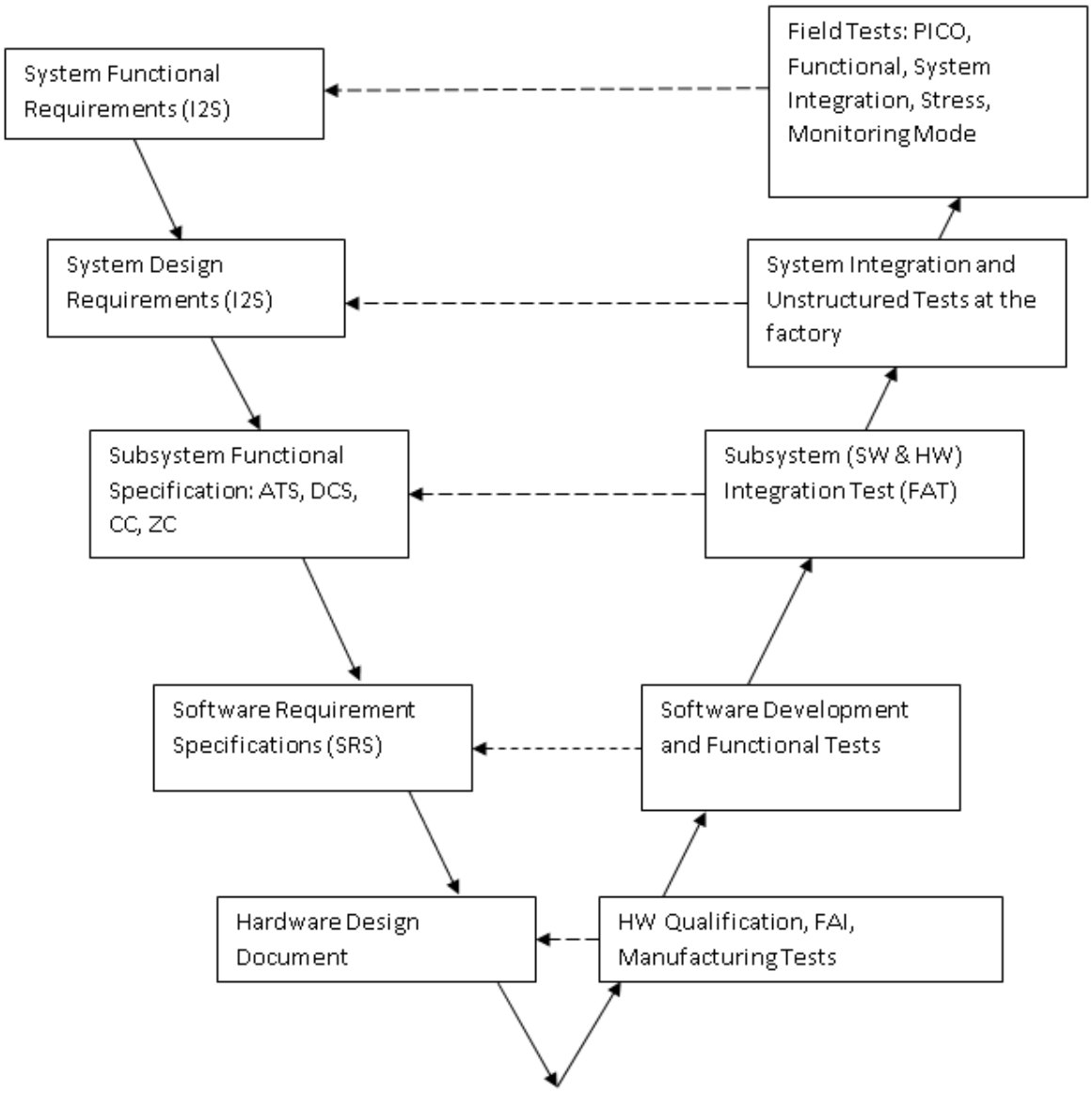


Figure 3 V Diagram for Test Traceability & Coverage

9.1.3 Codes, Standards, and Specifications

a. Codes, standards and specifications referenced in this section are to be the latest edition in effect at the time of contract award unless otherwise noted, and are considered to be part of this Specification as applicable:
    1. AREMA Communications and Signals Manual of Recommended Practices
    2. IEEE 829 Standard for Software and System Test Documentation
    3. IEEE 1008 Standard for Software Unit Testing
    4. IEEE 1474.4 Recommended Practice for Functional Testing of a Communications Based Train Control (CBTC) System

9.1.4 Submittals

a. The Contractor shall prepare and submit Inspection and Test Plan documentation for the Train Control System and sub-systems to the Engineer for approval. These plans shall include the following:
    1. System Test Plan.
    2. Factory Test Plan. (if applicable)
    3. Post Installation Inspection/ Check Out Plans.
    4. Field / Site Test Plan.
    5. Cutover/ Phasing Test Plan.
b. The Contractor shall prepare and submit detailed test procedure documentation to the Engineer for approval for each test identified in the Test Plan documentation (under a. above) no later than 60 days prior to testing.
c. The Contractor shall prepare and submit a detailed test schedule matrix of all the Train Control System's field tests. The test matrix shall be submitted on a bi-weekly basis and be reviewed jointly with NYCT.
    1. The test matrix shall include the following information for each required test:
        i. Test scheduled date
        ii. Test name
        iii. Location of test and equipment required to complete the test (include the identification of track, enclosure, and train-unit needs).
        iv. Completion status (including Pass or Fail and reasons for failure). In the case of failed tests, the associated punch list item number.
d. The Contractor shall prepare and submit 2-week look-ahead schedules detailing all planned test activities (factory and field) proposed for the period covered. Estimated start and completion dates and times, as well as the required resources shall be detailed for each test. The schedule shall note tests that are dependent on other activities. The first schedule shall be submitted 30 days prior to the first test scheduled. Revised schedules shall be submitted every 2 weeks thereafter.
e. The Contractor shall prepare and submit Test Reports containing the results of all tests conducted at all factory or field locations. All test reports shall be certified and signed by an approved member of the Contractor's staff and shall be submitted to the Engineer within 30 days of the completion of the test.
f. The Contractor shall prepare and submit Inspection Reports and Punch Lists, to the Engineer each time a deviation from the requirements of these Specifications is detected during the inspection and test activities. Inspection Reports and Punch Lists shall address all issues discovered during the inspection activity or test, and address concerns raised during Working Group reviews, and test witnessing observations by NYCT test witnesses.
g. The Contractor shall prepare and submit a General Order (GO) calendar using Microsoft Excel (or approved equivalent) that captures all installation, test, field training activities, GO types as defined in the Contract, along with resources (staff, equipment, NYCT resources), and test/ activity ID for approval to the Engineer. The activities identified in this GO calendar shall be integrated/correlated to the project schedule and shall be updated and maintained on a bi-weekly basis. A template for this calendar will be made available upon request. A first GO calendar must be provided with at least one month look ahead with first level of information and then is updated on a regular basis with all details.

9.2 Inspection and Test Documentation

9.2.1 System Test Plan

a. A System Test Plan shall be submitted to the Engineer for approval. The plan shall contain, as a minimum, the following:
    1. A flow diagram indicating the logical sequence of tests starting with material receiving inspections and tests and concluding with system demonstration tests.
    2. Test methodology, test categorization and test readiness reviews.
    3. Definition of each participant's responsibilities related to the testing of the Train Control System.
    4. Inspection and test organization showing the reporting structure within the Contractor's organization.
    5. Inspection and test documentation – flow and sequence of documentation submission, formal, internal documentation; traceability management of test documentation to approved design requirements.
    6. Organization and resources required for performing tests.
    7. Test schedule, including NYCT test witnessing stages; approach for utilization of GO/Diversions.
    8. Procedures for monitoring, correcting, and re-testing including Punch List items.
    9. Procedures for controlling and documenting all changes made to the hardware and software during all stages of the test program, including procedures for handling changes during a particular phase of testing.
    10. Locations at which all tests/inspections will be performed.
    11. Field testing strategies that minimize service disruptions by restricting the number of service interlockings affected by GO/Diversions as much as possible.
    12. Baseline list of planned software releases/builds for each subsystem and system for each stage of testing.
b. The System Test plan shall also include the approach, methodology adopted by the Contractor to test that UWB-equipped trains are properly working on the Project Limits.
c. After initial approval of the System Inspection and Test Plan, the plan shall be revised as required by the Contractor during the life of the Contract to reflect changes in system design or identification of additional testing requirements. Each revision shall be submitted for approval.

9.2.2 Factory Test Plan

a. The Factory Test Plan shall describe the test process followed during Factory Acceptance Tests (FATs) at the Contractor's premises, to ensure that all Train Control equipment including the CBTC-ATS, SSI subsystem, DCS and UWB carborne subsystem software and hardware are fully tested to the extent practicable. The Contractor shall make checks on the subsystems by simulating all control inputs, response combinations, and failure injection scenarios. The Factory Test Plan shall contain the following:
    1. Test approach to hardware, software integration and validation, and factory acceptance.
    2. Block diagrams of the hardware test configuration including external interfaces, and detailed descriptions of all test and simulation equipment and tools.
    3. Test sequencing and pre-requisites.
    4. Test categories including hardware qualification testing, hardware production/ series FATs, software V&V, unit testing, subsystem integration.
    5. Complete list of tests with brief description, test ID, test objectives, estimated test durations, resources and location or target equipment.

6. Inspection intervals during various stages of manufacture.
7. Traceability matrix to the design requirements.
8. Procedures for monitoring, correcting, and re-testing.
9. Procedures for controlling and documenting all changes made to the hardware and software after the start of testing.
10. System and subsystem release version identification for each system and sub system at each stage of the test process.
11. A suite of regression tests to be performed on each modified software release to ensure that no degradation of baseline functionality has occurred.
12. A suite of tests to be performed to verify the functionality of the newly implemented features.
13. Any limitation related to System Functionality Testing of the Factory Testing Facility (if any). In order to be in place those limitations must be approved by NYCT.

9.2.3 Post Installation Check-Out (PICO) Plans

a. PICO plans shall be submitted to the Engineer for approval and shall cover all subsystems:
    1. Wayside installation (including UWB Anchors).
    2. ATS and ATS interface installation.
    3. DCS (wayside wired network and wayside radio network) installation.
    4. Carborne equipment installation.
b. Wayside PICO plan shall describe the test and inspection process followed after field installation of wayside CBTC equipment. The testing and inspection shall include a complete inspection of the installed equipment necessary to powerup and commence all integration and functional testing. The plan shall cover the following aspects:
    1. Methodology and approach implemented for proper installation of the correct equipment configuration in the specified field environment conditions in which the equipment operates.
    2. Conformance of equipment wiring, cabling and grounding to cable plans, manufacturer's specifications, electrical codes and standards of workmanship.
    3. Process followed to ensure proper installation of wayside equipment according to specified technical requirements including mounting specifications and track layout.
    4. Process of verification that completed assemblies are properly interconnected per approved drawings.
    5. Complete list of PICO tests, test IDs, test objectives, resources, test durations, GO/Signal Bulletin requirements as needed with brief description to assess adequate coverage of PICO and all equipment supplied.
    6. Plan for submission of Test Documentation – Procedures and Reports; Procedures shall be submitted to the Engineer for approval. Reports shall be issued to certify that all equipment has been installed, interconnected and successfully passed the tests.
c. ATS and ATS Interface PICO plan shall describe the test and inspection process to be followed after field installation of ATS Remote Work Stations. The testing and inspection plan shall include a complete inspection of the installed equipment necessary to power up and commence all integration and functional testing as appropriate. The plan shall cover the following aspects:
    1. Methodology and approach implemented for proper installation of the correct equipment configuration in the specified environment conditions at Remote Work Station locations where the equipment operates.
    2. Conformance of equipment wiring, cabling and grounding to cable plans, manufacturer's specifications, electrical codes and standards of workmanship.

3. Process followed to ensure proper installation of ATS equipment according to specified technical requirements including mounting specifications.
4. Process of verification that completed assemblies are properly interconnected per approved drawings.
5. Process of verification that completed assemblies are properly interconnected to external devices per approved drawings.
6. Complete list of PICO tests, test IDs, test objectives, resources, test durations, GO/ Signal Bulletin requirements as needed with brief description to assess adequate coverage of PICO and all equipment supplied.
7. Plan for submission of Test Documentation – Procedures and Reports; Procedures shall be submitted to the Engineer for approval. Reports shall be issued to certify that all equipment has been installed, interconnected and successfully passed the tests.

d. DCS Wayside Network and Radio PICO plan shall describe the test and inspection process to be followed after field installation of all DCS Wayside Network and Radio equipment. The testing and inspection plan shall include a complete inspection of the installed equipment necessary to commence all power up, integration and functional testing. The plan shall cover the following aspects:
    1. Methodology and approach implemented for proper installation of the correct equipment configuration in the specified environment conditions at all locations where the DCS Wayside Network and Radio equipment is to be installed.
    2. Conformance of equipment wiring, cabling and grounding to cable plans, manufacturer's specifications, electrical codes and standards of workmanship.
    3. Process followed to ensure proper installation of DCS Wayside Network and Radio equipment according to specified technical requirements including mounting specifications.
    4. Process of verification that completed assemblies are properly interconnected per approved drawings. The tests shall demonstrate the interfaces of the DCS Wayside Network and Radio subsystem with other subsystems such as ATS, carborne and wayside equipment.
    5. Complete list of PICO tests, test IDs, test objectives, resources, test durations, GO/Signal Bulletin requirements as needed with brief description to assess adequate coverage of PICO and all equipment supplied.
    6. Plan for submission of Test Documentation – Procedures and Reports; Procedures shall be submitted to the Engineer for approval. Reports shall be issued to certify that all equipment has been installed, interconnected and successfully passed the tests.
e. Carborne Equipment PICO plan shall describe the test and inspection process to be followed after installation of car-borne Train Control equipment where Carborne Train Control equipment is required by the contract. The test and inspection plan shall include Static (train stationary in shop) PICO and Dynamic (tests involving train movement) PICO. Static PICO shall include complete inspection/ test of the installed equipment necessary to commence all dynamic PICO, integration and functional testing. The plan shall cover the following aspects:
    1. Static and dynamic check-out testing shall be conducted by the Contractor with supporting labor provided by NYCT. PICOs are conducted at NYCT facilities.
    2. The plan should cover complete check-out of equipment being furnished for the Project. The interfaces should be checked out to verify the approved Interface Control Documents (ICDs) and Carborne Train Control design requirements.
    3. The plan should clearly define approach for conducting PICOs for equipment being installed at NYCT premises under Contractor supervision.
    4. The plan shall incorporate inspection and testing to include the following:

i. Train Control Carborne equipment shall be delivered in a kit of parts for each unit installation and shall be inspected when received at the installation facility prior to handing to NYCT.
ii. Proper installation of the right equipment configuration in the specified field environment conditions in which the equipment operates.
iii. Conformance of equipment wiring, cabling and grounding to cable plans, manufacturer's specifications, electrical codes and standards of workmanship mandated by NYCT carshop.
iv. Proper installation of carborne equipment according to specified technical requirements including mounting specifications.
v. Verification that completed assemblies have been correctly interconnected.

5. After the carborne equipment is installed a series of static and dynamic tests shall be conducted to verify basic train functions and full demonstration of interfaces with train and other subsystems and shall include the following as a minimum:
   i. Communication between wayside equipment and the train.
   ii. Carborne equipment and train interface characterization including propulsion, brakes, emergency brake system, car controls, and Maintenance and Diagnostic System.
   iii. Speed and position reporting.
   iv. Train operator displays.
6. Complete list of PICO tests, test IDs, test objectives, resources, test durations, GO/ Signal Bulletin/ Diversion requirements as needed with brief description to assess adequate coverage of PICO and all equipment supplied.
7. Plan for submission of Test Documentation – Procedures and Reports; Procedures shall be submitted to the Engineer for approval. Reports shall be issued to certify that all equipment has been installed, interconnected and successfully passed the tests.
8. The number of technical support and quality control personnel that will be located at NYCT shop/ Car- builder to oversee the installation and perform the test.

9.2.4 Field Test Plan

a. The Field Test Plan shall describe the test process followed during integration and functional tests in the field to ensure that all Train Control equipment including the ATS, Zone Controller (if applicable), DCS and Carborne Controller are correctly functioning together. The field tests shall identify defects, demonstrate that defects have been removed and system adequately re-tested successfully. The field tests shall also verify that the modules perform their intended functions as stated in the specification.
b. The Field Test Plan shall contain the following:
   1. Complete list and sequence of field tests, Test IDs, test objectives, proposed test locations, resources required, GOs/Signal bulletins/Diversions required, estimated test durations, specific identification of safety related tests and an initial test schedule.
   2. Complete list of tests that are planned to be performed at the Test Track area, in between revenue service trains and under GO/Diversions.
   3. Block diagrams of the hardware test configuration including external transmission interfaces, and detailed descriptions of any and all test and/or simulation equipment.
   4. Traceability matrix that identifies the tests and test groups to functional requirements.
   5. Flow of test program and prerequisites required for starting each test.
   6. Equipment and instrumentation required.

7. Coordination needed from NYCT Operations and Maintenance Department.
8. Pre-test briefings.
9. Summary of GOs/diversions required to verify adherence to contractually allowed quantity.
10. Process for monitoring, correcting, and re-testing Punch List items.
11. Process for controlling and documenting all changes made to the hardware and software after the start of testing.
12. Configuration management of software/system version releases for all subsystems.
13. A suite of field regression tests that is to be performed on each modified software release to ensure that no degradation of baseline functionality has occurred.
14. A suite of tests to be performed to verify the functionality of the newly implemented features.
15. A set of criteria from which the scope of any retest can be determined.
16. A suite of degraded mode tests including failover and redundancy testing.
17. NYCT resources needed to perform each test, of critical importance are the number of units and trains together with the operating crew requirements.

c. Describe how the track under test will be isolated from the revenue tracks.
d. Describe how the outputs of the Train Control System will be isolated from impacting the revenue system when the Train Control System is under test.
e. It is recognized that for a system such as the Train Control System under test, not every test needs be conducted on every section of the wayside or on every unit. Submit justification for this approach, where adopted in the plan for NYCT approval prior to finalizing the detailed matrix. Include in the plan a detailed matrix of tests that indicate where tests are conducted at all locations, on every unit, at one location, and on one or two units.

9.2.5 Shadow Mode Test Plan

a. The Shade Mode Test Plan shall describe all stages involved in making the transition into the final Shadow Mode testing of the Train Control System, including tests, and shall contain, as a minimum, the following:
    1. The sequence of placing sections in Shade Mode Testing.
    2. Prerequisite tests to be completed specifically for each cutover stage.
    3. Test location.
    4. Equipment and instrumentation required including NYCT resources needed to perform each test, of critical importance are the number of units and trains together with the operating crew requirements.
    5. Coordination needed from NYCT Operations and Maintenance Department.
    6. Estimated duration of Shadow Mode testing.
    7. Phasing/ hand over of ATS operation, Train Control operation at each stage including the functionality proposed for each stage, the status and changes if any to different disciplines for Shadow Mode Testing (e.g. ATS operations, Existing Tower MCP operations, Maintenance, Train operation). The descriptions of this phasing shall be presented in a clear visual format for each stage and shall also list the limitations/ operating or maintenance constraints to be considered when transitioning between each stage.
    8. Solid State Interlocking (SSI) integration and interface testing activities.
    9. For each phase the following information must be provided:
        i. Description
        ii. Pre-requisites
        iii. System configuration

iv. AWS configuration
v. Rules and constraints for Operation and Maintenance

9.2.6 Test Procedures

a. The test procedures shall describe the individual tests and the steps to be followed in detail to achieve the test objective and test set up. No formal tests shall be conducted without approval of the procedure by the Engineer. In the event that the test procedure has been red-lined prior to the start of the test, the modifications must be reviewed and agreed with the Engineer's representative before the test(s) commence. The test procedures shall include the following items:
    1. Title of each test with revision level and reference number.
    2. The name of the feature and/or function to be tested.
    3. References to the functional, design, user, and any other documents describing the function.
    4. Test location.
    5. System revision release numbers of components of the system.
    6. The setup and initial conditions for each test, including descriptions of the test equipment and data to be supplied by the Contractor and by the Engineer.
    7. Description and instructions for all test software tools and displays.
    8. Prerequisite tests.
    9. Step-by-step descriptions of each test, including the inputs and user actions for each test step with designated check off list/boxes.
    10. Data to be recorded (data sheet).
    11. Estimated time.
    12. The expected results for each test segment, including pass/fail criteria.
    13. Descriptions of the techniques and scenarios to be used to simulate system field inputs and controlled equipment.
    14. Copies of any certified test data to be used in lieu of testing with prior approval by the Engineer.

9.2.7 Test Reports, Inspection Reports and Punch Lists

a. Complete certified Test Reports, Inspection Reports and Punch Lists of all factory and site acceptance tests results shall be maintained by the Contractor and delivered to the Engineer. All test reports shall be certified and signed by the tester and a reviewer. Test failures shall be recorded in the form of Punch Lists that clearly describe the nature of the problem and the actions to be taken to correct the problems. The reports shall be linked to the test procedures. The following items shall be included in the test reports:
    1. Reference to the appropriate test procedure with revision level.
    2. Location and date of the test.
    3. Software revision release numbers of components of the system.
    4. Description of any test conditions, input data, or user actions differing from that described in the test procedure.
    5. Test results for each test including a passed/failed status.
    6. Identification of the Contractor's test engineer and of the Engineer's representative.
    7. Provision for comments by Engineer's representative.
    8. Punch Lists generated.
    9. Reports, display copies, and any other hardcopy generated as part of the test.
    10. Names of any log files used to verify results.
    11. A summary to indicate completed tests, outstanding tests and reference to any punch lists generated.

9.3 Execution

9.3.1 Test Witnessing

a. The Engineer reserves the right to witness any and all testing. To facilitate the witnessing of testing, the Contractor shall give notice in writing a minimum of 60 days in advance of each test/inspection and include a detailed schedule of the inspection and/or the test.

9.3.2 Test Initiation

a. The following conditions must be satisfied before starting any test:
    1. All test plans and procedures for the test shall be approved by the Engineer.
    2. All planned and scheduled hardware and software engineering design change orders shall be incorporated into the system under test.
    3. All relevant documentation including drawings, software functional documents, and design documents shall be approved by the Engineer.
    4. Other documentation such as simulator manuals and scripts that are relevant prerequisite to testing shall be provided and approved by Engineer as required.
    5. A briefing shall be conducted for all personnel involved in the test, including testers, NYCT operations and maintenance personnel supporting the test, and NYCT test witnesses.
    6. The Contractor shall submit a detailed Test Matrix for the test area to be covered for a period of 2 weeks at least 2 weeks prior to the planned test date. This matrix shall be updated to indicate the outcome of testing within 3 days of completion of the attempted tests and submitted for review.
    7. The Contractor shall submit a configuration list for hardware and software to be installed, actively in operation, or removed from subsystems 1 week prior to the planned date of the test. The Configuration sheet shall be signed off at the end of the test session by the person in charge of the test and the Engineer.
b. A complete, clean (error free) dry run of each factory test using the approved test plans and procedures shall be conducted by the Contractor. Written confirmation that the dry run has been successfully completed shall be provided to the Engineer at least one week prior to the start of the formally witnessed Factory Acceptance Test (FAT).

9.3.3 Reporting of Failures to Pass Tests and Detected Problems

a. Prepare and submit punch list (or discrepancy list/defect tracking list) reports to the Engineer for deviations from the requirements of these Specifications or failures detected during any test. The report shall include a complete description of the problem, including:
    1. A sequential identifying number assigned to the problem.
    2. The date and time the problem was detected.
    3. Problem name/title
    4. Problem description
    5. Problem status (open, under analysis, under correction, … closed),
    6. Appropriate references to the test procedures and these Specifications.
    7. A description of the test conditions at the time the problem was detected and a methodology for reproducing the problem.
    8. Subsystem, Hardware and software revision in which the problem was identified.
    9. Categorization of the problem as impacting safety (safety critical or safety related), non-safety, and operations. If the problem is either safety or operations related, corresponding mitigation and bulletins must be issued with the Engineer's approval.

10. Priority of the problem (high, medium, low).
11. Identification of Contractor's and Engineer's representatives.
12. A description of the cause of the problem, the affected system elements and corrective actions taken (or to be completed as part of the problem resolution process).
13. A dated signature line for the Contractor's representatives to signify correction of the problem.
14. Follow-up actions, correction date, version where corrected, correction time.
15. Variance list for any modifications.

b. Upon the identification of an event requiring a problem report, the Contractor's and Engineer's representatives shall agree on one of the following courses of action:
    1. Testing will immediately stop and the Contractor will evaluate and correct the problem before testing is resumed.
    2. Testing will continue and the problem will be evaluated and corrected at a mutually agreed upon time.
c. The Contractor shall maintain and submit periodically (as mutually agreed) a problem summary report in the form of an updated Punch List that lists for each problem the ID, a brief description of the problem, its current status (open or resolved), revision of software/hardware in which the fix is expected to be incorporated.
d. NYCT will also prepare problem reports in the form of a Master Punch List of all test problems reported by test witnesses of all tests whether preparatory testing, formal testing, endurance runs, training exercises, or in revenue operation.
e. The Contractor shall review with the Engineer the Contractor's and the Engineer's Punch List(s) periodically and bring them to closure.

9.3.4 Resolution of Problems

a. All actions taken to correct problems shall be documented on the punch list by the Contractor. Sufficient information shall be provided to enable the Engineer's representative to determine the need for and extent of re-testing, the need for testing interactions of the correction with any previously tested hardware or software, the need for new additional testing not previously included and the need for updating appropriate documentation. Where applicable, screen shots and pictures of the correction shall be provided to the Engineer. A problem shall be deemed resolved only when all re-testing has been performed to the satisfaction of the Engineer and after the Contractor's and the Engineer's representatives acknowledge correction of the problem on the punch list.

9.3.5 Test Completion

a. A test shall be deemed to be successfully completed only when:
    1. All problems on the Punch Lists have been resolved to the satisfaction of the Engineer.
    2. All Test Reports, Inspection Reports and Punch Lists have been transmitted to the Engineer and approved.

9.3.6 Test Suspension

a. If the Engineer believes, at any time that the quantity or severity of items on the Train Control System Punch Lists warrants suspension of any or all testing, the test shall be halted, remedial work shall be performed, and the complete test shall be repeated. The repeat of the test shall be scheduled for a date and time agreed upon by both the Contractor and the Engineer.

10 SYSTEM SAFETY

10.1 General System Safety Program Requirements

10.1.1 Scope of Work

a. This specification section defines the NYCT Safety Program scope of work requirements for the Ultra-Wideband-based Train Control System (TCS) being furnished as a part of this project. These requirements are applicable to the Contractor to ensure the safe design, implementation, installation, operation, deployment, and post deployment maintenance or removal of the TCS. (Note: Heretofore in this specification section, the UWB-based TCS shall be referred to as TCS.)
b. The deployment area will be concentrated between the two territories as described in Section 1.1.
c. The requirements of this specification section shall apply to the TCS system based on the deployment goals, e.g., lite-train operation, or Shadow Mode. Revenue Service of the TCS system shall not be required for this contract.
d. With regard to submittal requirements, this Scope of Work shall follow the NYCT best-practices concept of “tailoring-down and not tailoring out”. This is in recognition of the overall contract scope and duration. For example, the contractor may submit, present, or provide for audit/inspection, any company-internal documentation with a formally submitted explanation (i.e., letter to the NYCT Construction Manager) of its application to this TCS project. Examples may include the System/Software Configuration Management Plan, Software Project Management Plans (for the product and site-specific data), and Software Design Documentation. Within the first 30 days after contract award, the contractor shall submit a CDRL document presenting their plan for meeting the submittal requirements described in this specification section, including the “tailored-down” requirements, as applicable.
    1. Tailoring-down is acceptable for this project since the scope of this project does not include revenue service operation. For revenue service deployments NYCT requires the formal submittal of all CDRL documents to the NYCT Construction Manager’s office, and no tailoring-down is acceptable.

10.1.2 Codes, Standards, and Specifications

a. Codes, standards and specifications referenced in this Section are to be the latest edition in effect at the time of contract award unless otherwise noted, and are considered to be a part of this Section as applicable.
    1. NYCT System Safety Certification Plan (SSCP) section of the NYCT Railroad Safety Program Plan (RSPP) for Safety Critical Systems, NYCT System Safety Certification Board (SSCB) / Vital Systems Integrity (VSI) NYCT. (See section 13.2 of this specification section).
    2. Communications and Signals Manual of Recommended Practices. American Railway Engineering and Maintenance of Way Association (AREMA)
    3. 1228-1994, IEEE Standard for Software Safety Plans.
    4. 49 CFR 236 Subpart H – Standards for Processor Based Signal and Train Control systems
    5. MIL-STD-882E System Safety Program Requirements, May 2012
    6. 1483-2000, IEEE Standard for Verification of Vital Functions in Processor-Based Systems.
    7. CENELEC Standard Publication EN 50126:1999: Railway applications. The

specification and demonstration of reliability, availability, maintainability and safety (RAMS).

8. CENELEC Standard Publication EN 50128:2011: Railway applications - Communication, signaling and processing systems - Software for railway control and protection systems. March 2001.
9. CENELEC Standard Publication EN 50129:2003: Railway applications. Communication, signaling and processing systems. Safety related electronic systems for signaling.
10. Federal Transit Administration Handbook for Safety and Security Certification. FTA-MA-90-5006-02-01. November 2002.
11. Federal Transit Administration Hazard Analysis Guidelines for Transit Projects. DOT-FTA-MA- 26-5005-00-01. January 2000.
12. Nuclear Regulatory Commission Fault Tree Handbook NUREG-0492. January 1981.
13. IEC 61820 Analysis techniques for system reliability – Procedure for failure mode and effects analysis (FMEA). IEC 60812:2006.
14. IEC 61820 Analysis techniques for system reliability – Procedure for failure mode and effects analysis (FMECA). IEC 60812:2006.

10.1.3 Definitions

NOTE: Where definitions shown in the reference documents differ from those identified within this specification section, the definitions listed in this specification section are to be used.

a. NYCT Demo/Test Site Release – A system version deployed for demonstration, Shadow Mode, or test and that interacts with revenue service equipment.
b. NYCT Revenue Service Release – A system version deployed for revenue service.
c. Project/Product Safety Plan (PPSP) - A formal document describing the planned tasks and activities to be used to implement the required system safety program for the project. This description includes organizational responsibilities, resources, methods of accomplishment, milestones, depth of effort, and integration with other program engineering and management activities and related systems. In addition, the PPSP describes, in detail, all of the safety aspects of the product, including but not limited to procedures for its development, installation, implementation, operation, maintenance, repair, inspection, testing and modification, as well as analyses supporting its safety claims.
d. Safety - Freedom from those conditions that can cause death, injury, occupational illness, damage to or loss of equipment, property, or the environment.
e. Safety critical - (a) A term applied to a system or function, the correct performance of which is critical to safety of personnel and/or equipment; (b) A term applied to a system or function, the incorrect performance of which may result in a Category I or II hazard.
f. TCS System Certification – The safety certification required for the Train Control System.
g. System - A composite, at any level of complexity, of personnel, procedures, materials, tools, equipment, facilities and software. The elements of this composite entity are used together in the intended operational or support environment to perform a given task or achieve a specific purpose, support, or mission requirement. In the context of this contract specification, the system comprises all the subsystems, software, and the interface-level of other external equipment.
h. System Safety - The application of engineering and management principles, criteria and techniques to optimize all aspects of safety within the constraints of operational effectiveness, time and cost throughout all phases of the system life-cycle.

i. System Safety Management - A management discipline that defines system safety program requirements and ensures the planning, implementation and accomplishment of system safety tasks and activities consistent with the overall program requirements.
j. System Safety Program - The combined tasks and activities of system safety management and system safety engineering implemented by acquisition project managers.
k. Unsafe Condition -Those conditions that can cause death, injury, occupational illness or damage to or loss of, equipment, property, or the environment.

10.1.4 Safety Certification Requirements

a. The safety certification goals of this project include:
    1. TCS Product NYCT Safety Certification
    2. TCS Shadow Mode NYCT Safety Certification
b. Safety Certification of the Train Control System shall be in accordance with the NYCT Rail Safety Program Plan (RSPP) / System Safety Certification Plan (SSCP) and this specification. NOTE: The NYCT RSPP follows the guidance provided by the Federal Railroad Administration (FRA) 49 CFR 236 Subpart H.
c. Each safety critical system and subsystem shall come with a Generic Product Safety Case (GPSC). This does not include the site-specific data for the system, nor does it include the site-specific system configuration, such as the I/O layout and the (multi) processor arrangement. Note that independent SIL4 certification of each platform system and subsystem is strongly encouraged. Independent evaluations must be performed by a CENELEC-approved company.
d. A Specific Application Safety Case (SASC), based on the GPSC of the Train Control System, shall be provided to cover site-specific data and the site-specific configuration for the system.
e. Site specific data for the system, and the site-specific system configuration, such as the I/O layout, and (multi) processor arrangement shall be fully safety assessed by the Contractor as a prerequisite to NYCT Safety Certification.
f. The Contractor shall be responsible for achieving NYCT Safety Certification.
g. The Contractor shall support the NYCT Safety Certification process, which includes:
    1. Presenting and participating in various NYCT safety meetings (engineering-level working groups, and executive-level System Safety Certification Board (SSCB) meetings,
    2. Supporting NYCT-managed Independent Safety Assessor (ISA) consultant audits and ISA requests for information.
    3. Identifying, allocating and compiling the evidence required to obtain safety certification for the TCS system.
    4. Developing safety certification plans to be documented in the Project/Product Safety Plan and the Cutover (Shadow Mode) Safety Plan (see section 10.2.1 of this specification section) for the Train Control System in conjunction with the Engineer's input and approval.
h. When modifications, such as product enhancements, corrections, software updates and/or hardware changes are made during the course of the project, the Contractor shall:
    1. Undergo recertification of the Train Control System
    2. Complete the safety certification for the modifications to the Train Control System prior to resuming Shadow Mode/site-testing that involves interaction with other revenue service equipment/subsystems, based on inputs from NYCT and the Independent Safety Assessor.
    3. Furnish updated TCS System requirements, design, and test document submittals for the system, hardware, and software.
    4. Provide TCS System change management evidence.

5. Perform TCS System Reliability, Availability, Maintainability, and Safety (RAMS) analyses of the specific modifications and the TCS System as a whole with the modifications incorporated.
6. Provide sufficient time for NYCT to review and approve the modification and the verification and testing details prior to the modification being deployed for on-site testing/deployment at NYCT.

10.1.5 Safety Program Overview

a. The safety program for the project, as detailed herein, is designed to ensure that safety is integrated into the design, implementation, testing, deployment and maintenance of the TCS system. The safety program has the following main elements:
    1. The analysis of safety relevant functions of the TCS system and its interfaces to external systems.
    2. The identification and management of system hazards.
    3. The compilation of safety certification evidence to demonstrate compliance of the TCS system against the relevant sections of this specification.
b. The safety program provides details of the ongoing procedures and processes to be implemented to ensure that the safety of the TCS system is maintained throughout the life-time of the system and its subsystems.
c. The safety program provides details of safe equipment removals and obsolescence monitoring.
d. Configuration management and revision control methods are important elements of the safety program. They are required to ensure that the functional safety requirements and safety-critical hazard mitigation measures and processes are not compromised as a result of changes. This applies to modifications made to the TCS System during the development, commissioning and post implementation (as applicable) phases of the project system.

10.1.5.1 Safety Program Responsibilities

a. NYCT
    1. NYCT has established the overall safety program and the required safety performance levels as defined in this Specification.
    2. NYCT will review and monitor all aspects of the Contractor's safety program to ensure that the TCS system and its subsystem requirements, design parameters, operational factors and system support environment are consistent with the required safety performance levels.
    3. NYCT is not subject to Federal or other government certification prior to placing a signal/train control system in service. As described in the NYCT RSPP [1], the NYCT System Safety Certification Board (SSCB), staffed by NYCT executive-level management, is responsible for the safety certification the TCS system. In summary, this entails making presentations of safety verification evidence to the SSCB. The Contractor, NYCT ISA, and other NYCT stakeholder groups are responsible for presenting verification evidence to the SSCB. The safety verification evidence requirements are summarized in the NYCT 10-steps of Safety Certification which are described in detail in the NYCT RSPP [1]. The 10-steps apply to the project's TCS System and is required for each NYCT onsite release of the system. The NYCT 10-Steps are summarized in the following table. The detailed descriptions are contained in the NYCT RSPP, SSCP-section [1].

NYCT Safety Certification 10-Steps	
STEP #	**DESCRIPTION**
1	Contractor Final Safety Report approved
2	Independent Safety Assessor (ISA) recommendation completed
3	Mean Time Between Hazardous Events (MTBHE) independent analysis completed; NOTE Mean Time To Hazard Event (MTTHE) is used interchangeably with MTBHE in this contract specification
4	Hazards Closed
5	Testing Completed
6	Operating Rules and Procedures: verification of safe operation with system with NYCT Operating Rules and Procedures
7	Maintenance Manuals approval (Tailored for the TCS Project, as applicable)
8	Training materials approved, and training completed (Tailored for the TCS Project, as applicable)
9	NYCT Working Group checklist/reports completed
10	SSCB certification: SSCB Signed Safety Certificate

b. NYCT Independent Safety Assessor
   1. The Independent Safety Assessor (ISA) will audit compliance with the safety program and audit the system development, test processes and safety analysis and safety methods used by the Contractor. In performing this role, the Independent Safety Assessor will retain independence from the execution of the program and provide independent safety program guidance to NYCT. The ISA will use 49 CFR 236 Subpart H as guidance in the activities undertaken for the Project.
   2. In particular, the Independent Safety Assessor (ISA) will audit the following:
      i. Acceptability of the design criteria to be applied by the Contractor to achieve the specified safety performance.
      ii. The safety analysis methods and safety verification techniques employed by the Contractor.
      iii. The Contractor's test plans and data collection program. This will be audited to verify safety performance of the TCS system.
      iv. Compliance with the safety assurance process as defined in the Contractor's System Safety Program Plan, and documented in their Project/Product Safety Plan (PPSP).
      v. Hazard documentation traceability for accuracy and completeness.
      vi. Compliance with the Contractor's Project/Product Safety Plan
      vii. Acceptability and suitability of the post-implementation testing and configuration management processes.
   3. The ISA is responsible for generating independent assessment reports for submittal to NYCT. These include:
      i. Independent System/Subsystem Review Report: Key elements for review are the Product Platform hardware and software, hardware and software developed for the NYCT application, data, configurations, and TCS system interfaces, both internal and external.
      ii. Independent Hazard Analysis
      iii. Milestone Completion Reports
      iv. Data and Configuration Verification Report.
      v. Audit Reports
      vi. Submittal Review comments

c. <u>The Contractor</u>
   1. The Contractor shall demonstrate compliance with FRA 49 CFR 236 Subpart H

and the safety program requirements for the TCS system in the NYCT environment. Reference the SSCP section of the RSPP [1] for a table mapping the FRA requirements to NYCT requirements.

2. The Contractor shall provide safety documentation for NYCT approval in accordance with the requirements of the FRA 49 CFR 236 Subpart H as specified in this Contract Specification (Section 10.2.1).
3. The Contractor shall support the NYCT Independent Safety Assessor (ISA) whose role it is to independently recommend the safety of vital signaling systems during the course of project execution. This includes, but is not limited to, the audit of Contractor, review of submittals to NYCT, review of Contractor-internal documentation, review of change management evidence, review of the Contractor's safety analyses and if applicable review of independently certified SIL-4 certification documentation.
4. During an audit, the Contractor shall provide company-internal documentation to the NYCT/ISA, as appropriate, to demonstrate the safety of the TCS system supplied for this project and its implementation in the NYCT environment.
5. The Contractor shall be responsible for performing system level, subsystem level, software-level, and integration safety activities, such as analyses, reviews and tests, leading to safety assurance, safety justification and safety certification of the TCS system.
6. The Contractor shall verify and validate that the TCS system and subsystems meet allocated safety requirements.
7. The Contractor shall be responsible for ensuring that the TCS system safely interfaces with the conventional relay-based signaling system as implemented and designed on the project for Shadow Mode operation.
8. The Contractor shall be responsible for providing analysis indicating that the TCS system can safely interface to the applicable signaling system elements (e.g. switches, signals, ATS) for future implementations.
9. The Contractor shall be responsible for ensuring that the TCS system safely interfaces with the Communications-Based Train Control (CBTC) signaling system, if applicable, as implemented and designed for the project.
10. The Contractor shall perform safety assessment and testing of the TCS System and its interfaces to other external signaling system elements, as applicable.
11. The Contractor shall be responsible for implementing a safety-critical (vital) communication protocol that is subject to the approval of the Engineer.
12. The Contractor shall retain the responsibility for ensuring that all relevant hazards have been identified and included in the analysis of the TCS system and its interfaces within the overall existing signaling systems.
13. The Contractor shall address safety and hazard issues throughout the Project. The safety program requirements and activities are detailed in Section 10.3 of this specification section.
14. The Contractor shall be responsible for providing a process for the post-implementation testing and configuration management to NYCT to address the requirements of 49 CFR 236 Subpart H, Items (18) and (20).
15. The Contractor shall recommend to NYCT the testing, configuration control, maintenance, and training processes to be implemented to assure the ongoing safety of the system.
16. The Contractor shall implement the following safety program activities throughout the design, manufacture, installation, test and commissioning phases:
    i. Establish and maintain a project specific Project Hazard Log as the basis for the safety program and safety justification for the TCS system for the Project.

ii. Manage hazard analysis activities including the identification, assessment, and mitigation of:
    (a) System-level, subsystem-level, interface hazards.
    (b) TCS hazards with regard to the ATS interface, if applicable.
    (c) TCS hazards with regard to the CBTC interface, if applicable.
    (d) TCS hazards with regard to the Solid State Interlocking interface, if applicable.
    (e) TCS hazards with regard to the conventional signaling system interface (AWS), as applicable.
    (f) TCS hazards with regard project-specific designs, if applicable.
    (g) TCS hazards with regard to site-specific data and configurations.
    (h) TCS hazards with regard to the computing platform (product-level), i.e., Safety Related Application Conditions (SRACs) of the Generic Product Safety Case (GPSC).
iii. The computing platform safety-case shall be made available to the Engineer for ISA review.
iv. If the platform has been safety certified by an independent (3rd-party) SIL-4 Certification Company, then the SIL-4 certification reports generated by the SIL-4 certification company shall be made available on an audit basis to NYCT and the ISA at the Contractor's facilities.
v. If the platform has not been certified by an independent (3rd party) SIL-4 certification company, then the Contractor shall be subject to additional audits, and additional submittals, as indicated in Section 10.2.1 of this specification section.
vi. If the platform has undergone modification without re-certification since the last SIL-4 certification (by an independent SIL-4 certification company), then the Contractor shall be subject to additional audits, and additional submittals, as indicated in Section 10.2.1 of this specification section.
vii. Manage hazard analysis activities including the resolution of actions to mitigate identified TCS system-level and subsystem-level specific hazards.
viii. Hazards/mitigations for hazards that are not mitigated by the TCS system shall be exported to NYCT, for example track maintenance, adherence to operational rules.
ix. Identify items and elements requiring safety certification and include them into the TCS system Certifiable Items List, as indicated in Section 10.2.1 of this specification section.
x. Identify safety requirements for the TCS system.
xi. Review of compliance with the identified safety requirements.
xii. Review of hazard mitigation actions through the Contractor's hazard management process.
xiii. Document hazards and hazard resolution, perform compliance reviews of the TCS System.
xiv. Manage and perform the system safety approval process for the TCS system.
xv. Maintain complete responsibility for the safety of the TCS system and perform and document all required safety analyses and tests to verify that they satisfy the safety program and performance levels established by NYCT.
xvi. Compile evidence to support safety certification of the TCS system, including the development of Final Safety Reports for each system release (update)

10.1.6 Safety Program Milestones

a. The TCS system safety program and its deliverables are scheduled around the major project design reviews, testing phases, and Shadow-mode/demo milestones. The safety program is required to support all project design review activities, including test and demo/shadow-mode readiness-assessments and software releases.
b. A summary list of the submittals required for each milestone is provided in the milestone/phase descriptions of the following subparagraphs. Detailed submittal descriptions and their delivery schedules are described in Section 10.2.1 of this specification section. In addition, a comprehensive list of the Safety-required CDRL documentation required by NYCT is contained in the CDRL Submittal Schedule Table at the end of this specification section.

10.1.6.1 Pilot Design and Installation Phase (PD&I)

a. The purpose of the PD&I phase is to:
    1. Establish the plans for the project;
    2. Allocate system functions to high-level system architecture;
    3. Demonstrate that the design meets all system requirements via allocation of requirements to design (includes derived requirements);
    4. Define interfaces (internal to the TCS system and external to the TCS system);
    5. Describe the verification and validation methods.
    6. Completion of the safety program analyses required for Shadow Mode operation and eventual NYCT Safety Certification of the system for operation (as applicable).
    7. Demonstrate that the system's design maturity has progressed adequately for manufacturing and testing.
b. Non-functional requirements including safety requirements and performance requirements shall be allocated to specific elements (subsystems and functions) of the design for the PD&I Phase as applicable.
c. The Contractor shall identify and map all vital and safety critical requirements to the functions and to the subsystems of their design for PD&I Phase.
    1. Allocation of Mean Time Between Hazardous Events (MTBHE), shall be allocated to the subsystems.
    2. This mapping shall be documented in the System Design Document.
    3. The MTBHE calculations shall be provided during the PD&I Phase. (Final calculations shall be included in the Final Safety Report (Section 10.2 of this specification section).
d. The Project Hazard Log shall be populated with hazards as soon as they are identified allowing early implementation of the hazard management processes detailed in Section 10.2.1. of this specification section.
e. The requirements of the PD&I Phase shall be fulfilled by the Contractor and will be evaluated by the System Safety Working Group (SSWG) and the ISA.
f. The Contractor shall schedule the Safety-related Project PD&I Phase requirements within the overall Project PD&I Phase schedule.
g. The table below lists the CDRL documentation required for the PD&I Phase. Detailed requirements for each CDRL document are included in Section 10.2.1 of this specification section. In addition, a comprehensive list of the CDRL documentation required by NYCT is contained in the CDRL Submittal Schedule Table at the end of this specification section.

#	CDRL Title	Submittal Date
1	Contract Data-items Requirements List	Initial version NTP+30 days
2	The Project Safety Plan (PSP)	Initial version

#	CDRL Title	Submittal Date
		NTP+30 days
3	Certifiable Items List (CIL) • The initial version of the CIL is a standalone document to be submitted 30 days after NTP. • The Final CIL **shall** be incorporated in each Final Safety Report which are due in later phase(s).	Initial version NTP + 30 days
4	Preliminary Hazard Analysis • For Shadow Mode • For NYCT Safety Certification of the product	Initial version NTP + 30 days
5	System Hazard Analysis (System Level Fault Tree Analysis) • For Shadow Mode • For NYCT Safety Certification of the product	During the PD&I Phase
6	System Safety Concepts Document (SSCD) • For product NYCT Safety Certification	Initial version NTP + 30 days
7	System and Software Configuration Management Plan (CMP)	Initial version NTP + 30 days
8	Software Project Management Plan (SPMP) for platform/executive software / NYCT application software	Initial version NTP + 30 days
9	Project Hazard Log (PHL) • For Shadow Mode • For NYCT Safety Certification of the product	During the PD&I Phase
10	Subsystem Hazard Analysis (SSHA) • For Shadow Mode • For NYCT Safety Certification of the product	During the PD&I Phase
11	Failure Modes Effects and Criticality Analyses (FMECA) • For Shadow Mode • For NYCT Safety Certification of the product	During the PD&I Phase
12	Operating and Support Hazard Analysis (O&SHA) • For Shadow Mode • For NYCT Safety Certification of the product	During the PD&I Phase
15	Timing Analysis Document (TAD) • For Shadow Mode • For NYCT Safety Certification of the product	During the PD&I Phase
16	Requirements Traceability Matrix (RTM)	During the PD&I Phase
15	System/Software Verification and Validation Plan (SSV&VP) for the TCS System hardware/software/system, and associated databases, site maps and software configuration files.	During the PD&I Phase
14	MTBHE Calculations (initial version)	During the PD&I Phase
System Documentation		

#	CDRL Title	Submittal Date
15	System Requirements Documents (SRDs)	During the PD&I Phase
16	System Design Description (SDDs)	During the PD&I Phase
17	Subsystem Design Documents (SSDDs)	During the PD&I Phase
18	Software Requirement Documents (SWRDs)	During the PD&I Phase
19	Software Design Documents (SWDDs)	During the PD&I Phase
20	Software System-Map/database Design Document	During the PD&I Phase
15, 16	Data Logger specification (include as part of the SRD and SSDD) • Train • Wayside • PTE/ATS • Other, as applicable	During the PD&I Phase
28	Shadow Mode Test Procedures: • including methods of data collection • pass/fail criteria	During the PD&I Phase
29	Environmental certification for Hardware: • EMI/EMC • Temperature • Shock • Vibration	During the PD&I Phase
30	Communication system • Description and • Approvals for the NYCT environment	During the PD&I Phase
31	Final Safety Report for: • For Shadow Mode • For NYCT Safety Certification of the product	During the PD&I Phase
-----	Prior to the start of Shadow Mode, all submittals submitted during this phase **shall** be updated (as applicable) and approved or approved-as-noted (AAN), i.e., approved with comments.	During the PD&I Phase

10.1.6.2 Shadow Mode Phase (SMP)

a. The SMP phase shall commence upon the completion of the safety program analyses required for Shadow Mode and Safety Certification of the system for operation, as applicable.
b. The Contractor shall submit sufficient evidence prior to the start of the SMP Phase that the TCS System is Shadow Mode-ready.
c. The purpose of the SMP is to:
    1. Verify that the final design fulfills the specifications and designs established during PD&I phase.
    2. Validate that the final design fulfills the specifications and designs established during PD&I phase.
d. Non-functional performance requirements such as MTBHE, Mean Time Before Failure

(MTBF) and Mean Time Between Functional Failure (MTBFF) shall be verified with detailed analyses during the SMP.

e. The Safety analyses commenced in the earlier phase of the project shall be re-submitted, if any system/software modifications necessitate their update.
f. Analyses shall be revised, as necessary, after completion of the SMPP milestone.
g. The Project Hazard Log shall be amended to include the outputs of the Safety Analyses.
h. Demonstration of key elements of the safety program during the SMP phase shall include:
    1. Verification of performance of safety critical/vital system and subsystem operation for Shadow Mode. This shall include GPSC considerations as well as safe operation/interaction with existing systems.
    2. Verification of operational safety devices, warning devices, procedures and training to protect personnel and equipment, as applicable to Shadow Mode. This shall include GPSC considerations as well as safe operation/interaction with existing systems.
    3. Identification of residual risk for Shadow Mode. This shall include GPSC considerations as well as safe operation/interaction with existing systems.
    4. Gathering and inclusion of all verification assurance documentation and supporting data for Shadow Mode. This shall include GPSC considerations as well as safe operation/interaction with existing systems.
    5. Acceptance of residual risk for Shadow Mode. This shall include GPSC considerations as well as safe operation/interaction with existing systems.

10.1.6.3 System Safety Certification Board (SSCB) Reviews

a. SSCB Reviews shall be conducted throughout the project duration as follows:
    1. Informational SSCB- to report on safety assessment status, i.e., design and test progress.
    2. SSCB Safety Certification Meetings (for NYCT certification SSCB approval/sign-off) of the system, (includes each subsystem, software, database, etc.) for Shadow Mode, initial field testing, and testing where the TCS system is interacting with revenue service equipment (wayside, ATS, trains, etc.)
b. SSCB Safety Certification meetings shall be conducted during the Shadow Mode (Demo, and Test) Phase(s).
c. The following shall be presented to the SSCB for consideration of NYCT Safety Certification for each Shadow Mode and NYCT Site-release.:
    1. Verification of the test reports of each subsystem including all related Change Reports.
    2. Verification of the test reports of the TCS system including all related Change Reports.
    3. Verification of the Train Operator training material and courses, as applicable.
    4. Verification of the Train Maintenance Manuals and training courses, as applicable.
    5. Verification of the Wayside Maintenance Manuals and training courses, as applicable.
    6. Hazard closure and acceptance of residual risks by NYCT.
    7. Version Description Documents that describe the software to be deployed, installation instructions, including but not limited to a listing and description of Change Reports, a summary the factory test results, a safety constraints section, and a list known issues and limitations.
    8. A formally submitted list of Safety Constraints, if any, for the deployed products.
    9. A formally submitted list of Operational Constraints, if any, for the deployed products.
d. The Contractor shall provide the updated Contractor-Specific System Final Safety Report.
e. The Contractor shall provide updates to safety documentation to reflect latest proposed

Shadow Mode configuration (or demo/test configuration, as applicable), and shall provide documented safety reviews/analyses relating to all changes to vital hardware, software, databases, and vital system interfaces. In each Final Safety Report (for each release) the Contractor shall provide:

1. The baselines (software/hardware/database versions) analyzed.
2. Version Description Documents for the specific software being deployed.
3. The reference to all related safety reports, system and software documentation and safety analyses.
4. The limitations of use.

f. The table below lists the Contract Data-item Requirements List (CDRL) documentation required for the Safety checklist of the SMP phase. Detailed requirements for each CDRL document are included in Section 10.2.1 of this specification section. In addition, a comprehensive list of the CDRL documentation required by NYCT is contained in the CDRL Submittal Schedule Table at the end of this specification section.

Table 10-1 CDRL's Required for SMP Phase

SMP Phase		
#	**CDRL Title**	**Date**
1	Project Hazard Log (PHL) • Updates	Updated prior to Shadow Mode
2	Shadow Mode Final Safety Report a. Shall include o MTBHE Calculations o MTBF Calculations o MTBFF Calculations	Updated prior to during Shadow Mode as necessary.
3	Version Description Documents for each software release	Updated prior to during Shadow Mode as necessary.
4	Final Safety Report for each system release	During Shadow Mode
-----	All submittals submitted in the prior phase **shall** be updated (as applicable) and approved or approved-as-noted (AAN), i.e., with comments.	During Shadow Mode

10.2 Submittals

a. With regard to submittal requirements, this Scope of Work shall follow the NYCT best-practices concept of “tailoring-down and not tailoring out.” This is in recognition of the overall contract scope and duration. For example, the contractor may submit, present, or provide for audit/inspection, any company-internal documentation with a formally submitted explanation (i.e., letter to the NYCT Construction Manager) of its application to this TCS project. Examples may include the System/Software Configuration Management Plan, Software Project Management Plans (for the product and site-specific data), Software Design Documentation. Within the first 30 days after contract award, the contractor shall submit a CDRL document presenting their plan for meeting the submittal requirements described in this specification section, including the “tailored-down” requirements, as applicable.

1. The Contractor shall submit any other documents that are necessary to show compliance with the system safety requirements.
2. The documents and deliverables shall conform to the project configuration control requirements per the Contractor's Configuration Management Plan Submittal as described below.
3. The analyses shall follow the guidance provided in MIL-STD 882E, IEC, CENELEC, or Communications and Signals Manual of Recommended Practices, American Railway Engineering and Maintenance of Way Association (AREMA) – 2004 – Part 17 unless specifically detailed in the Contractor's Project Safety Plan and approved by NYCT.
4. All submittals provided for Certification (e.g., Final Safety Reports, Safety analyses / Software Delivery Files (SDFs), Contractor Project Management Deployment Request Letters, etc.) shall include:
    i. Clear description of the design baseline, system baseline, software versions, hardware versions, and system build versions which is the subject of the request for certification, and
    ii. Description of the intended use (e.g., testing between revenue service trains, shadow mode, applicable limits (locations) of operation/test).
5. Any deviations from the guidance of these Specifications requires prior approval of the Engineer. To obtain approval for the deviation, the Contractor shall submit an application for deviation for each relevant deliverable to the Construction Manager. The deviation is allowed when the Construction Manager has given formal approval.
6. All submittals related to requests for certification of the system or major subsystems by NYCT shall be submitted no later than 10 working days prior to the request for certification at NYCT System Safety Certification Board (SSCB) meetings.

10.2.1 Safety/System Submittals

a. CDRL Document
    1. The Contractor shall submit a Contract Data-items Requirements List (CDRL) document within 30 days after the Notice of Award. The CDRL shall list all contract deliverables required for this contract including the submittal dates, review times and manufacturing dates as applicable.
    2. The CDRL document shall also list which documents the contractor plans to tailor-down, as described in Section 10.2 of this specification section.
b. Project/Product Safety Plan
    1. The Project/Product Safety Plan (PPSP) is the core of the Safety Program. The Project/Product Safety Plan provides a formal basis of understanding between the Contractor, and NYCT and its Consultants, including the Independent Safety Assessor (ISA), Engineering Specialists, etc.
    2. The PPSP shall be submitted 30 days after NTP.
    3. The PPSP shall be updated and resubmitted during the project execution period if the plans, processes and procedures described in the PSP undergo a major change.
    4. The Project/Product Safety Plan shall:
        i. Define the safety criteria, safety requirements and the tasks necessary to implement them, the resources needed to accomplish the defined tasks, as well as identifying the authority to implement all the activities.
        ii. Define how the Contractor's safety program will support the PD&I Phase, Shadow mode, and testing milestones as applicable.

iii. Define the acceptable safety risk for the scope addressed by the plan.
iv. Assign acceptable safety risk for the TCS System.
v. Describe the project and associated safety tasks, as well as the identification of required, associated safety standards and specifications.
vi. Include the TCS elements and interfaces of the system in the Scope section.
vii. Include a description of the safety-critical design processes that the Contractor will follow, and specific safety standards (e.g. ISO-9001 procedures, CENELEC, internal safety standards, etc.) employed by the Contractor for the Project.
viii. Include a description of the safety analysis methodologies that the Contractor will employ.
ix. Include a description of the safety management procedures that the Contractor will adopt throughout the design, manufacture and installation phases.
x. Include a description of the Contractor's system safety organization and responsibilities.
xi. Include a description of the Contractor's plans for safety verification and safety validation, with specific reference to the methods of verification of safety-critical and vital software. (This may be provided via reference to other documents.)
xii. Provide definition of the test planning processes throughout the project life cycle from factory testing through Shadow Mode.
xiii. Include details of the ongoing life-cycle tests, including their periodicity and the required record-keeping of the processes and procedures for defining the on-going tests. This shall be provided irrespective of the goal of the project, i.e., Shadow Mode only, to gain insight into the test/maintenance requirements of the system.
    (a) These details shall also be included in the Maintenance manuals.
xiv. Include the assignment of responsibilities for safety related testing.
xv. Provide identification of any NYCT responsibilities, including safety interfaces between the Project System and facilities, subsystems, equipment and components provided by others, to assure safe operation of the Project System in the NYCT environment.
xvi. Include the process for identifying the post-implementation testing to be performed by NYCT to ensure the continued safe operation of the system. This shall be provided irrespective of the goal of the project, i.e., Shadow Mode only, to gain insight into the test/maintenance requirements of the system.
    (a) These details shall also be included in the Maintenance manuals.
xvii. Include a description of the Contractor's plans to document hazard identification, reporting, tracking and resolution, using the Project Hazard Log and Certifiable Items List as required.
xviii. Provide the Contractor's milestone schedule for completion of activities and submittals required by the System Safety Program.
xix. Include a section describing the software safety plan for the project, covering executive (platform) software, databases, and configuration software development methodologies. The contents software safety plan section shall meet the intent of the requirements of IEEE 1228:1994-Section 4, CENELEC standards, or IEC61508.
xx. The software safety plan section shall address the safety issues associated with software development, including:

(a) Software Safety Management
(1) Organization and responsibilities
(2) Software life cycle
(3) Software configuration management activities
(4) Software quality assurance activities
(5) Software verification and validation activities
(6) Tool support and approval
(b) Software Safety Analyses
(1) Software safety analyses preparation
(2) Software safety requirements analysis
(3) Software safety design analysis
(4) Software safety code analysis
(5) Software safety test analysis
(6) Software safety change analysis

xxi. Training: The contractor shall describe the approach to training of NYCT personnel, including but not limited to Train Operators, ATS, Wayside Maintenance, and Train Maintenance.

xxii. Deployment (for Shadow Mode and site testing)
(a) Installation
(b) Startup and transition
(c) Operations support
(d) Maintenance

c. Certifiable Items List (CIL)
1. The Contractor shall submit a Certifiable Items List identifying system, equipment, module level items and/or functions and software that are considered to be vital and that affect the safety of the TCS system. Non safety-critical components and software that affect the safety of the system shall also be identified in the CIL.
2. The initial CIL shall be submitted 30 days after NTP. Note that the Engineer may request an update if there is a change of CIL items during the contract execution period.
3. The CIL shall be developed to meet the intent of the FTA Handbook for Safety and Security Certification [11].
4. The Certifiable Items List shall be subjected to the processes documented in the NYCT System Safety Certification Plan Section of the NYCT RSPP [1].
5. The Final CIL shall be incorporated in the FSR, for the Shadow Mode and test releases of the system, and updated accordingly for each release.

d. Preliminary Hazard Analysis
1. The Preliminary Hazard Analysis (PHA) shall identify the hazards associated with the top level functional requirements as defined in the system specifications and top level functional design.
2. The PHA shall document the initial safety assessment of the system, its operation and maintenance, and support processes, independent of the manner in which the functions are to be implemented in hardware and software.
3. Information from the PHA shall be used to develop safety requirements, identify the system functions which must be implemented, and provide criteria for design, equipment, performance specifications and process/procedure definition. The PHA top-level hazards also are used to help develop the lower level analyses.
4. The Contractor shall submit the PHA 30 days after NTP.

e. System Safety Concepts Document (SSCD)
1. The Contractor shall submit a System Safety Concepts Document (SSCD) 30 days after NTP.
2. Resubmittal shall be required if the methodologies, tools, and safety concepts are

modified during execution of the contract.

3. The System Safety Concepts Document shall describe the Contractor's application of the system-level concepts which assure the TCS system's safety, in accordance with IEEE 1483-2000 [6] including but not limited to:
   i. Fail-safe design (hardware and software (includes databases, site specific or equipment specific configuration data)) approaches used in the implementation of processor-based safety-critical equipment;
   ii. Operational safeguards
   iii. Methods of ensuring safety-critical data integrity.
4. The Contractor shall identify, analyze and classify inherent risks in each type of technology used in the applicable subsystems.
5. For the software configuration items, this shall include the risks inherent in each part of the software (i.e. operating system, application software, and databases (includes site specific or equipment specific configuration data)), and the methodologies and tools used for their development.
6. The System Safety Concepts Document shall explain the safety design approach and underlying principles at the system level and at the safety-critical subsystem level.
7. The System Safety Concepts Document shall define the design methodologies upon which the implementation of the requirements will be based, consistent with the stated concepts.
8. The System Safety Concepts Document shall, at a minimum, discuss the following Safety topics:
   i. Dependence on the vital AWS train control system, such as interlocking indications, track circuits, train stops, Solid State Interlockings (SSIs), etc.
   ii. Methods used to protect all software (includes all executable software, databases, site specific or equipment specific configuration data) from corruption in its development, programming, installation in the TCS equipment, and ongoing operation at NYCT.
   iii. Fail-Safe hardware providing vital inputs to the TCS system and vital outputs from the TCS system.
   iv. Vital enforcement of TCS operating modes (Shadow Mode, revenue service, bypass mode, Mixed-mode (manual and TCS trains (if applicable) etc.)
   v. Safe response to failures of safety-critical TCS equipment.
   vi. Dependence on partitioning of the system into vital subsystems, vital interfaces, and subsystems which are non-vital, and the rationale for determining vital and non-vital subsystems. Based on the partitioning of functions, those subsystems performing vital functions and thus requiring fail-safe implementation, shall require detailed safety analysis.

f. Configuration Management Plan (CMP)
   1. The CMP shall include, but is not limited to:
      i. Configuration management processes relating to internal and deliverable documentation, software and hardware version control.
      ii. Change Management: Development, testing, Shadow Mode Phases.
      iii. Field delivery controls throughout the development life-cycle, i.e., Shadow Mode and site testing/installation.
      iv. Describe the processes and documents generated due to a configuration, obsolescence and/or system functional change that requires a hardware and/or software revision.
      v. Describe the configuration management and revision control methods required to ensure that the functional safety requirements and safety-

critical hazard mitigation measures and processes are not compromised as a result of changes. This applies to modification processes of the TCS System to be made during the development, commissioning and post implementation phases of the project system, as applicable.

vi. Description of the configuration management processes to ensure that the appropriate level of analysis and testing at the factory and the site are performed and controlled.

vii. Detail the documentation types generated for each system / software / hardware change to closure.

g. Change Control Documentation
   1. Change Control documentation (for hardware, software, databases, site specific software configuration files, etc.) generated during contract execution shall be available for NYCT inspection.

h. Requirements Traceability Matrix
   1. The purpose of the Requirements Traceability Matrix (RTM) is to determine where requirements, including the interface requirements, are satisfied by the design and the design specifications are satisfied by the hardware and the software code. The RTM is also used to assist in the analysis of proposed changes. In addition, the RTM shows where requirements are validated (tested) by mapping them to test procedures. Requirements traceability refers to the ability to follow the life of a requirement, in both forwards and backwards direction, i.e., from its origins, through its development and specification, to its subsequent deployment and use, and through periods of ongoing refinement and iteration in any of these phases. Requirements traceability is used to capture the relationships between requirements, design, test, and implementation of a system.
   2. The RTM can also expose requirements that have not been satisfied or tested and expose design specifications that have not been satisfied with hardware and software code. Viewing the RTM from the opposite perspective can expose design and test scripts for which no requirement has been written and code or hardware which have no corresponding design specifications. The lack of requirements may mean that the design or test scripts have become obsolete or from the opposite perspective, that the missing requirements are valid but have never been documented.
   3. The RTM shall be in the form of a table, or multiple tables.
   4. The top-level RTM shall be the System Requirements and the Interface requirements.
   5. Each requirement shall be assigned a unique identifier for tracing/mapping to lower level elements, such as system design, subsystem requirements, subsystem design, hardware, and software code, and test procedures.
   6. Forward and backward traceability shall be required.

i. Software Project Management Plan (SPMP)
   1. The SPMP (can be encompassed in SDP) shall meet the intent of IEEE-Std 1058-1998.
   2. Its scope shall include:
      i. Platform/Product level software
      ii. Software developed specifically for this project
      iii. Databases/geographical data
      iv. Software Configuration Files
      v. Other data files
      vi. Format of Software Version Description Documents that shall be provided with every release to the field.

j. Project Hazard Log

1. The hazard management process will be central to the safety program for the TCS system.
2. The Contractor shall use the Preliminary Hazard Analysis (PHA) as the initial input to Project Hazard Log.
3. The Project Hazard Log shall include hazards identified by the Contractor as being relevant to the TCS system.
4. The Project Hazard Log shall contain all the exported constraints, for example, Safety Related Application Conditions (SRACs) and all the restrictions of use coming from the generic part of the TCS system.
5. During all phases of the project, hazards that are identified shall be recorded and managed in accordance with the hazard management process as detailed in Paragraph below.
6. The Project Hazard Log is the project-specific Hazard Log that the Contractor develops during the course of project execution. It shall be considered a live document that is updated periodically (monthly), throughout the duration of the contract.
7. The Project Hazard Log shall act as the central record of all hazards (and their status) associated with the implementation of the TCS system.
8. The Project Hazard Log shall address system level hazards, including those associated with the TCS subsystem interfaces.
9. The Hazard Management Process shall include:
    i. Traceability of source of hazard.
    ii. Traceability of hazard analyses (FTA, FMECA, O&SHA, etc.) and mitigation actions (design, maintenance, operations, etc.).
10. All hazards identified shall be entered into the TCS system's project hazard log.
11. Follow-up analyses shall be used to update the hazard status.
12. The Project HL shall include EMI/EMC hazards.
13. Design mitigation assuring fail-safe TCS system behavior (and safe EMI/EMC-levels) shall be logged in the Project HL.
14. The mitigation of hazards assigned to NYCT shall be formalized through the Hazard Mitigation Form process as described in the NYCT Rail Safety Program Plan [1]. A blank Hazard Mitigation Form (HMF) is attached as Appendix A to this Section.
15. The Project Hazard Log shall be developed with Microsoft Office Excel.
16. The columns headings shall be as listed in the following table:

NOTE: Columns and rows are transposed (from the intended format) for this Specification's formatting only.

Table 10-2 Hazard Log Table

HAZARD LOG TABLE	
Column Headings:	***EXAMPLE ROW (hazard-record) DATA***
Log Number	1
Source Document	TCS Preliminary Hazard Analysis
Hazard Title	Obstruction-1
FTA Ref.	SHA 1.1.1
Hazard Description	Undetected Obstruction on Track

HAZARD LOG TABLE	
Column Headings:	***EXAMPLE ROW (hazard-record) DATA***
Hazard Source	System Interface Maintenance
Exposed Group	Passenger Staff
Operation Type	Degraded
System	TCS
Potential Cause	System fails to correctly register track occupancy
Accident/Mishap	Head on Collision Rear end Collision Side-swipe Collision Derailment
Initial Sev	1
Initial Freq	B
Initial Risk	Unacc
Control Measures	1: The TCS system shall provide correct track occupancy status. 2: The interface between TCS and the Signaling system shall be vitally designed and implemented. 3: All vehicles shall be maintained to ensure proper TCS inputs.
Control Type	1: Design 2: Design 3: Maintenance
Final Sev	1
Final Freq	E
Final Risk	Acc w/ Rev
Responsible Body	1: TCS Supplier 2: TCS Supplier AWS Supplier 3: NYCT Rolling Stock Maintenance
Contractor Status	Open
Remarks	As applicable

17. All identified hazards will be assigned severity and probability of occurrence categories in line with the guidance provided in MIL-STD-882E. A summary of the MIL-STD-882E categories follows:

i. Category I: Catastrophic – a failure which may cause death or whole system loss.
ii. Category II: Critical – a failure which may cause severe injury, major property damage, or major system damage which may result in mission loss.
iii. Category III: Marginal – a failure which may cause minor injury, minor property damage, or minor system damage which may result in delay or loss of system availability.
iv. Category IV: Minor (Negligible) – a failure not serious enough to cause injury, property damage, or system damage, but which will result in unscheduled maintenance or repair.

18. Hazard probability and severity shall be assigned by the Contractor's System Safety Engineer. When assigning the probability of occurrence, the absence of probability data calls for qualitative assignments (per MIL-STD-882E) of the following:
    i. A: Frequent - Likely to occur frequently
    ii. B: Probable - Will occur several times in the life of an item
    iii. C: Occasional - Likely to occur sometime in the life of an item
    iv. D: Remote - Unlikely but possible to occur in life of an item
    v. E: Improbable - So unlikely, it can be assumed occurrence may not be experienced
19. The following matrix provides the graphical ideology of the probability and severity relationships. This matrix was referenced from the hazard risk index definition, provided from MIL-STD 882E.

Table 10-3 Hazard Probability and Severity Relationships

Frequency of Occurrence	I Catastrophic	II Critical	III Marginal	IV Negligible
A – Frequent	1A	2A	3A	4A
B – Probable	1B	2B	3B	4B
C – Occasional	1C	2C	3C	4C
D – Remote	1D	2D	3D	4D
E – Improbable	1E	2E	3E	4E

a) Unacceptable, 1A, 1B, 1C, 2A, 2B, 3A – Shall be eliminated.
b) Undesirable, 1D, 2C, 2D, 3B, 3C – Shall only be accepted when risk reduction is impracticable and with the acceptance of NYCT.
c) Acceptable with review, 1E, 2E, 3D, 3E, 4A, 4B – Acceptable with review by NYCT.
d) Acceptable without review, 4C, 4D, 4E – Acceptable without review.

20. After the initial formal submittal, the Project Hazard Log shall be delivered monthly throughout the duration of the project. Monthly submittals shall be informal, and presented at the monthly System Safety Working Group (SSWG) meetings. Major, formal Project Hazard Log revisions shall be submitted prior to Shadow Mode and at project completion.

k. Safety Hazard Analysis: Fault Tree Analysis (FTA), Functional Fault Tree Analysis (FFTA)
    1. The System Hazard Analysis (SHA) shall expand upon the analysis accomplished for the Preliminary Hazard Analysis to provide a detailed description of system-level and interface-level failures or faults that may lead to hazards.
    2. The System Hazard Analysis shall include a risk assessment of the hazards/faults.
    3. A system-level Fault Tree Analysis (FTA) and/or Functional Fault Tree Analysis (FFT) shall be included in the SHA.
    4. The FTA/FFTA shall be used as part of the evidence to support compliance with the quantified safety requirements allocated to the TCS system.
    5. The FTA/FFTA analysis shall provide a structured means of identifying faults associated with the TCS system, which shall be mitigated.
    6. The FTA/FFTA analysis shall identify the system functions requiring fail-safe implementation.
    7. The FTA/FFTA shall identify the system and subsystem faults, starting with the top-level TCS system design and the identified hazards, clearly identifying the logical combinations of faults which are contributors to the hazard, and subsequently developed to the subsystem and interface level.
        i. Logical combinations of faults shall be provided in a summary trace-table in the SHA.
        ii. Single point failures shall be unacceptable.
        iii. Common mode failures shall be unacceptable.
    8. The system-level FTA/FFTA terminal events shall be used as the top-level events of detailed Fault Tree Analysis (FTA), which analyze the hardware, and software of each TCS subsystem performing vital functions.
    9. System level FTA/FFTA terminal faults shall be reviewed for possible transfer to the Project Hazard Log for action, tracking, and review.
    10. The FTA/FFTA shall be developed in accordance with NRC Fault Tree Handbook (NUREG-0492) (Ref 13).
    11. The Fault Tree Analysis deliverables shall contain, at a minimum, the following elements:
        i. A discussion of the analytic techniques used to generate the fault tree.
        ii. Explanation of the types of faults considered part of the TCS system and those which are external to the TCS system, if any.
        iii. A comprehensive FTA/FFTA diagram, using a graphical tool, which is suitable for the presentation of the tree logic in a clear and understandable manner. The symbols used, and their meaning shall be explained in the text. Each fault or hazard shall be uniquely identified by a reference number.
        iv. Reference from the unique terminal faults to where their resolution (mitigation) is addressed (e.g., further safety analysis, specific design techniques, Safety V&V, test).
    12. The SHA shall also cover key functional algorithms/functions including but not limited to:
        i. Safe Braking Model
        ii. Speed Enforcement
        iii. Train Localization
        iv. Movement Authority
        v. Movement Authority Enforcement
        vi. Operating Modes
        vii. Safe traversing over switches
        viii. Signal Aspects TCS interface
        ix. Train Tracking

x. Route Setting
xi. EB interfaces
xii. Propulsion System Interfaces
xiii. Secure commands ATS , e.g., for work zones, Slow Speed Orders)

l. Failure Modes, Effects and Criticality Analysis (FMECA)

1. The FMECA is a traditional qualitative/quantitative analysis used to identify and analyze single-point failure modes and their combinations in Class I hardware circuits to the level of the electronic components. The purpose is to verify safe operation under conditions of hardware failure, power supply anomalies, as well as, to the extent possible, under conditions of abnormal inputs.
2. The Contractor shall submit a Failure Modes, Effects and Criticality Analysis (FMECA) report which analyzes each unit of Class I fail-safe hardware to the level of the electronic components.
3. The Contractor shall provide FMECAs for all vital hardware. The FMECA report analyzes each unit of Class I, as defined in AREMA, fail-safe hardware to the level of the electronic components.
4. A FMECA shall be provided for each item of vital hardware.
5. The FMECA shall be developed in accordance with IEC 60812 [14].
6. Any Class I component failures identified as the cause of a hazard in the project hazard analyses shall be analyzed in the FMECA. If the failure is determined to be fail-safe, the hazard shall be closed.
7. Each FMECA shall, at a minimum, address the following:
   i. Single point hardware failures as induced or simulated for all circuit components, their effects on the hardware circuit, their effects on the overall system, and the means by which the failure is detected.
   ii. All modes of failure relevant to the component, including changes in component values outside normal tolerances. No single point failure shall be shown to cause an unsafe condition.
   iii. The effects of all failure modes shall be classified as self-revealing or non-self-revealing.
   iv. All combinations of failures shall be shown to not result in unsafe conditions, except for combinations of simultaneous independent self-revealing failures.
   v. Failures that are not self-revealing shall be analyzed in all combinations with all other failures (excluding combinations with two self-revealing failures). In the instance of a non-self-revealing failure, a subsequent failure cannot be considered as independent.
   vi. If the Contractor determines that analysis of a non-self-revealing failure in combination with all other failures (excluding combinations with two self-revealing failures) is not required, the Contractor shall document the reasons justifying this decision in the FMECA.
   vii. The Contractor shall show that if any unsafe condition results from a combination of two or more failures, then those failures are independent and self-revealing.
   viii. The FMECA shall, at a minimum, present text to describe the FMECA approach taken and justifications where needed.
   ix. The FMECA shall present results in a tabular format containing the following elements:
      (a) Description of the circuit or module under analysis.
      (b) Item identifier and component description and designation.
      (c) Failure mode examined.
      (d) Effect on circuit performance and/or other components.

(e) Means of failure manifestation and determination if failure is self-evident.
(f) System reaction to failure or other evidence.
(g) Determination of the fail-safe acceptability of system reaction, or requirement for design modifications (to be transferred to the Hazard Log for tracking.

m. System/Software Verification and Validation Plan (SSVVP)
1. The System/Software Verification and Validation Plan shall incorporate the Contractor's approach to safety-critical verification and validation of vital (safety-critical) functions (including those carried out by hardware, software, databases, software configuration files or a combination thereof.
2. The SSV&VP shall be in accordance with the IEEE Standard for Software Verification IEEE 1012-2004.
3. The SSV&VP shall describe the approach for demonstrating that the TCS system operates in a safe manner through verification and validation of the overall system, its subsystems, hardware, software, databases, software configuration files, etc.
4. The Safety Validation Tests shall be those which confirm the resolution of hazards by the implementation of the TCS system and demonstrate that the TCS system operates in a safe manner.
5. The results of the SV&VP shall be included in clearly identified sections of the test reports.
6. The Contractor shall describe their approach to safety-critical validation tests and safety demonstration tests in the SSV&VP.
7. The Test Plan shall distinctly define the safety-critical tests that the Contractor will perform as part of the Factory Acceptance Test (FAT), system integration, and system testing.
8. The Contractor shall include Safety Validation Test procedures as part of the test procedures. These shall include both system and subsystem tests.
9. The Contractor's V&V and Test Plans shall demonstrate the testing process to ensure that all elements introduced as part of the TCS system can be introduced safely, having been appropriately tested.
10. The V&V and Test Plans shall address the testing of modifications to the TCS system including hardware and software and all other elements which could impact the safety of the TCS system.
11. The V&V and Test Plans shall address regression testing in the event of modifications to any aspect of the system.
12. Safety-critical test results shall be included as part of the required test reports the safety testing results which illustrate the successful completion of safety-critical validations and tests but clearly identified from other reported results at the unit, subsystem, and system level, as defined per the Contractor's Test Plan.
13. The SV&VP shall include verification & validation procedures necessary to cover hardware as well as software development to assure that safety is integrated into the development process.
14. The SV&VP shall include the validation of the interfaces and the communication protocol(s). The validation procedure shall cover the nominal, degraded and boundary scenarios.
15. The Contractor shall provide details of the Post Installation Check-out procedures required at field sites and for the trains.

n. Timing and Sizing Analysis Document (TSAD)
1. The TSAD Document shall provide the timing and sizing analysis of the TCS System and its associated subsystem/devices for operational scenarios:
i. Nominal

ii. Worst-Case
iii. Fault-detection/system reaction
iv. Failure detection/system reaction
v. Communication system
vi. Signal indication status to train(s)-train reaction
vii. Track occupancy status to trains/train reaction
viii. Other applicable operating scenarios
ix. Availability limits due to system loading, i.e., communication limits, number of trains, number of wayside devices

o. EMI/EMC Safety Analysis
   1. The EMI/EMC Safety Analysis shall provide the EMI and EMC characteristics of the TCS System. NYCT standards include MIL-STD-461 (army) and FCC standards.
   2. The EMI/EMC Safety Analysis shall apply to the TCS system and its associated subsystem/devices.
   3. The EMI/EMC Safety Analysis shall cover the systems reaction to EMI (e.g., fail-safe). This shall include a survey of the operating environment (wayside/trains).
   4. The EMI/EMC Safety Analysis shall provide EMC characteristics of the various components of the TCS system to verify compatibility and safety of the operating environment.
p. Environmental Safety Analysis
   1. The Environmental Safety Analysis shall comprise safety analyses of the TCS (and its subsystems / equipment) for:
      i. Temperature (operational limits)
      ii. Shock and Vibration (operational limits)
      iii. Humidity (operational limits)
      iv. Debris/transmission media /Constraints (operational limits)
      v. Power levels (operational limits/limitations/constraints)
      vi. Life-time replacement model in the NYCT environment
      vii. Availability limits due to system loading, i.e., communication limits, number of trains, number of wayside devices
   2. NYCT adheres to AREMA standards for environmental requirements.
q. Communication System Safety Analysis
   1. The Communication System Safety Analysis shall describe the safety criticality of all aspects / components of the communication system. This shall include but is not limited to the following considerations:
      i. Safety dependency on the communication system
      ii. Reliability of the communication system
      iii. Availability of the communication system
   2. Interference in normal operating environment: other trains, structures, etc., equipment on other tracks (operational limits)
   3. Transmission medium restrictions
   4. FCC requirements
   5. sensor crosstalk
   6. Availability limits due to system loading, i.e., communication limits, number of trains, number of wayside devices
r. System and Software Documentation
   1. The following requirements and design documents shall be submitted for the TCS systems.
   2. Site specific information shall be included, as applicable, for the system-level documents.
   3. The format and content of these documents shall follow industry-standard

guidelines, such as the IEEE.

4. The documents below are due by PD&I Phase. They shall be updated and resubmitted during the course of the project duration if the requirements and design of the TCS system are modified.

Table 10-4 TCS System and Software Documents

#	TCS System and Software Documents
i	System Requirements Document (SRD) (Shall cover all aspects of the system, including the data loggers.)
ii	System Design Description (SDD) (Shall cover all aspects of the system, including the data loggers.)
iii	Subsystem Requirements Documents (SSRDs)
iv	Subsystem Design Documents (SSDDs)
v	Software Requirement Documents (SWRDs)
vi	Software Design Documents (SWDDs)
vii	Software Version Description Documents (for each Software Configuration Item for each release)

s. Database / Track Topography Design Document
   1. The Database / Track Topography Design Document shall:
      i. Provide the design of Database/Track Topography map of the TCS.
      ii. Describe the generation method of the Database/Track Topography map.
      iii. Describe the verification and validation methods of the Database/Track Topography map.

t. Operating and Support Hazard Analysis (O&SHA)
   1. The Operating and Support Hazard Analysis (O&SHA) identifies and evaluates hazards associated with operation and maintenance of the system.
   2. The Operating and Support Analysis (O&SHA) shall be developed in accordance with the FTA Hazard Analysis Guidelines [12], Section 3 Operating Hazard Analysis.
   3. The O&SHA shall provide the analysis of all processes, procedures, and external systems (such as train control) that are relied upon to mitigate certain potential TCS hazards, including procedures, which could cause a hazard if not properly followed.
   4. Operations performed by the train operator, maintenance staff, or other NYCT personnel shall be considered, as well as system support and maintenance activities which have an impact on TCS safety assurance. The purpose of the O&SHA is to identify those specific procedural requirements that protect passengers and/or personnel from hazards.
   5. The O&SHA shall be performed and documented on the complete TCS system.
   6. The O&SHA shall consider the system configuration, the system state, phase of activity, environment, support equipment and all other factors that could affect operational and support safety.
   7. The O&SHA shall, at a minimum, address:
      i. Facilities, support equipment, training and certification related to safety

operations and maintenance.

ii. Activities which occur under hazardous conditions, time periods, and the actions necessary to minimize risk.

iii. Changes in functional or design requirements needed to eliminate or control hazards or reduce associated risks.

iv. Requirements for safety devices and equipment.

v. Warnings, cautions, and special emergency procedures.

vi. Requirements for packaging, handling, transportation, maintenance, and disposal of hazardous materials (if any).

vii. Requirements for safety training and personnel certification.

viii. Effects of commercial equipment, both hardware and software, across the interface with other components or subsystems.

ix. Potentially hazardous system states under operator control (hardware/software).

8. The O&SHA shall contain a Failure Management Plan for operations during Shadow Mode and revenue service to gain insight into future recovery plans.

u. Subsystem Hazard Analysis (SSHA)

1. A Subsystem Hazard Analysis (SSHA) shall be documented to verify safety compliance and identify hazards associated with each subsystem.
2. The SSHA shall be in accordance with the IEEE Standard for Verification of Vital Functions in Processor-Based Systems 1483-2000.
3. As an extension of the System FTA/FFTA, the main focus of the SSHA shall be on the faults recognized within each subsystem, and TCS interfaces.
   i. Subsequent to the system-level FTA/FFTA, the Contractor shall perform subsystem level FTA to identify any elements that can combine resulting in Category I events.
4. Methods or actions for eliminating, minimizing, or controlling each hazard, as well as the recommended approach for eliminating, controlling, or minimizing each hazard that is identified during this analysis shall be documented in the SSHA. For example:
   i. Possible independent, dependent and simultaneous events or failures and system interactions that could create increased risk.
   ii. Effects of reasonable human errors.
   iii. Determination of/that:
      (a) Potential effect on system safety from the functional, interoperable relationships between Subsystems.
      (b) Safety design criteria has been satisfied (hardware, software).
      (c) Implementation of safety recommendations and corrective actions will not impair or degrade safety performance of hardware, software, and will not create additional hazards.
5. The SSHA is performed and documented to verify compliance with safety requirements and identify hazards associated with the design of subsystems. This includes hazards caused by component failure modes, critical human error inputs, and hazards resulting from functional relationships between equipment compromising each subsystem. The following issues shall be considered during the performance of a SSHA:
   i. Modes of failure including reasonable human errors, single point and common mode failures, and the effects of failures on subsystem elements.
   ii. Potential contribution of hardware and software controlled events, faults and occurrences.
   iii. Satisfaction of all safety design criteria.
   iv. Integrating safety testing into hardware and software testing programs.

v. Integrating Formal Methods into software development, when used.
vi. System level hazards attributed to subsystems are controlled.
vii. Input information from other subsystems that is/are required to perform the functions of the TCS system in a safe manner.

v. Cutover (for Shadow Mode) Safety Analysis
1. The Cutover of the TCS system introduces the potential for hazards associated with the physical cutover and the system transition.
2. The Contractor shall compile a Cutover Safety Analysis for their TCS system to prove that there are no safety hazards introduced due to the processes adopted during cutover, temporary connections or wiring changes, transitional or staged software releases to account for interim track layout configuration, or phased functionality.
3. The Cutover Safety Analysis shall:
i. Define the Contractor's approach to safety during the cutover period, based on the NYCT-approved cutover plan
ii. Include cutover hazards from the TCS system and identify the required mitigations relating to design, procedure, training, etc. The list of hazards shall be documented in the Cutover Safety Analysis.
iii. Provide sufficient information to allow NYCT and the ISA to judge the effectiveness of the TCS system (and its interfaces) and cutover approach, processes, modifications and configuration management during the cutover period.

w. Final Safety Report
1. The Contractor shall submit a Final Safety Report which provides a summary of the results of the overall analysis, safety verification, safety validation, and system safety demonstration for the complete TCS system.
2. Prior to developing the Final Safety Report, the Contractor shall submit the document's outline (format) for approval by NYCT.
3. The Final Safety Reports shall follow the Safety Case structure defined in the CENELEC 50129 standard.
4. The Final Safety Report shall
i. Provide evidence that the safety program has been completed in accordance with the requirements of this specification.
ii. Build on the Safety Analyses, Hazard Log and any other relevant outputs from the TCS Safety Program.
iii. Document the calculations and methodology to show that the Project System satisfies the MTTHE requirement defined in Section 10.3.8 of this specification section.
iv. Document any actions taken or any system design features included to minimize risk to the specified level.
v. Address all risk reduction actions taken during system design, production, test, operation, and maintenance, including mitigation of faults caused by the following:
(a) Operating scenarios.
(b) Failures of plant and equipment.
(c) Latent design errors in system hardware and software.
(d) Installation errors.
(e) Human reaction to situations and events resulting from failures, unusual operating situations, and events beyond NYCT's direct control.
(f) Post implementation changes to the software or hardware.
vi. Contain the evidence of the resolution of hazards, as reviewed and

approved by NYCT.

vii. The evidence of resolution of hazards shall consist of the satisfactory closure of the items as listed in the Project Hazard Log and the achievement of certification of the items on the Certified Items List.

5. The Final CIL shall be contained in the Final Safety Report.
6. The Final Safety Report shall be considered draft until such time as the TCS system is Safety Certified or certified for Shadow Mode.
7. The Final Safety Report shall be submitted for System Safety Certification Board (SSCB) certification prior to Shadow Mode, dynamic testing, testing outside of a diversion, and permanent and temporary connection of wayside equipment.
8. After the initial SSCB certification, the Final Safety Report shall be revised and re-submitted whenever the system is updated, the characteristics of the territory, system or any subsystem interface is modified in a way that impacts on system safety.
9. In addition, the Final Safety Report shall contain an analysis of non-vital system interfaces to the TCS system. The Final Safety Report must prevent evidence that non-vital system interfaces (and their possible modifications) have no adverse effects on safety.

10.3 System Safety Requirements

10.3.1 System Safety Program Management Requirements

a. The Contractor shall designate a single individual within their organization as the System Safety Manager for the project.
b. The Contractor shall present the qualifications of the nominated individual for approval by the Engineer.
c. The System Safety Manager shall:
    1. Have a separate reporting chain to an executive-level senior manager of the organization, independent of the TCS project design, development and test teams.
    2. Be vested with single point responsibility for all TCS system safety issues involved in performing the work.
    3. Coordinate with the Engineer on all issues relating to safety.
    4. Have the appropriate stature, qualifications, experience, and reporting authority within each Contractor's organization.
    5. Have overall responsibility for ensuring the implementation and management of the Project Safety Plan.
    6. Be responsible for ensuring all Contractor-related staff are informed of the importance of safety and their respective safety responsibilities.
d. The Contractor shall ensure adequate competence and continuity of personnel responsible for the safety of the project's TCS System.
e. The Contractor shall have independence between system developers and the safety program staff.
f. The Contractor shall use proper project management techniques to maximize the visibility of system safety activities and associated results to all Project participants and to facilitate the timely identification and resolution of hazards and help minimize the existence of unsafe system aspects.
g. The Contractor shall establish safety roles and responsibilities for each sub-Contractor, and coordinate and monitor the system safety activities of all sub-Contractors to ensure the safe interface and integration of sub-Contractor products and the proper integration of all safety activities for the entire system.
h. The Contractor's activities shall include:

1. Flowing down all applicable safety requirements,
2. Coordinating all safety analyses, verification and validation activities including testing for products being provided,
3. Establishing a schedule consistent with that of the Contractor's safety activities/deliverables,
4. Monitoring the progress and results of safety activities for integration into the Contractor's hazard tracking and safety reporting process.

i. The Contractor shall conduct and document internal and Subcontractor audits periodically to ensure that the Project Safety Plan is followed.
j. The Contractor shall support external audits of system safety activities by NYCT and ISA staff.
k. The Contractor shall support NYCT and ISA staff site visits to audit and observe system safety and design activities, discuss safety issues and provide documentation, as available, to support the audit.
l. The Contractor shall address and clearly identify non-conformances.
m. The Contractor's safety reviews/audits shall:
    1. Address system safety concerns in a timely fashion as identified through their safety activities or by other Project participants.
    2. Discuss possible means of resolving those concerns through the incorporation of special system features, design/procedural changes, or other means.
    3. Assign action items for the resolution of those concerns.
    4. Track progress, track problems related to the implementation of their system safety program, and to allow all personnel to remain closely informed of safety activities and responsibilities.
n. The Contractor shall present the results of these audits to be reviewed at the System Safety working group (SSWG).
o. The Contractor shall include system safety program progress summaries with Project monthly reports (to be presented at SSWG or NYCT Construction Manager meetings).
p. These summaries shall be presented monthly SSWG meetings, or (NYCT Construction Manager meetings) and address:
    1. The status of system safety activities with respect to the Project schedule (Safety Progress Report).
    2. Upcoming Safety Submittals and Safety activities planned for the next three periods.
    3. Identified hazards for which adequate mitigation has yet to be provided, in the form of an updated Hazard Log.
    4. Safety issues requiring discussion with NYCT/ISA staff.
    5. System safety incidents, which have occurred on the Project since the last report.
q. The Project schedule shall include planned relationship between safety activities, and the design and testing tasks, which depend on successful completion of safety tasks, and overall Project milestones.
r. Estimated start and completion dates shall be provided for all system safety program activities, associated reports and submittals, and reviews.
s. Project and Safety Management shall provide the status of subcontracting companies, as applicable.

10.3.2 Safety Assurance Requirements

a. The Contractor shall document the principles, strategies, and tools used to implement the safety requirements through the System Safety Concepts Document, V&V Plan, Test Plan, etc.
b. The safety analysis of the vital design techniques incorporated in the Project System shall be traceable to both the Project and concept-specific safety requirements and identify the hazards being addressed.
c. Fail-Safe Equivalence. - Safety critical (vital) functions shall be implemented in a manner which is fail-safe. Processor-based designs which are equivalent to fail-safe will be considered for performing safety-critical functions when their fail-safe equivalence is explicitly shown by use of acceptable safety assurance concepts, and then proven by undertaking safety analysis and safety verification in accordance with this Specification.
d. The system analysis shall demonstrate that the probability of any failure, or combinations of failures, which could result in an unsafe condition satisfies the safety design criteria as per this Specification.
e. Implementation of fail-safe equivalent functions shall follow an explicitly defined safety assurance concept. Concepts will be acceptable if defined in adequate detail in the System Safety Concepts document and presented to the Engineer for approval.
f. To verify that the safety assurance concept, as implemented, adequately mitigates the effects of hardware failures and/or software errors, the safety assurance concept methods of verification shall address, at a minimum, the following list of potential processor-based system faults caused by hardware failures and/or software errors.
g. Other methods appropriate to the concept used shall be defined in the System Safety Concepts document and conducted to sufficiently determine the level of safety assurance of the design. Design considerations include but are not limited to:
    1. Incorrect or ambiguous system inputs
    2. Inputs not present at the prescribed time
    3. Incorrect system outputs
    4. Outputs not present at the prescribed time
    5. System output when necessary inputs are not present
    6. Changed memory contents
    7. Changed clock rate
    8. Data not current
    9. Failure to exit from loop
    10. Arithmetic error
    11. Sign error
    12. Entry to or exit from a routine at the wrong time
    13. Illegal entry to a routine
    14. Improper execution of instructions
    15. Skipping of program segments
    16. Latent faults
    17. Common cause faults
    18. Transient faults
    19. Other faults particular to the specific technology
    20. Clear identification of unused code

10.3.3 Design Safety Implementation Requirements

a. Human factors issues shall be taken into consideration in the design of the safety-critical and safety related equipment.
b. The Human Factors analysis shall comply with the guidelines of 49 CFR 236 Subpart H, or equivalent as approved by NYCT.
c. The system design shall minimize the impact of human error on the TCS operation, eliminating manual intervention in all operations where it can be avoided.
d. All human intervention actions shall be designed to be intuitive to the user, where possible.
e. Human Factors analysis shall be integrated into the safety analyses throughout the safety program, including O&SHA.
f. Security is an important element in the design and development of products to address issues such as developing measures to prevent hackers from gaining access to software and developing measures to preclude sudden system shutdown. The System Requirements Document and the System Design Document shall address the security measures taken into account in the design of the TCS system.
g. The Contractor shall identify the methods used in development of the system and subsystems to prevent security issues including those detailed above.
h. The description of the security processes shall be included in the Contractor's Project/Product Safety Plan.
i. The Contractor shall ensure that the security approaches are compatible and address any interface issues to ensure ongoing safe, secure operation of the TCS system by NYCT.
j. The accuracy, resolution, and integrity of the train location system shall be consistent with limits established for safe braking distance, enforcement of speed and movement authority limits, switch protection, and other safety functions.
k. TCS vital functions shall be implemented using concepts which can be verified as being both correct and sufficiently robust to mitigate the hazards of the system.
l. The safety concepts for processor-based system shall be in accordance with the IEEE Standard for Verification of Vital Functions in Processor-Based Systems 1483-2000.
m. Safety-critical elements of the TCS System shall be designed with sufficient margin to operate in a fail-safe manner over the entire range of environmental specifications (as specified in AREMA), as appropriate for the location of the element.
n. All safety analyses shall consider the effects of environmental variations on the system.
o. All data communication subsystems within the TCS System that transfer safety-critical data shall be designed to provide adequate levels of error detection to meet the safety goals as defined in Section 10.3.8 of this specification section.
p. Certain equipment and components are declared to be fail-safe by their compliance with existing codes and standards for these particular devices (e.g. vital signaling relays) and may be used, in an appropriate manner, in the design of a safety critical system element.
q. The Contractor shall be responsible to present the safety certifiable evidence of these inherent fail-safe equipment and components to be used.
r. The Contractor shall provide metrics for timing and loading. These metrics will reflect the design criteria for the TCS system, taking into account spare capacity and timing constraint requirements.
s. The architecture of the system and its modifications during the course of the project shall be subjected to rigorous safety analysis.
t. The Contractor shall retain responsibility for ensuring that all hazards have been identified and appropriately mitigated.
u. The Contractor shall address (in the various project safety analyses and the Project Hazard Log) the following hazards:
    1. Relocation of track equipment not amended in the database.
    2. Removal of track equipment not addressed in the database.

3. Addition of track equipment not addressed in the database.
4. Update of database (track topology) leads to unsafe state.
5. Redundant update of database leads to conflicting system states leading to unsafe or reduced safety state.

v. The Contractor shall demonstrate compliance with the following:
   1. Vital input / output circuit wiring, terminals, printed circuit boards / components shall comply with AREMA / NYCT specifications for Class 1 safety hardware.
   2. The TCS design shall have proper grounding and electrical isolation to reduce the potential for transients and false signaling (information) from being generated and to protect against false energization of relays, sneak paths that can bypass vital circuitry, or false vital inputs which may be undetectable.
   3. The TCS design shall ensure that shutdown of the TCS does not prevent the completion of switch machine movements, for example, the failure to complete the stroke such as open switch points.
   4. The TCS design shall include closed loop principles where “turnoff / shutdown / Bypass / EB” is an automatic default condition and not dependent on other processes (or non-vital equipment).
   5. The TCS design shall eliminate potential common faults (those occurring within the current cycle check window) as well as the potential inability to assure “shutdown” via vital relays and its associated circuitry.
   6. The TCS design shall interlock (fail safe) by preventing an unsafe condition from occurring due to TCS failure. For example, the transition of the TCS System output to an unintended state will be prevented prior to fault-detection by the TCS diagnostics.
   7. The TCS design shall allow for the physical disabling of redundant output boards. If only a logical disabling is used in the design, the application’s configuration wiring shall ensure a physical interlock to prevent a standby processor from delivering momentary outputs prior to a fault being detected.
   8. The TCS design shall ensure that a momentary transition (spike) of a single output cannot cause an unsafe condition.
   9. Concurrent Power-up of redundant processors shall not cause an inadvertent change of state of an output signal (e.g. due to going on line at the same time).
   10. The TCS design shall prevent valid outputs from being generated to a “high” state due to preconditions for functions such as switch operation. Application design should consider a timing window for such operations and force outputs to a “low” state until after the expiration of time and log all faults for maintenance.
   11. Monitoring of variables, inputs, outputs, utilizing a trace or pause facility within the application software with the use of a tool or facility connected to the online processor shall not trigger an inadvertent output or variable state.
   12. The TCS system shall have a safe design regarding missed sensors (UWB Anchors, etc.). The missed sensors/faulty sensors must be reported to the TCS diagnostics system.

w. The Contractor shall identify the verification and validation processes undertaken to approve the translated documents for use in the TCS design.
x. The Contractor shall submit details of the “rules / guidelines” used by systems engineering to establish the sequence of code, determining applicable I/Os, etc. for the TCS design.
y. The safety program and analysis for the TCS system shall include review of the whole system in terms of such items as interleaving of logic execution and integrity checks with fail safe power removal.
z. The safety review and analysis shall not be limited to those items specifically modified for the NYCT equipment and environment.
aa. The safety program shall consider the integrity of diagnostic checks.

bb. Safety implications of system "worst case" timing responses shall be considered within the safety consideration of the TCS system.
cc. The TCS safety analysis shall consider system response times with respect to interfacing equipment for the: time to report and act upon new switch status, new movement authorities, new train tracking information, etc.

10.3.4 Software Safety Implementation Requirements

a. Safety-critical system functions:
    1. Have a direct impact on the safety and integrity of the system and therefore are relied upon to provide reasonable continuity of service, and,
    2. Are required to be available for support of an emergency situation.
b. Safety-critical system functions may be performed utilizing logic resident in software. The impact on the safety of the system may be different in each case, and the contribution of a particular software subsystem to an identified hazard shall be evaluated using the safety verification and validation techniques in these Specifications.
c. The design and development of safety-critical software shall be in accordance with recognized national or international software standards applicable to critical, high integrity systems.
d. Where software is employed to perform a safety-critical function, then that software shall have been developed to a rigorous interpretation of these design and development processes and confirmed by verifying the requirements of these Specifications.
e. Safety-critical decision processes within the software shall be structured to ensure minimum complexity and allow rigorous safety verification, safety validation, and testing.
f. The dependence of safety of the system on a single software decision process, logic path, or critical data element shall be minimized or avoided where possible.
g. The Contractor shall verify these requirements by performing documented analysis and testing of the safety-critical software.
h. Where vital and non-vital software is to be implemented on a single hardware platform, then all of the software shall meet the requirements for vital software unless appropriate techniques, acceptable to the Engineer, are used to ensure vital software is sufficiently partitioned to be unaffected by the non-vital software.
i. The Contractor shall use requirement-elicitation and system-design methodologies that are preventive of errors (of commission or omission) in safety related and safety-critical logic, so as to minimize schedule and cost impacts later in the project's life-cycle due to correction and re-work.
j. NYCT supports the use of Formal Methods for software design and generation.
k. The Contractor shall ensure that the safety processes in place for the initial production and later modification of databases (track topology maps, configuration files), address the safety of the data.
    1. Specifically, the Contractor shall address compatibility issues and the on-site testing required to ensure the safety of the TCS system as implemented in this project.

10.3.5 Software Safety Verification and Validation Requirements

a. When vital software is included in the TCS design, the Contractor shall conduct software safety verification and safety validation activities as part of the Software V&V to assure software-based functions/algorithms being used are correct (the desired ones) and are implemented in a safe manner.
b. Plans for conducting software safety V&V shall be clearly defined in a NYCT-approved System/Software V&V Plan.

c. The Contractor shall coordinate the System/Software V&V Plan (SSV&VP) with the Software Development Plan so objectives and relationships between software development, software V&V, software safety V&V, and software quality assurance activities are clearly defined. Software development phases include software requirements, architectural design, detailed design, implementation, integration and test.

10.3.6 System Safety Validation Requirements

a. System safety validation activities are conducted to demonstrate that the correct system has been implemented such that the overall system operates safely in its intended environment - specifically that the system meets all qualitative and quantitative system safety requirements, and does not compromise the safety of the existing NYCT subway system.
b. The Contractor shall submit for NYCT approval the SSV&VP that clearly defines all safety validation activities on the overall TCS system prior to starting.
c. The Contractor shall coordinate the activities of the SSV&VP with the system development, test and commissioning activities so objectives and relationships between system test and development assurance activities are clearly defined. System development phases include requirements, architectural design, detailed design, implementation, integration and test.
d. Results of system V&V activities shall be included along with other project documentation and be clearly designated as pertaining to safety aspects.
e. SSV&VP shall include analyses, testing, inspections and/or walkthroughs directed to the safety aspects of the development and implementation phase.
f. Verification & Validation procedures shall address hardware as well as software development to assure that safety is fully integrated into the development process.
g. Testing is an important aspect in the system development and system V&V process.
h. Testing shall be conducted on individual equipment as well as integrated system.
i. Tests shall include normal range testing (i.e. exercising test cases under various load and throughput conditions) and boundary value testing (i.e., checking execution at parameter limits).
j. Tests shall also be directed to the hazards identified from the verification to show that hazards are mitigated where possible.
k. Testing of the overall system shall encompass functional and “black box” techniques. The primary intent is to show, via testing, the overall system is “fit for purpose” from a safety standpoint. This shall include the reliability and availability of the system to perform the required operational and safety functions.
l. Safety validation shows that the integrated system performs safety-critical functions in a safe manner under all anticipated operating conditions (e.g., normal operation, hardware failures, external influences); and confirms that all unacceptable hazards as identified by the safety analyses have been eliminated or mitigated to acceptable levels.
m. The software safety validation activities shall be performed as part of the Contractor’s tasks.
n. Safety validation of modifications to one or more TCS subsystems shall be addressed by the software verification and validation processes. In addition to testing the modifications, this shall include a defined regression testing approach.

10.3.7 System Safety Testing Requirements

a. The Contractor shall ensure that the test and commissioning program demonstrates the ability of the TCS system and TCS subsystems to safely provide all of the functionality defined in these Specifications.
b. The Contractor's Safety/RAMS departments shall thoroughly review the test plans, procedures and test results produced.
c. The Contractor's Safety/RAMS department shall recommend additional tests to be conducted in order to assure and demonstrate that each subsystem and the integrated subsystems perform the correct safety system functions and operate safely over the anticipated operating conditions.
d. The Contractor's testing process and testing program shall comply with the requirements of 49 CFR 236 Subpart H, Product Safety Plan items 17 and 18 [5].
    1. **17.0 Initial Implementation Testing** – A description of initial implementation testing procedures necessary to establish that safety-functional requirements are met, and safety-critical hazards are appropriately mitigated.
    2. **18.0 Post-Implementation Testing** – A description of post-implementation testing (validation) and monitoring procedures, including the intervals, as well as a description of the record keeping necessary to ensure the safety of the system that is associated with periodic maintenance, inspections, tests, repairs, replacements, adjustments, and the system's resulting conditions. This shall be provided to gain insight into the maintenance requirements of the TCS system.
e. The test program shall include the requirements of post-implementation testing and those tests required to ensure the safe implementation of modifications.
f. The post implementation testing requirements appropriate to maintenance shall be reflected in the response to the requirements detailed in this specification section, especially those tests related to maintaining safety.
g. The Contractor shall submit the regression testing requirements to NYCT for approval.
h. The regression testing requirements shall include the process describing the development of the regression testing requirements for each release along with the minimum regression test requirements for each system element.
i. Following the first release of the system for shadow mode, the requirements for regression testing shall be enforced.
j. All subsequent system modifications shall be the subject of approved regression testing.
k. The acceptance of the regression testing shall form part of the certification process.

10.3.7.1 Subsystem/System Safety Verification & Validation Testing

a. Verification and Validation testing shall be performed on system hardware and integrated hardware/software portions to supplement verification analyses and help demonstrate safety critical functions have been implemented in a sufficiently robust and fail-safe manner.
b. The Verification and Validation tests shall involve all Classes of hardware and software associated with implementing safety critical and safety related functions, including any tests described in the methods of verification section of the System Safety Concepts document deliverable.
c. The Verification and Validation tests shall be conducted to demonstrate safe performance of safety functions under the following three (3) conditions:
    1. Normal operation with no component failures.
    2. Hardware failures that could not be confirmed through analytical means.
    3. Abnormal inputs and other abnormal, but possible, operating conditions.
d. Anticipated operating conditions shall include normal operation, random hardware failure and external influences including abnormal/improper inputs, power supply anomalies and

other electrical, mechanical and climatic conditions.

e. Testing under conditions of normal operation shall be directed to the safe performance of the correct safety subsystem and system functions within the normal range of input and other operating conditions and with no component failures.
f. Testing under conditions of hardware failure shall be directed to the safe performance of the correct safety subsystem and system functions with inserted/simulated hardware failures in particularly critical areas (as identified by the Hazard Log) and with normal input/operating conditions.
g. Testing under conditions of abnormal/improper inputs and other external influences, a type of "robustness" testing, shall demonstrate the safe performance of subsystem and system functions under stress conditions - abnormal or improper inputs and other abnormal operating conditions.
h. All verification and validation testing shall be directed to demonstrate that safety-critical functions have been implemented in a fail-safe manner.
i. The results of verification and validation testing shall be included with the relevant subsystem implementation safety analysis reports.
j. Safety verification and validation testing shall include the process required to repeat safety verification testing in the event of modifications to one or more elements of the TCS system and subsystems.
k. Overall, the testing shall demonstrate that the system operates safely in a large representative set of scenarios and responds to identified failures in a safe manner. The purpose is to ensure that the design has been implemented in a robust manner to be safe within the full range of operational demands and environmental conditions.
l. Safety verification and validation tests results shall be recorded in accordance with approved test plans, and the safety analysis reports clearly describe the successful completion of each test conducted.

10.3.7.2 Factory/Field Safety Demonstration Testing

a. Factory/Field Safety Demonstration test activities shall be conducted to complete the safety verification and validation process.
b. Safety Demonstration tests results shall be recorded in accordance with approved test plans, and the safety analysis reports clearly describe the successful completion of each test conducted.

10.3.8 System Safety Performance Requirements

a. Achievement of System Safety is a primary design and performance requirement for the TCS system. The TCS system shall perform in a safe manner under all operating conditions.
b. The Contractor shall allocate and flow down quantified safety requirements to all the TCS subsystems.
c. The safety requirements allocation shall take into account the functions required from the TCS subsystems as well as the requirement to meet or exceed the overall system requirement.

10.3.8.1 Qualitative Safety Requirements

a. The Contractor shall design and implement the system including the development of processes, procedures and other means so as to assure the system safely performs the correct safety critical functions.

10.3.8.2 Quantitative Safety Requirements

a. The quantified requirements are derived from the IEEE, IEC and CENELEC standards.
b. The Contractor's TCS system shall have a total calculated aggregate MTTHE of at least 109 operating hours. Peak operating hours shall be considered.

11 PROJECT MANAGEMENT AND MISCELLANEOUS

11.1 General

a. The intent of this Contract is for the Contractor to furnish all engineering and design, fabrication, construction, and the supervision of installation of an Ultra-Wideband based Train Control System for NYCT. This work shall include testing of the Wayside, Communications, Carbone, and ATS Systems including all hardware and software, sub-systems, and components to satisfy the requirements of a Safety Certifiable System as defined in Section 10. The Contractor shall provide a fully functional Train Control System as defined in Sections 3 and 4.
b. The wayside and carborne installations shall be performed by NYCT forces, a 3rd party contractor or a combination of these resources. Portions of the installations that may be performed by a 3rd party will be managed by NYCT.
c. This project name is: Ultra-Wideband (UWB)-based Train Control System Pilot Program.
d. The Proposer shall prepare complete, detailed designs for the wayside and carborne installations.
    1. The Proposer is solely responsible for the accuracy, code compliance and compliance with established NYCT and industry standards and safety of the design.
    2. The drawings and specifications shall be prepared and submitted by an engineer hired by the Proposer.
    3. The engineer shall possess a valid NYS Professional Engineer's License.
    4. Design drawings, installation drawings, shop drawings, amplifying drawings and such other drawings as determined by NYCT shall be sealed with a professional engineer's seal and signed by that engineer.
e. The Proposer shall be wholly responsible for all aspects of the test program exclusive only of the actual installation activities.
    1. The Proposer shall be responsible to provide technical oversight of the installations to ensure that the installations comply with the design intent and requirements of the drawings and specifications.
f. The Proposer shall engage the services of an Approved Signal Engineer and a Signalman who shall be submitted for approval by NYCT based on their training and experience in work of similar nature involving train control and wayside signal systems in the NYCT environment.
    1. The approved Signal Engineer shall possess a valid NYS Professional Engineer's License.
    2. The Signal Engineer shall approve all designs, additions, removals or modifications involving wayside signaling and train control equipment and systems.
    3. The Signalman shall be present and personally supervise any work on or in proximity of NYCT's operating signal equipment and systems.
    4. The Signal Engineer shall be present at and supervise the testing and placing in service of all signal modifications.
    5. It shall be permissible for the Signal Engineer to perform the duties of the Signalman subject to NYCT approval.
g. If the Contractor provides justification, NYCT may accept waiving some requirements in this section. If the Contractor's system does not comply with all specifications of this section, the Contractor shall identify each line item that cannot be satisfied by the Train Control System per the Gap Analysis (see Section 1.6). **Unless a written waiver is provided to the Contractor by the NYCT Program Manager, it shall not be assumed**

that any requirements of this section are waived.

11.2 Submittals

a. Wherever possible, throughout the Contract Documents, the minimum acceptable quality of workmanship and materials has been defined by manufacturer's name and catalog number, reference to recognized industry and government standards, or description of required attributes and performance. The Contractor shall provide all submittals required by the Specifications, and shall revise and resubmit the submittals as necessary to establish compliance with the specified requirements.
b. Related submittals shall be made in logical groups and the submittal shall explicitly identify the relationship with other submittals, in terms of impacts and interfaces.
c. All product submittals shall explicitly detail the application and location of each product. Approval, if any, shall apply only to the specific application for which approval was requested.
d. Equipment, systems, and associated materials manufactured or procured by the Contractor, prior to approval, shall be done so at the Contractor's own risk. Subsequent rejection, if any, shall not be the basis for additional costs under this project.
e. Coordination of Submittals: Prior to each submittal, carefully review and coordinate all aspects of each item being submitted and verify that each item and the submittal for it conforms in all respects with the requirements of the Specifications. By affixing the Contractor's signature to each submittal, certify that this coordination has been performed.
f. Each page of every submittal shall be stamped with the submittal number, including the revision number. The first page shall also be stamped with the related submittal, in cases where submittals are submitted in groups.
g. Maintain an accurate submittal log for the duration of the Program, showing current status of all submittals at all times. Make the submittal log available and provide copies of the log for the NYCT Program Manager's review upon request.
h. Timing of Submittals
    1. Make all submittals far enough in advance of scheduled dates for installation to provide all time required for reviews, for securing necessary approvals, for possible revisions and resubmittals, and for placing orders and securing delivery.
    2. Delays caused by tardiness in receipt of submittals will not be an acceptable basis for extension of the Program Completion Date.
    3. Provide fourteen (14) calendar days of review time between the date of receipt of a submittal by the NYCT Program Manager, and the date of return by the NYCT Project Manager, in most cases. Certain Prototypical design reviews may take up to twenty one (21) days for review, such as, 1st vehicle submissions and communication design.
i. If drawings show variations from the Specifications because of standard shop practice or for other reasons, describe such variations in the letter of transmittal. Failure to describe such variations shall not offer relief from the responsibility for executing the work in accordance with the Contract, even though such drawings have been reviewed.
j. Drawings Not in Conformance:
    1. If corrections to the drawings and submittals are required, each submittal will be marked "REJECTED", "AMEND AND RESUBMIT", or "CONFORMS AS NOTED" and in which case the required corrections will be shown.
    2. Resubmittals will be handled in the same manner as first submittals.
    3. Direct specific attention, in writing or on resubmitted drawings, to revisions other than the corrections requested by NYCT.
    4. If any corrections indicated on the submittals and drawings constitute a change to the Specifications, give notice to the NYCT Program Manager.

5. Work Indicated on drawings marked “CONFORMS AS NOTED” may be carried out prior to resubmission and final review if progressed “AS NOTED”.

k. Drawings in Conformance:
   1. Each drawing or submittal will be identified as conforming by being stamped “CONFORMS” and dated.
   2. When Shop and Working Drawings have been completed and stamped “CONFORMS”, carry out the construction in accordance therewith and make no further changes therein except upon written instructions from the NYCT Program Manager.

l. All submittals shall be uploaded to the NYCT SharePoint site and two (2) Hard Copies shall be mailed to NYCT. An email to NYCT shall be sent anytime the Contractor uploads / mails documents for approval.
   1. Once given Notice to Proceed, NYCT will assign a point of contact for all submittal correspondence.
   2. Once given Notice to Proceed, NYCT will provide the Contractor with access to the Program’s SharePoint site.
   3. The Contractor is required to maintain their own independent record of all submittals.

11.3 Coordination with other Contractors and NYCT Personnel

a. The Authority reserves the right to perform work with their own employees and by other contractors within the limits of this project during the duration of this Contract.
b. It is expected, but not guaranteed, that the work under this Contract can proceed without interruption.
c. In the event that work under other contracts is in progress during any phase of the construction under this Contract, complete cooperation with such other contractors is mandatory.
   1. It will be necessary for the Contractor to coordinate its schedule of operations with others, through the Program Manager.
   2. The Program Manager will decide any disputed questions regarding the performance of the work, access to and cleaning up of the site, and priority of performance between the various contractors.
d. The contractor shall make no claims for damages due to delays caused by the necessary operations of other contractors.
   1. In the event there is expected to be a complete stoppage of all Contractor's operations for a period in excess of five (5) consecutive working days, contractor shall be required to submit a "work around" plan for review by the Program Manager.
   2. In the event NYCT's Program Manager, at his or hers sole discretion, determines that there is no way to "work around" the expected stoppage of all contract operations for a period in excess of five (5) working days, the Contractor shall be permitted to request an equitable adjustment to the Contract price for costs directly attributable to and incurred by the described delay which shall ultimately be negotiated between the Authority and Contractor.

11.4 Protection of Cables and Equipment

a. As the Authority cannot provide complete plans of existing cable routes in the construction area, the Contractor shall verify, in conjunction with the Authority, the locations of the cable systems in the area.
b. The Contractor shall take precautions to protect all high voltage and low voltage, vital and

non-vital signal, communications, and power cables located in the construction area. Cables are suspended from the pole lines on either side of the mainline tracks, the open areas, on walls, and direct buried. The integrity of these cables is vital to normal train operations and must be maintained in full service until such time as declared abandoned by the Authority. Adequate clearance must be maintained by Contractor's equipment during installation of new cables and apparatus in both tunnel and open areas.

c. Adequate clearance must be maintained by the Contractor's equipment during installation of new cables and apparatus.
d. The Contractor shall also take all precautions necessary to protect all equipment and material on the Authority's system. Should any material or equipment be damaged, the Contractor shall immediately notify the NYCT Program Manager on the specifics of the damage. The Contractor shall be held accountable and liable for all costs incurred by the Authority for such repairs.
e. All Wire and Cable furnished by the Contractor shall comply the with NYCT Wire and Cable Specifications (Section 13.2).

11.5 Project Meetings

a. To enable orderly review during progress of the Work, and to provide for systematic discussion of problems, the NYCT Program Manager or a designated designee will conduct project meetings throughout the design, construction and testing periods.
b. One of the persons designated by the Contractor to attend and participate in the project meetings shall have all required authority to commit the Contractor to solutions agreed upon in the project meetings.
c. Meeting Locations
    1. To the maximum extent practicable, meetings shall be held at the MTA's Office in 2 Broadway, New York, NY. Otherwise, the meeting site will be determined by the NYCT Program Manager.
    2. Progress meetings may be included with design review, or other meetings organized in the development of the systems.
d. Kick-off Meeting
    1. A kickoff meeting shall be scheduled within ten (10) days after NYCT has issued Notice to Proceed. The Contractor shall ensure the attendance by key Contractor personnel and authorized representatives of the Contractor's Sub-Contractors.
    2. Minimum Agenda: Distribute data on, and discuss:
        i. Organizational arrangement of Contractor's forces and personnel, and those of Sub-Contractors, materials suppliers, and NYCT Program Manager, which includes Organizational Chart and Contact List.
        ii. Channels and procedures for communications.
        iii. Project office location and main contacts.
        iv. Design and Construction schedule, including sequence of critical work.
        v. Interfacing with other Contractors.
        vi. Submittal procedures.
        vii. Issues resolution procedures.
        viii. Materials to be ordered.
        ix. Equipment to be used.
        x. Processing of Drawings and other data submitted to the NYCT Program Manager for review.
        xi. Rules and regulations governing performance of the Work, Safety training, etc.
        xii. Procedures for safety and first aid, security, quality control, housekeeping and other related matters.

xiii. Methods for maintaining and protecting on-going Authority operations during construction.

3. The Contractor and the NYCT Program Manager will arrange for their authorized representatives to meet and review details of design and construction, and if appropriate, to walk the project with the Contractor and carefully observe all pertinent conditions relating to the design and construction of the Work, including the status of right-of-way, structures and obstructions to be removed, altered or changed.

e. Project Progress Meetings

1. To the maximum extent practicable, assign the same person or persons to represent the Contractor at project meetings throughout progress of the work. Attendance by key personnel and, a technical report by the Contractor's Program Manager, or designee, shall be mandatory. The NYCT Program Manager may require the Contractor's employees to attend meetings as directed. Sub-Contractors, materials suppliers, and other may be required to attend those project meetings in which their aspects of the work are involved.
2. Be prepared to discuss progress of the work in sufficient detail for both the Contractor and NYCT to confidently control and monitor the prescribed work scope and schedule.
3. Prepare a bar chart for presentation at each meeting showing status of major phases of the work, delineating work that is behind schedule.
4. Minimum Agenda:
    i. Previous Meeting Minutes: Review, revise as necessary, and approve minutes of previous meeting.
    ii. Safety.
    iii. Progress of Work: Review progress of the work since last meeting, including status of submittals for approval. Review submittal schedules; expedite as required to maintain schedule.
    iv. Open Issues: Identify problems which impede planned progress. Discuss technical issues and resolve or direct actions to be taken.
    v. Schedule: Develop corrective measures and procedures to regain planned schedule, using the construction schedule as the basis.
        (a) Review changes proposed by NYCT for:
            1. Effect on Construction Schedule
            2. Effect on Completion date
    vi. Projected work: Planned work for the next period.
        (a) This plan shall be accompanied by a written daily schedule of work proposed for the two calendar weeks commencing on the Sunday after the Project Meeting. As a minimum, the schedule should show the number and types of equipment that will be working, material and equipment delivery, and the type and number of NYCT support personnel that will be required.
        (b) Coordinate projected progress with work by NYCT and other Contractors, if applicable.
    vii. Contract Issues: Review and resolve any Potential Change Orders (PCO). The Contractors PCO listing shall conform to the NYCT Program Manager's listing.
    viii. The status of Requests for Information (RFIs) shall be discussed and updated.
5. Additional project meetings will be called for by the NYCT Program Manager as necessary. The Contractor may request additional meetings to discuss special issues. The NYCT Program Manager will review such requests and schedule a

meeting if the NYCT Program Manager considers it necessary.

6. Revisions to minutes.
    i. Unless published minutes are challenged in writing, within five (5) working days of the distribution date they will be accepted as properly stating the activities and decisions made at the meeting.
    ii. Any individual challenging published minutes shall provide proper supporting documentation acceptable to the NYCT Program Manager to verify that the challenged item was truly discussed during the subject meeting.
    iii. Challenge to minutes shall be settled as priority portion of "Previous Meeting Minutes" at the next regularly scheduled meeting. The NYCT Program Manager's decisions concerning challenged item(s) shall be binding on the Contractor.

11.6 Project Schedules

a. The Contractor shall maintain a project schedule to facilitate coordination between various contracts, constraints and stakeholders that impact this Contract.
b. The Contractor shall assist NYCT in the management of the schedule to assess risk, plan pre-emptive delay avoidance, respond rapidly to slippage, and formulate recovery initiatives.
c. The Contractor shall be responsible for identifying all deliverables, and delivery dates, required to ensure that the subsystem equipment configuration shall achieve the overall project schedule and milestones of the entire Train Control System Project.
d. The Contractor shall propose a scheduling tool (e.g. Microsoft Projects, Primavera P6, or equivalent) for approval by the NYCT Program Manager.

11.7 Construction Safety Program

a. It is the Contractor's responsibility to inform all personnel working on this project of the standard Authority safety procedures for working in the vicinity of the line and to make certain that all personnel follow the procedures.
b. It is the Contractor's responsibility to work in a manner consistent with all federal and/or state OSHA regulations. The Authority reserves the right to stop any work being done if work is inconsistent with NYCT, FTA or OSHA safety regulations.
c. The work shall be performed on an existing transit facility which will be kept in operation at all times. The Contractor's work must be organized to provide safe, clean and unobstructed patron passageways and facilities.
d. The Authority reserves the right for final approval of the site. The Contractor will be responsible to maintain the site in a neat and orderly manner and will be required to remove construction debris and discarded and demolished materials from the site in a reasonable time period as determined by the NYCT Program Manager. Restoration of the site to its original condition will be the sole responsibility of the Contractor and no separate payment will be considered for this restoration.
e. Members of the Authority's Safety, Rules and Training Department may visit worksites with or without advance notice.
f. Safe and efficient service to the riding public is the highest priority and must be considered in every instance that would impact public service. The construction activities shall require close coordination with operating divisions; all coordination will be through the NYCT Program Manager.

11.8 User Manuals

a. The Contractor shall develop user manuals which at a minimum define any applicable requirements to operate and maintain the system during the Shadow Mode phase.

11.9 Key Personnel

a. The Contractor shall maintain an Organization Chart for their project team.
b. The Contractor shall propose the personnel structure and number of personnel required to execute this scope, however, NYCT reserves the right to request additional resources or the replacement of named resources if the NYCT determines that the project team is not capable of executing the scope.

12 DELIVERABLES

a. This section contains a list of all submittals required under this Contract.
b. Submittals may be consolidated if approved by the NYCT Program Manager.
c. The Contractor shall reference each section of this Specification for a list of submittals relevant to that section.
d. NYCT reserves the right to raise any safety concerns regarding any documents that are submitted for Information Only or auditable documents. Any safety concerns shall be addressed by the Contractor.
e. The following is the consolidated list of documents to be submitted for review and approval:
    1. Systems Integration Management Plan
    2. CDRL
    3. Configuration Management Plan
    4. System Database Definition
    5. Subsystem Database Definition (if applicable)
    6. UWB-Train Control System ICD (if integrating multiple suppliers)
    7. DCS-Train Control System ICD (if integrating multiple suppliers)
    8. Requirements Traceability Matrix
    9. Periodic Systems Integration Progress Report
    10. Periodic V&V Compliance Report
    11. Preliminary Performance Simulation Report
    12. Final Performance Simulation Report
    13. Safe Braking Model
    14. UWB-CBTC Speed and Position Comparison Outline
    15. UWB-CBTC Speed and Position Comparison Report
    16. List of all Train Control Equipment
    17. Environmental Test Plan.
    18. Environmental Test Procedures.
    19. Environmental Survey Test Plan.
    20. Environmental Site Survey Report.
    21. Environmental Test Report.
    22. EMC Control Plan.
    23. EMC Design Report.
    24. EMC Test Plan.
    25. EMC Site Survey Test Procedure.
    26. EMC Site Survey Report.
    27. EMC Signaling Compatibility Analysis.
    28. EMC Final Field Test Procedure.
    29. EMC Final Field Test Report.
    30. EMC Safety Analysis.
    31. Software Project Management Plan (SPMP)
    32. Software Development Plan (SDP)
    33. Software Configuration Management Plan (SCMP)
    34. Software Verification and Validation Plan (SVVP)
    35. Software Quality Assurance Plan (SQAP)
    36. Software Requirements Specification (SRS)
    37. Software Configuration Item List (SCIL)
    38. Software Test Plan (STP)
    39. Software Acceptance-For-Test Form
    40. Firmware and Software Installation List

41. Timing and Sizing Document
42. DCS Preliminary Design Review
43. DCS Final Design Review
44. Wayside Equipment Preliminary Design Review
45. Wayside Equipment Final Design Review
46. Vehicles Preliminary Design Review
47. Vehicles Final Design Review
48. Project/Product Safety Plan (PPSP)
49. Certifiable Items List (CIL)
50. Preliminary Hazard Analysis (PHA)
51. System Safety Concepts Document (SSCD)
52. Configuration Management Plan (CMP)
53. Project Hazard Log
54. Safety Hazard Analysis
55. Failure Modes, Effects and Criticality Analysis
56. Operating and Support Hazard Analysis (O&SHA)
57. Subsystem Hazard Analysis (SSHA)
58. Cutover (Shadow Mode) Safety Analysis
59. Final Safety Report

f. The following documents shall be submitted for information only:
    1. Metric reports
    2. Software Version Description (SVD)
    3. Software Test Procedures
    4. Software Test Report
    5. Software Verification and Validation Report (SVVR)
    6. Software Change Report
    7. Software Design Description (SDD)
    8. Database Design Description (DBDD)

g. The following documents are subject to review and audit by NYCT:
    1. Firmware Design Description
    2. Software Development Folder (SDF)
    3. Software Problem Report

13 APPENDICES

13.1 List of Acronyms/Abbreviations

Acronym	Meaning
AREMA	American Railway Engineering and Maintenance of Way Association
ATO	Automatic Train Operation
ATP	Automatic Train Protection
ATPM	Automatic Train Protection Manual
ATS	Automatic Train Supervision
AWS	Auxiliary Wayside System
CBTC	Communications Based Train Control
CDRL	Contract Data Requirements List
CIL	Certifiable Items List
CMP	Configuration Management Plan
COTS	Commercial Off The Shelf
DCS	Data Communications System
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
FDR	Final Design Report
I2S	Interoperability Interface Specification
IEEE	Institute of Electrical and Electronics Engineers
MDBF	Mean Distance Between Failure
MDBSCF	Mean Distance Between System Component Failure
MRTT	Mean Repair Travel Time
MTA	Metropolitan Transportation Authority
MTBF	Mean Time Between Failures
MTBFF	Mean Time Between Functional Failure
MTTR	Mean Time To Repair
NYCT	New York City Transit
O&SHA	Operating and Support Hazard Analysis
PDR	Preliminary Design Report
PICO	Post Installation Check Out
PHA	Preliminary Hazard Analysis
POC	Proof of Concept
PPSP	Project/Product Safety Plan
RAM	Reliability, Availability, and Maintainability
RFP	Request for Proposal
RTM	Requirements Traceability Matrix
SCIL	Software Configuration Item List
SCMP	Software Configuration Management Plan
SDP	Software Development Plan
SIMP	Systems Integration Management Plan
SPMP	Software Project Management Plan
SQAP	Software Quality Assurance Plan
SRS	Software Requirements Specification
SSCD	System Safety Concepts Document
SSHA	Subsystem Hazard Analysis
SSI	Solid State Interlocking

SVVP	Software Verification and Validation Plan
TCS	Train Control System
TPH	Trains per Hour
TSAD	Timing and Sizing Document
UWB	Ultra-Wideband
V&V	Verification and Validation
ZC	Zone Controller

13.2 Attachments

a. The attachments referenced in this section are either attached to this Specification or uploaded to a SharePoint site for the proposers to access. SharePoint site access will be coordinated via the NYCT Point of Contact defined in Section 1.
b. If the Proposer requests additional information during the Proposal phase, requests shall be made to the NYCT Point of Contact who will coordinate the upload of the requested documents.
c. The following documents are attached to this Specification:
    1. Terms and Conditions
    2. Proposer's Proposal
    3. Schedule A
    4. Schedule G
    5. Schedule H
    6. Schedule J
    7. Schedule W
d. The following documents will be available in the SharePoint site:
    1. NYCT Wire and Cable Specifications Package
    2. Canarsie Single Line and Cable Plan Drawings (for Project Area)
    3. Jamaica Single Line and Cable Plan Drawings (for Project Area)
    4. R-160 Vehicle Drawings
    5. R-143 Vehicle Drawings
    6. 'System Safety Certification Plan' section of the RSPP
    7. I2S Specifications
    8. UWB Position Determination Proof of Concept 1 Results

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EXHIBIT E

News

MTA and Piper Networks Demonstrate Successful Ultra Wideband Pilot

JAN 29, 2020 / THE PIPER TEAM / SAFETY, TECHNOLOGY, TRANSIT / COMMENTS DISABLED



New & Innovative Technologies Complement New York City Transit's Unprecedented $7.1 Billion Investment to Modernize Outdated

Signaling System

Successful 9-Month Ultra-Wide Band Pilot & Proof of Concept Result of MTA Genius Transit Challenge First Launched in 2017

New York, NY (January 23, 2020)

MTA New York City Transit today demonstrated the successful results of a nine-month pilot of ultra-wideband (UWB) technology on the Flushing and Canarsie lines to modernize the agency's signaling system and deliver safer, faster and more reliable service for customers.

MTA officials were joined by executives from Thales and Piper Networks along the line who have completed the nine-month pilot program with strong results and demonstrated the potential for UWB positioning technologies to integrate seamlessly with Communications-Based Train Control (CBTC) to improve system reliability and the speed of delivery for upgraded signaling systems. The innovative pilot complements the MTA's unprecedented $7.1 billion investment into modernizing its outdated signaling system over the next several years as part of the historic $51.5 billion Capital Plan. The initiative and partnership are the result of the MTA's Genius Transit Challenge first launched in 2017, which challenged leading companies from around the world to improve subway signals, capacity and communications for the future.

"Signals have long been described as the backbone of the subway system, and the work to modernize them is very much at the heart of our transformation work," said Mark Dowd, the MTA's Chief Innovation Officer. "Today is an essential first step in our broader efforts to rethink everything we do when it comes to signaling and how we can achieve greater reliability for our customers across the system."

"Ultra-wideband wireless technology brings the promise of fewer and shorter delays, and faster and cheaper installation of modern CBTC signaling, by eliminating much of the equipment traditionally fitted under trains and on tracks. This is a game-changer for our customers," said Pete Tomlin, New York City Transit's head of signaling. "We are eager to work with innovative companies as we continue to reimagine our approach to installing modern signaling across the system as part of the MTA's historic 2020-2024 Capital Plan."

In March 2019, the NYC Transit awarded Thales, in partnership with Piper, a contract for a UWB-based Train Control System Pilot Program on the line. At the same time, NYC Transit awarded Siemens, in partnership with Humatics, a contract for a UWB-based Train Control System Pilot Program on the Canarsie line. The scope of the pilot was to prepare the new

platform for safety certifiability and it consisted of nine months of testing and collecting 2,500 hours of operational data. An automated data upload facility at Corona Yard has allowed for cloud-based processing of all collected sensor data from the line, which could then be compared with data from the Communications-Based Train Control (CBTC) system and a LIDAR-based “ground truth” digital map.

As part of the pilot program, four trains on the line, which is one of two lines in the system already equipped with CBTC, have been outfitted with the Thales’ CBTC system that integrates Piper’s UWB technology. Four trains on the Canarsie line were outfitted with Siemens’ CBTC system that integrates Humatics UWB technology.

> Ultra-wideband wireless technology brings the promise of fewer and shorter delays, and faster and cheaper installation of modern CBTC signaling, by eliminating much of the equipment traditionally fitted under trains and on tracks. This is a game-changer for our customers.
>
> - Pete Tomlin, Signaling Chief for the Metropolitan Transportation Authority (MTA)

The demonstration, which took place on the express track of the line between the 61 St-Woodside and 40 St stations, showed the potential of an even more precise positioning system, UWB, to improve system performance and recovery. The pilot proved it could also help accelerate the implementation of CBTC. Additionally, because UWB technology is installed off the tracks rather than on the tracks, it could be considerably easier for NYCT personnel to maintain in the long term and cut down on delays stemming from malfunctioning equipment on the tracks.

Key advantages of UWB pilot as the MTA works to modernize its signaling system as demonstrated in the include:

- Rapid implementation, achieved through a reduction of train-borne equipment by removal of undercarriage installation, which would enable the MTA to modernize aging subway infrastructure on an accelerated timeline.
- Increased train positioning accuracy, achieved through utilization of modern onboard sensors including UWB radios, which could contribute to fewer and shorter service delays for passengers.
- Accelerated start-up position initialization, enabling a train to initialize and switch to

Automatic Train Operation (ATO) faster than current-generation CBTC systems.

“Thanks to this partnership with NYCT, we’re delivering cutting edge technology as we test the next generation of train positioning,” said Dominique Gaiardo, Vice President and Managing Director for urban rail signaling business at Thales. “Thales has integrated modern onboard sensors with a UWB network to create an enhanced next generation positioning system for our CBTC digital signaling architecture. The new system has higher accuracy, resiliency, and availability and is quicker to deploy than current generation products.”

“Today we took an exciting step in safety certifying Piper’s Ultra-Wideband technology for the MTA, and we’re looking forward to rolling out this technology across other subway lines as part of the Fast Forward program,” said Robert Hanczor, CEO of Piper Networks. “Together with our partner Thales, we worked closely with the NYCT leadership team to who continually demonstrated their desire to support new technology providers and encourage innovation in the transit sector.”

To help accelerate the modernization of the signaling system, NYC Transit has announced a third vendor, Mitsubishi Electrical Power Products, to qualify as a CBTC supplier. Mitsubishi successfully completed, within budget, a development and safety certification program awarded in September 2015.

NEXT STEPS

NYC Transit will take the lessons learned from CBTC implementation on the Flushing line and incorporate industry best practices to improve and expedite future implementation on other subway line corridors, including better costing estimates, formalized personnel structure and responsibilities, enhanced project and contractor monitoring, more frequency surveys and enhanced attention on subway car interfacing. NYC Transit has created a new database to capture cross-discipline feedback and information from CBTC projects to better track such valuable information to help improve future CBTC processes.

MTA Press Release

MTA Demonstrates Successful Ultra-Wideband Technology Pilot on Flushing and Canarsie Lines – January 23, 2020



Solutions

ETLS Train

Positioning

Track Worker

Safety

Grade Crossing

Detection

Data

Communications

Warehouse Asset

Tracking

ViTRACE™

Benefits

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Case Studies

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EXHIBIT F

HUMATICS



HUMATICS RAIL NAVIGATION SYSTEM

PRECISION POSITIONING FOR RAIL & TRANSIT VEHICLES

Humatics' Rail Navigation System is a drop-in replacement for traditional railway odometry sensors such as tachometers, transponders, and doppler radars. Humatics' systems consist of industrial-grade ultra-wideband (UWB) beacons and Inertial Measurement Units (IMU) providing position, speed, and acceleration to vital and non-vital carborne systems for signaling, train control, train management, and passenger information.

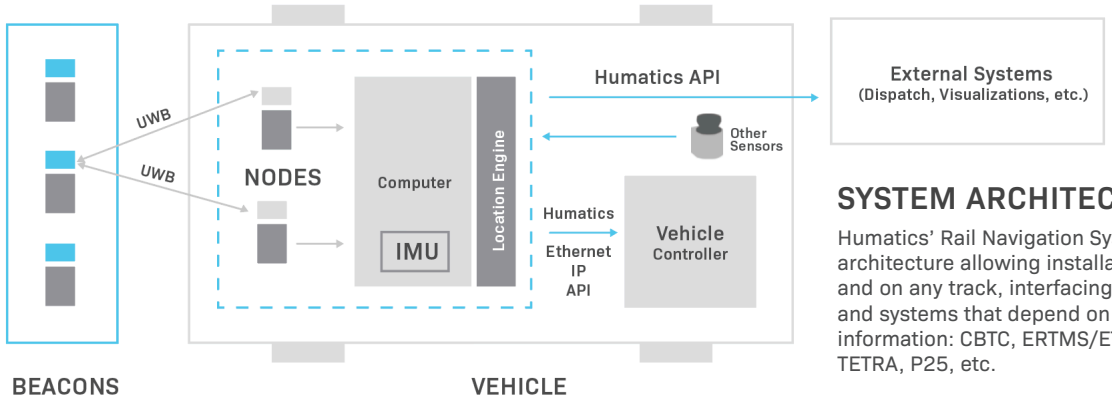
Humatics' Rail Navigation System operates similarly to satellite positioning serving as "terrestrial satellites" and works by continually ranging from carborne beacons to a constellation of UWB beacons. Given this architecture, UWB ranging is especially well-suited to augment GNSS positioning on sections of track with poor or no signal reception such as urban canyons and tunnels.

BENEFITS

1. Alternative to GNSS in tunnels, stations, depots, and urban canyons
2. Precise sub-10cm safety-critical positioning at high speed in all weather conditions
3. Longest-ranging ultra-wideband radio technology on the market

Through its high-availability and ultra-precise UWB localization network, Humatics enables safety-critical train positioning in all conditions, unlocking a variety of applications including automatic train operations, platooning, advanced driver assistance, platform door control, roadway worker safety, and emergency location services.

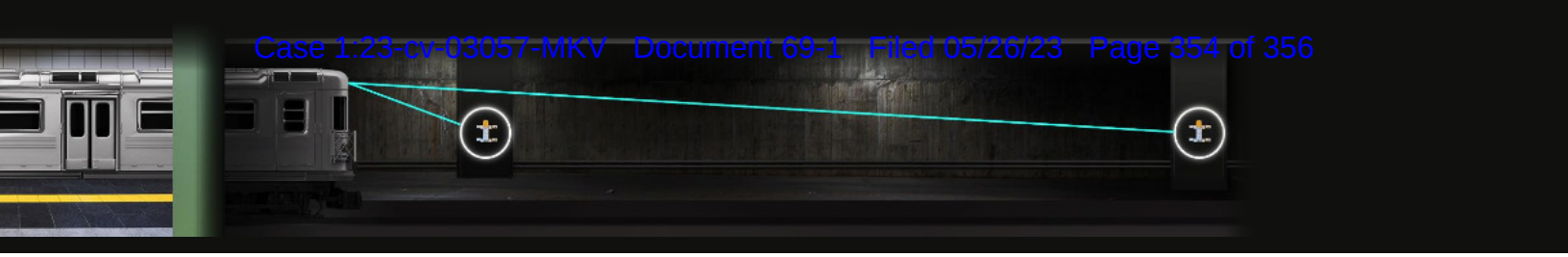
Humatics' engineering team develops system architectures to meet your functional requirements and Reliability, Availability, Maintainability, Safety (RAMS) targets. In the process of doing so, we balance the tradeoffs between positioning precision and cost of deployment. Alternatively, Humatics provides a robust UWB ranging API if your team prefers to integrate our UWB radios into your own navigation solution.



SYSTEM ARCHITECTURE

Humatics' Rail Navigation System has a simple architecture allowing installation within any vehicle and on any track, interfacing into vehicle controllers and systems that depend on safety-critical positioning information: CBTC, ERTMS/ETCS, PTC, TCMS, CAD/AVL, TETRA, P25, etc.

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APPLICATIONS

SIGNALING & TRAIN CONTROL
Replace legacy odometry systems such as wheel sensors and track-mounted transponders. Interfaces with Communication-Based Train Control (CBTC), European Train Control System (ETCS/ERTMS), Positive Train Control (PTC), and transit CAD/AVL systems.

DRIVER ASSISTANCE SYSTEMS
Integrate with the onboard Train Control & Management System (TCMS) and Driver Machine Interface (DMI) to provide situational awareness and enable precision stops at platforms. Provide zero-speed signal and train type information to SIL-4 door controllers.

AUTOMATIC TRAIN OPERATION (ATO)
Train-to-train UWB ranging provides the ultra-precise high-frequency relative positioning information necessary for vehicle platooning. In addition, train-to-train UWB communication enables the synchronization of braking and traction between trainsets.

HI-RAIL VEHICLES AND ROADWAY WORKER PROTECTION
UWB provides the ranging and communication infrastructure for roadway worker protection systems. The positioning precision allows for making the safety-critical distinction between workers and vehicles on and off the tracks.

YARD AND DEPOT MANAGEMENT
Track buses and railcars in yards and indoor maintenance facilities. Humatics industry-leading 300m ranging distance and robustness to interference means large depots require fewer UWB beacons to achieve precise vehicle positioning.

SPECIFICATIONS

PERFORMANCE
Provides position, speed, acceleration, direction, and associated uncertainties
10 seconds dead reckoning with IMU
Proven to track vehicles traveling over 55 mph (designed for >200 mph)
Variable update rate up to 200Hz
Flexible sensor fusion with GNSS, Lidar, Eurobalise, and other commonly used odometry technologies
Diversified and redundant architecture to meet project RAMS requirements

RELIABILITY
Wayside Beacon MTBF > 600,000 hours
Carborne Node MTBF > 165,000 hours
Carborne Computer MTBF > 52,000 hours

STANDARDS	
IEC 62278 / EN 50126	Specification and demonstration of reliability, availability, maintainability and safety (RAMS)
IEC 62279 / EN 50128	Software for railway control and protection systems
IEC 62280 / EN 50159	Safety-related communication in transmission systems
IEC 62425 / EN 50129	Safety-related electronic systems for signaling
IEC 62443	Industrial Automation and Control Systems (IACS) cybersecurity
IEEE 1474.1, 1474.4	Communications-Based Train Control (CBTC)
AREMA	Communications and Signals Manual
MIL-STD-810	Environmental Engineering Considerations and Laboratory Tests
NFPA 130	Fire protection and life safety requirements for underground, surface, and elevated fixed guideway transit and passenger rail systems.
IEC 61373	Rolling stock equipment – Shock and vibration tests
IEEE 1478	Environmental Conditions for Transit Railcar Electronic Equipment
EN 50121	Railway applications. Electromagnetic compatibility

UWB	
Range:	Line of sight, up to 300 meters
Ranging Precision:	Architecture-dependent, can be as low as +/- 2cm
Operating Spectrum:	4 - 4.9 GHz
Unique beacon IDs and channel codes protect transmission and enhance security	
Real-time diagnostics available for ease of maintenance	
FCC Part 15 Compliant	

IMU
Triaxial Accelerometer, Dynamic Range of +/- 40g
Triaxial Gyroscope, Dynamic Range of +/- 2000 degrees/second

CARBORNE EQUIPMENT	
Interface:	Ethernet IP
Navigation Computer Input Power:	5-48 VDC, nominal 37.5V
Power Consumption :	< 15 Watts @37.5V
Ambient Operating Temperature:	-40C to +70C
Mechanical Shock & Operating Vibration:	IEC 61373 Compliant
Ingress Protection:	IP 67

WAYSIDE BEACONS	
Input Power:	5-48VDC
Power Consumption:	< 5 Watts
Ambient Operating Temperature:	-40 to +70C
Mechanical Shock & Operating Vibration:	AREMA Communications and Signal Manual (C&S) Compliant
Ingress Protection:	IP 67

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EXHIBIT G

THE HUMATICS VISION FOR RAIL NAVIGATION

Humatics' approach to Rail and Transit hinges on four principles: (1) industrial UWB provides the precision, reliability, and robustness needed for train control; (2) high performance navigation requires fusing sensor data together for a given application; (3) safety critical applications, such as modernizing signaling, require a system's level approach to safety certification, and (4) system performance and capabilities are proven through data.

Humatics Created Industrial-Grade UWB

Humatics invented UWB in 1987 and has spent three decades perfecting and deploying the technology worldwide. The result is industrial-grade UWB. Most UWB systems use commercial UWB radios which have shorter range, inferior precision, and limited reliability and security. However, harsh environments and safety critical applications require more. Humatics industrial-grade UWB addresses these challenges through precise positioning down to an inch or less and unmatched security and robustness to challenging environmental conditions, such as dust and snow, multipath and interference.

Humatics' systems have a proven track record in rail applications: transit agencies and rail engineering firms have used Humatics' solutions to improve and modernize rail signaling. Humatics UWB was the underlying technology for two of the four signaling winners of the 2017 MTA Genius Challenge. Humatics' own success in the 2019 MTA UWB Pilot, outfitting over 5 miles of track and four trains, further proves the power of industrial UWB: for example, Humatics' UWB solution required wayside beacons every 360 feet on average compared to nearly 100 feet for commercial UWB solutions.

For Critical Applications, You Need More Than UWB

When safety and robustness matter, UWB alone won't do the job. UWB plays a key role, but critical navigation systems require fusing data from additional sensors. Relying on just one technology reduces performance and, more importantly, creates failure modes (when the singular technology fails) that compromise safety and reliability. Taking the best aspects of each sensor and tying them together with software provides a superior solution. History has proven this concept time and time again: it took people to the moon 50 years ago and is the foundation of how critical systems such as airplanes and industrial robots navigate.

Humatics acknowledges that UWB plays an important role in navigation moving forward but it is only part of the solution. Humatics combines UWB ranges with data from an inertial measurement unit device to fortify and enhance performance. This approach has been proven in the field: not only did Humatics' solution meet the performance requirements, but it also successfully positioned the train even when UWB sensors were unavailable for short periods of time. System "up-time" also benefits from this approach with the solution providing 99.9999% or greater availability in a 2-out-of-3 architecture in our deployment with the MTA. Furthermore, Humatics' navigation solution is capable of ingesting any sensor data allowing for the right sensors to be used to solve the problem at hand.

Safe Systems vs. Safe Components

Rail systems aren't just critical, they're safety critical. Transit systems all over the world are undergoing signaling transformations trying to upgrade the capacity and reliability of entire systems in a matter of years instead of decades. UWB-based navigation systems play a key role in signal modernization efforts, but achieving these goals --- increased rider capacity through more frequent, reliable train service --- requires coupling navigation systems with train control solutions such as communications-based train control. Combining two independent systems in a complex safety application requires a holistic approach towards system design and, more importantly, safety certification, examining navigation and train control together rather than an evaluation of the discrete parts.

Humatics advocates for a systems-safety centric approach to every project we undertake. Key decisions, such as implementing a specific safety architecture, should not be made in a vacuum. Rather than focusing on creating a "safe black box" for just the Humatics technology within the system, we collaborate with partners to create integrated safety-certified systems that solve the customer's problem. Safety has no shortcuts and the fastest path to revenue service is to certify an entire solution in a single process from the start.

The Proof is in the Data

At Humatics, claims of performance and capabilities are nice, but data speaks the truth. Data is what we use to gauge performance of our system, fuel continual improvement, and articulate our capabilities to our customers. Claiming that Humatics has a robust solution is fine, but showing a 99.9999% system availability over the course of thousands of runs proves that our customers can be confident in using our solution as part of their integrated system. Data collection and analyses is ingrained in our DNA and we provide the data driven evidence necessary for our customers to make informed decisions.

As Humatics partners and customers look to move forward with resignaling initiatives around the world, these concepts --- commiting to UWB sensor technologies built to perform in harsh environments, understanding that robust, high performance navigation requires combining UWB with other sensor technologies, recognizing that safety requires a system approach, and continually assessing with data --- are the fastest pathways to modern, robust, and safe transit signaling systems.

About Humatics

Recognized as the inventor and leader in industrial ultra-wideband, Humatics has built the first microlocation system for the industrial world that fuses proprietary industrial-grade UWB, sensors, and data, delivering best in class range and precision and enabling transit systems to navigate safely and reliably. Customers use Humatics' systems to solve mission-critical localization and navigation challenges in harsh environments where other technologies fall short.

Founded by world leaders in AI-assisted piloting, autonomous navigation, and high-precision radar, Humatics is headquartered in Waltham, Massachusetts with an office in Huntsville, Alabama. Humatics is the underlying technology behind two out of the four winners in the Signaling category for the MTA Genius Transit Challenge and, in 2019, completed a successful UWB Pilot with the MTA, demonstrating that UWB can cost effectively accelerate MTA signaling modernization. For more information, visit www.humatics.com.

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