

# TRAIN WRECK

## *The* **FORENSICS of** **RAIL DISASTERS**

**GEORGE BIBEL**

The Johns Hopkins University Press  
*Baltimore*

© 2012 The Johns Hopkins University Press  
All rights reserved. Published 2012  
Printed in the United States of America on acid-free paper  
9 8 7 6 5 4 3 2 1

The Johns Hopkins University Press  
2715 North Charles Street  
Baltimore, Maryland 21218-4363  
www.press.jhu.edu

Library of Congress Cataloging-in-Publication Data

Bibel, G. D. (George D.)

Train wreck : the forensics of rail disasters / George Bibel.

p. cm.

Includes bibliographical references and index.

ISBN 978-1-4214-0590-2 (alk. paper) — ISBN 978-1-4214-0652-7 (electronic)

— ISBN 1-4214-0590-3 (alk. paper) — ISBN 1-4214-0652-7 (electronic)

1. Railroad accidents—Investigation. I. Title.

HE1779.B535 2012

363.12'265—dc23 2011048389

A catalog record for this book is available from the British Library.

*Special discounts are available for bulk purchases of this book. For more information, please contact Special Sales at 410-516-6936 or [specialsales@press.jhu.edu](mailto:specialsales@press.jhu.edu).*

The Johns Hopkins University Press uses environmentally friendly book materials, including recycled text paper that is composed of at least 30 percent post-consumer waste, whenever possible.

*To my lovely bride, Mary Pat,  
who waited patiently for this train's caboose*

## CONTENTS

*Acknowledgments ix*

|           |                                                     |
|-----------|-----------------------------------------------------|
| <b>1</b>  | The Railroad Industry (as Seen through Accidents) 1 |
| <b>2</b>  | How Trains Crash, Then and Now 9                    |
| <b>3</b>  | Moderate-Speed Passenger Train Collisions 23        |
| <b>4</b>  | Freight Train Collisions 47                         |
| <b>5</b>  | Avoiding Collisions 65                              |
| <b>6</b>  | Positive Train Control 100                          |
| <b>7</b>  | Moving at the Wrong Speed 123                       |
| <b>8</b>  | Bearing Failures 156                                |
| <b>9</b>  | Gravity: It's the Law 190                           |
| <b>10</b> | More Runaways: Brake Failure 225                    |
| <b>11</b> | Broken Rail 257                                     |
| <b>12</b> | Buckled Track 281                                   |
|           | Epilogue: Safety in the Modern Era 304              |

*Notes 307*

*References 317*

*Index 351*

Another 1970 crash report describes the structural reinforcement of the caboose being almost 5 times greater than that of the locomotive. The locomotive had only 6 steel box beams protecting the cab compartment. Each beam box section was 2 inches  $\times$  2 inches (5  $\times$  5 cm) and only 0.125 inch (0.31 cm) thick. Depending on the steel's strength, modern collision posts appear to be perhaps 4 times stronger. Also, anti-climbers did not exist back then.

## 5

# Avoiding Collisions

**O**n October 30, 1972, Train 416, a Chicago commuter train, accidentally overshot the 27th Street station platform by 600 feet (183 m). In defiance of all common sense, the train backed up. At 7:38 a.m. Train 416 was struck from behind by Train 720, killing 45. The structural damage in this accident was previously described (see “Telescoping” in Chapter 3). The signal system, designed to prevent a collision, is described here.

The operating rules for this train actually allow backing up, provided the train is protected by a flagman. The flagman must be far behind the train with a clear view of any approaching trains. A flagman is an old-fashioned concept that has gone out of practice with the use of automatic signals. This train crew had never used a flagman and had forgotten the rule. The conductor leaned out an open door to look back while talking to the engineer through the train's intercom. A curve in the track blocked his view. Just before the collision the conductor shouted at the engineer to stop and jumped off the train.

The signal system, installed between 1926 and 1929, had three colors: green—“all clear,” yellow—“slow to 30 mph (48 km/h) and prepare to stop at the next signal,” and red—“stop.” Train 416 stopped past the signal near the platform (Figure 5.1). Because the train passed the signal (labeled Red in Figure 5.1) while moving forward, the previous signal

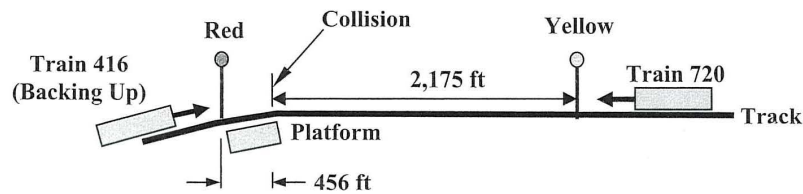


FIGURE 5.1. Train 416 overshoots a red signal by 400 feet (122 m) and backs up on the track. A curve in the track interrupts the line of sight.

(labeled Yellow in Figure 5.1) was reset to yellow. The yellow signal allowed Train 720 to enter the next block of track at 30 mph while preparing to stop at the next signal. When Train 416 reversed and drove past the signal near the platform again, the distant yellow light automatically changed to red. Unfortunately, it was too late for Train 720 to see the signal change and stop.

Train 720 was also speeding and only 2 to 3 minutes behind Train 416. (The trains normally run this close together during rush hour.) Train 720 was an express train and did not normally stop at the 27th Street Station. The normal speed at this location is 65 mph (105 km/h), but slows to 30 mph (48 km/h) when the signal light is yellow.

The engineer of Train 720 testified that he saw Train 416, on the curve, just 4 to 6 car lengths ahead (about 300–400 feet [91–122 m]). The engineer of Train 720 applied the emergency brakes, threw the train into reverse, blew the horn, and left his position to warn the passengers in his car. Both trains were multiple-unit (MU) trains without locomotives. (Each car of both trains was self-propelled with electric motors.)

Train 720 struck Train 416 at an estimated 44 to 50 mph (71–80 km/h). The first car of Train 720 was crushed about 10 feet (3 m) and telescoped about 35 feet (11 m) of the last car of Train 416. Most of the fatalities occurred in the telescoped car.

If Train 416 had not overshoot the platform or had chosen instead to continue to the next station or had backed up with proper protection, if there had not been a curve in the track restricting the conductor's view, if Train 720 had not been speeding or operating so closely behind Train 416 or otherwise had a chance to see the yellow signal light change to red, if the two trains had radio contact with a dispatcher, or maybe even if the

back of Train 416 had not been painted black with very small marker lights, the collision most likely would not have happened. These were not unlucky coincidences, however, but are instead examples of systemic failure and very sloppy and unsafe operating procedures.

Line-of-sight testing after the fact determined that Train 720 should have been able to see the distant red stop light at more than 1,700 feet (518 m) and the nearly stopped train at more than 1,800 feet (548 m)—more than enough distance to safely stop a 30-mph (48-km/h) train. The investigators concluded that colliding Train 720 was traveling too fast to safely stop.

THREE TYPES OF TRAIN COLLISIONS MUST BE PREVENTED: head-on, rear-end, and side collisions at crossovers (where trains move from one parallel track to another) and crossings (where two tracks intersect).

The locomotive engineer must plan ahead to stop. The fundamental problem is managing the kinetic energy of a long, heavy freight train or a very fast passenger train. Because of curves and/or adverse weather, the stopping distance can easily exceed the driver's line of sight. Most collisions are due to human error and can be easily prevented by following correct procedures.

WHEN RAILROADING FIRST BEGAN, it was easy to separate trains with long periods of time between departures. Even trains moving in opposing directions on the same track could be safely separated. The control system was a strictly followed timetable. As traffic increased, rules were developed to prevent potential collisions. Meetings became prearranged. An "inferior" train cleared the main track on a siding and waited for the "superior" train with higher priority to pass. Stopped trains were protected from a rear-end collision by flagmen. Problems still occurred when new trains were added to the schedule or lengthy delays occurred.

For a system totally dependent on time, surprisingly, nobody could agree what time it was. Every town used local sun time. There were 38 local times in Wisconsin and 27 in Illinois. The Pittsburgh train station used 6 different clocks to track the arrival and departure of trains. In 1883, railroads established Standard Time, and many localities followed. Congress finally agreed to codify standardized time in 1918.

The situation improved somewhat with the introduction of telegraphs. The timetable was still sacred, but could now be modified with written train orders. A dispatcher would issue train orders sent by a telegraph to an operator in the field, who would deliver the orders to the train crew at the next station.

Today train dispatchers issue orders directly to the train crew by radio. The most common version of this system today is known as Track Warrant Control, or TWC, commonly used on low-traffic routes. Under TWC there is no timetable. Track warrants are issued for each section of the trip.<sup>1</sup> The train crew repeats the instructions and writes them on a Track Warrant Form. An accident involving track warrants is described at the beginning of Chapter 4.

### BLOCKS

On busy routes two tracks replaced single track. Trains would operate in only one direction on each track, eliminating head-on collisions. Rear-end collisions were still possible.

A manual block system was first developed in England in the 1850s to separate trains traveling in the same direction. An operator controlled the entrance to each block with signals. A following train could enter the same block only after verifying (by telegraph) that the first train had entered the next block.

In 1907, the New York Central operated 226 block houses along the 395 miles (636 km) between New York City and Buffalo. As each train passed the block house, the operator would change the signals to prevent all following trains from entering the same block. The block operator also telegraphed the central dispatcher the position of each passing train.

One dispatcher kept track of perhaps 30 trains and sorted out any operational changes. If a freight train got off the main track at the same time and place every day to allow a faster passenger train to pass, the dispatcher had to adjust for any changes that altered the passing location. The dispatcher telegraphed the new location to the appropriate control tower. Signals and track switches were modified to guide the freight train off the main track at the new location.

In 1907, nearly 50,000 workers were required to operate all the trains to and from (and all points in between) New York City and Buffalo.<sup>2</sup> This

included signalmen, telegraph operators, dispatchers, porters, conductors, engineers, firemen, brakemen, switch tenders, and yardmen. Not included were track repair crews, mechanics, and clerks.

A block length is determined by the safe stopping distance of the hardest train to stop, that is, the train with the most kinetic energy of motion. The safe stopping distance depends on the length, weight, and speed of the train; gradient of any hills; and line of sight for signals. This distance can vary from a few hundred feet to many miles.

### AUTOMATIC BLOCK SIGNALS

Invented in America in 1872, the automatic block circuit changed railroading forever. In a track circuit a section of track is electrically isolated from adjacent track. A battery is connected at one end to an electromagnetic relay on the other, as shown in Figure 5.2.

A relay is an electromagnetically operated electric switch. The relay turns signal lights on and off. When the electromagnetic coil inside the relay box is energized by the track circuit, the armature pivots and completes the circuit for the green light (Figure 5.3).

If a train enters the block and shorts the circuit, the current flows through the train's steel wheels and axles instead of through the rails; the electromagnetic coil loses its magnetism. Gravity drops the armature and the red light or stop circuit is activated. The presence of the train sets the signal—not an operator.

The Automatic Block System (ABS) protects against rear-end collisions by signaling that the next block is occupied by a train. The automatic block signal circuit is considered “fail safe.” If the signal is de-energized by

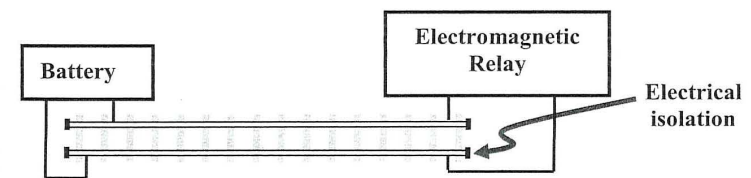


FIGURE 5.2. A battery is connected to both rails. The current from the battery powers an electromagnetic relay that controls additional signal circuits shown in Figure 5.3.

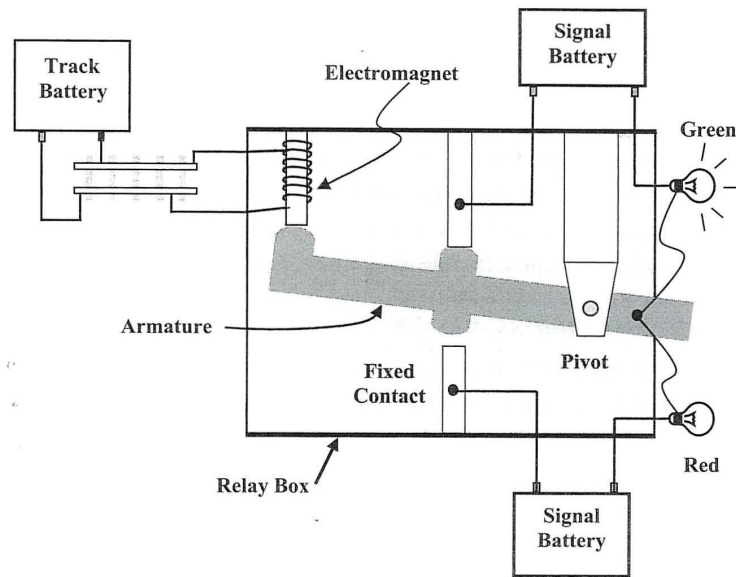


FIGURE 5.3. A relay box shown in the "all clear" position (green light on). The electromagnetic relay attracts the left end of the armature up and turns on the green light.

a broken wire (or dead battery), the signal defaults to its safest setting—"stop."<sup>3</sup> The automatic block signal can also detect a completely broken rail, but not a partially broken rail that might break under the next passing train.

While the block system circuit worked quite well, the actual signal devices were not reliable until small electric motors were perfected around 1900 and the venerated pivot arm semaphore came into wide use. Light bulbs had to wait until the bulbs were bright enough to be seen in the daytime.<sup>4</sup>

The track circuit described is called a two-aspect system—the signal can only describe "all clear" or "stop." A train entering an empty block will receive an "all clear" signal, even if a proceeding train stops just inside the next block. In this case a following train will see the stop signal and stopped train at the same time. The engineer has to anticipate the next signal being a "stop" and slow down or risk collision.

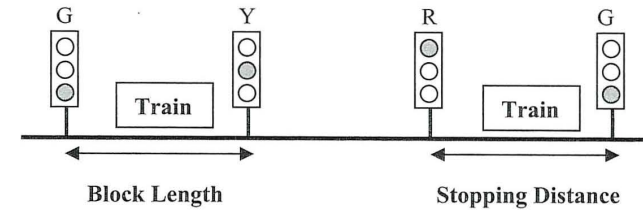


FIGURE 5.4. Three-aspect system. The block circuit keeps track of occupancy in the next two blocks. Green (G), Yellow (Y), and Red (R).

The automatic block signals were rewired to acknowledge trains in the next two blocks. This led to the three-aspect block system (Figure 5.4): red, green, and yellow—"stop," "approach," and "prepare to stop" at the next signal. Nevertheless, the two Chicago commuter trains at the beginning of this chapter managed to collide with three-aspect signals.

Sometimes a four-aspect system is used for faster trains. It keeps track of three blocks and provides a fourth signal for "all clear." An Amtrak train, operating with a four-aspect automatic block system, collided into the back of a freight train at 107 mph (172 km/h), described at the beginning of Chapter 6. The freight train defeated the additional warnings by accidentally entering the track immediately in front of the passenger train.

This is by no means a complete explanation of railroad signals. The Canadian Pacific operating rules list combinations of 13 different lighting configurations to indicate 54 different indications or instructions.

In official railroad signal jargon, a signal aspect is the visual appearance of the lights (i.e., two vertical red lights, two horizontal green lights, a flashing yellow light, etc.), while the signal indication is the actual meaning (i.e., "all clear," "stop," or "proceed at medium speed").

To list just a few (and show how we might arrive at a list of 54): stop and wait for a conflicting train to pass (called absolute stop), come to a complete stop and proceed at slow speed (called permissive stop), prepare to stop at the next signal, prepare to stop at the second signal, proceed at medium speed until the train clears all track switches, proceed on diverging route at prescribed speed through turnout, proceed at reduced speed, proceed at restricted speed, proceed prepared to pass the next

signal at slow speed. Slow, medium, limited, reduced, caution, and restricted speed are six different speed limits, depending on the situation and the railroad company. Caution speed might mean a speed that permits stopping within one-half the range of vision—which can vary greatly with the radius of a curve or in foggy conditions.

AUTOMATIC BLOCK SIGNALS substantially reduced rear-end collisions. The block system was also adopted to increase operating efficiency and pack more trains into a given stretch of track.

Today about 40% of U.S. tracks remain “dark territory,” or non-signaled, without automatic blocks (or centralized traffic control, discussed later).<sup>5</sup> Dark territory accounts for about 20% of train traffic and a very small percentage of passenger trains. In dark territory speeds are limited to 49 mph (79 km/h) for freight trains and 59 mph (95 km/h) for passenger trains.

### INTERLOCKS

An interlock is a machine that automates a sequence of signals and track switches to prevent two trains from occupying the same track. Interlocking is used at crossovers between two parallel tracks and at junctions where tracks intersect.

Interlocking was first invented in densely populated England in the 1850s. At that time multiple track switches and signals at busy junctions were controlled semi-remotely at one location with mechanical linkages. The next step was to interconnect or interlock the sequence of signals and switches. Interlocking required the switches to be correctly set before the signals could be changed. Levers for conflicting routes could not be pulled at the same time.

Initially, all interlocking was accomplished mechanically with levers in a control tower, as shown in Figure 5.5. The levers would directly connect to pipes controlling track switches and pipes or wires controlling signals. A 1925 signaling handbook refers to the thermal expansion of pipes up to 1,300 feet (396 m) long! Shown in Figure 5.6 are the pipes for the mechanical interlocking at Hancock Tower in Hancock, West Virginia. The levers and pipes remained in operation until 2007.<sup>6</sup>

Later, air pressure would transmit a signal perhaps thousands of feet.

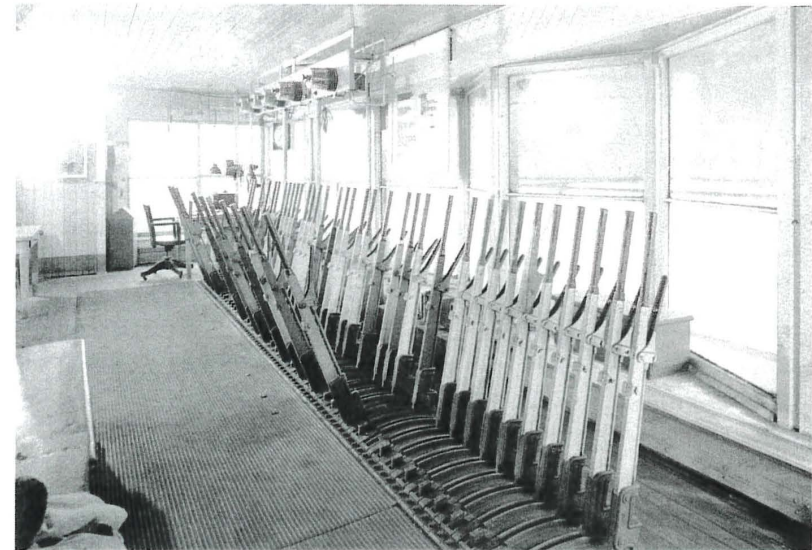


FIGURE 5.5. Wilson Tower, Chicago. The tower was constructed in 1900 and operated as a mechanical interlock until 1996. *Photo by Jack Boucher, Library of Congress.*

Remotely located pressurized air cylinders would activate switches and signals. For many decades air cylinders were the preferred method for actuating switches and signals. Until small electric motors became reliable, early electric signals controlled electromagnets that activated remote air cylinders.

### SIGNALING REVISITED

There are two main types of signaling: block signaling, to separate trains going in the same direction, and interlocking signaling, to avoid collisions when trains potentially share the same tracks. The two types of signaling require two different types of stop signals—absolute stop and permissive stop.

Permissive stops occur with automatic block signals. The train must stop at the red light. After stopping, the train may proceed at a speed that would allow stopping within the field of view, usually 15–20 mph (24–32 km/h) on straight, level ground, but much slower on curves or during



FIGURE 5.6. Mechanical interlocking pipes at Hancock Tower (Hancock, West Virginia) used to operate remote switches. *Photo Credit: Michael Brotzman.*

inclement weather. Trains were allowed to proceed (at reduced speed) because one faulty stop signal could gridlock the system.

An absolute stop occurs at interlockings where two or more trains can be routed onto the same track. At least one train must stop and remain stopped until the signal changes or the dispatcher gives permission to proceed.

On single track used in both directions one common arrangement is to use permissive stops for all trains going with the normal flow and absolute stops for trains traveling in the opposite direction.

#### **WHEN INTERLOCKING DERAILED TRAINS ON PURPOSE**

At the end of the nineteenth century and at least until the 1920s, it was common practice to derail a train to prevent a collision. A

device known as a derailer would protect busy track junctions by derailling any errant trains that missed a stop signal. The derailer was interlocked with track switches and signals.

AS TRAINS BECAME FASTER AND HEAVIER, it became harder to control a derailed train's momentum. The train could still reach the intersection, even when derailed by the derailer, as illustrated by the following accident.

In 1921, an eastbound Michigan Central train, the Canadian, left Chicago at 5:05 p.m. bound for Detroit. A westbound New York Central train, the Interstate Express, left Buffalo at 8:30 a.m. bound for Chicago.

The two trains arrived at the same intersection in Indiana every night at about the same time. Usually, the Canadian got there first and had the right of way. On the night of the accident, the Interstate Express got to the intersection first. The interlocking operator in the tower set the signals and derails to stop the Canadian and allow the Interstate Express to pass. The Canadian was derailed 310 feet (91 m) from the crossing. Amazingly, the locomotive re-railed itself and dragged all nine derailed cars until the third car stopped abruptly on the tracks in front of the oncoming train. The Interstate Express rammed into the stopped Canadian at 50 mph (80 km/h) at 6:20 p.m. on February 27, 1921, 40 miles (64 km) southeast of Chicago.

An eyewitness in the fourth car of the Canadian relates the following:

The car swayed suddenly and left the tracks. We humped along the tracks for a few feet at full speed. I looked out; there was another train bearing down on us at full speed. I couldn't move. My tongue stuck in the roof of my mouth. I tried to open the door into the day coach to shout to the people inside; my hand refused to function. It was perhaps not more than thirty seconds between the time I saw that train and the moment it hit us. It was ten years to me. The light from the headlight of the approaching train made everything as bright as day where I stood. I thought I was surely going to be killed.

As I stood I could see into the day coach. On the side from which the New York Central train was approaching I could see that other passengers had seen the train. A woman jumped up from her seat. She held a little girl—looked as though she was about 8 years old—to her breast. Men jumped up—one even

started for the door where I was. Then suddenly the side of the car buckled in. My last conscious impression was of everything dissolving in front of me. I remember seeing the nose of the engine . . . the lights in the car going out suddenly . . . hearing a scream that I'll never forget. And then came darkness.

I was thrown from the platform nearly fifty feet (15 m). I fell on the ground, the breath knocked out of me. When I sat up the whole middle of our train had gone. It was a little hell there for a few minutes.

Our eyewitness was uninjured except for a few bruises.

An eyewitness in the back of the New York Central train stated: "Out of the clear sky there came a crash that was like a cannon's roar. The car filled instantly with a cloud of dust. Men and women were hurled to the floor. Our train had been going full speed. As soon as it stopped I went through the car and saw that no one was seriously hurt."<sup>7</sup>

When asked what happened, the surviving Michigan Central engineer said: "The yellow warning at the distant block was against me and we slowed down. But the fireman said the home signal (at the crossing) was clear and I thought it was clear, too."<sup>8</sup>

There were 37 fatalities, including the engineer and fireman of the New York Central train. The third car of the Canadian, with 60 to 80 passengers, was totally destroyed. Most of the fatalities occurred in this car.

A DERAILER ALSO FAILED to stop a passenger train 490 feet (149 m) from a New Jersey drawbridge on September 15, 1958. Forty-eight people drowned when 2 locomotives and 3 passenger cars fell into Newark Bay. The speed limit on the bridge was 45 mph (72 km/h). The engineer drove past two signals. The first signal indicated that the train should reduce speed by one-half and prepare to stop at the next signal. The train was going 43 mph (69 km/h) when it ran through the derailleurs.

Derailers are still used today to prevent cars on a siding from accidentally entering the main track for whatever reason. In this case the derailleurs are effective because freight cars move slowly on sidings.

### THE MECHANICAL INTERLOCKING BED

Interlocking, a crude mechanical computer with its own logic (i.e., if lever 1 and lever 2 are thrown, lever 3 must be locked in place),

was accomplished with a mechanical "locking bed." Each lever in a mechanical interlock directly operates a track switch or signal. The levers also operate bars in the locking bed. A locking bed consists of vertical and horizontal locking bars. When an operator pulls a lever, a vertical bar in the locking bed moves. Attached to the vertical bar is a triangular wedge. This wedge contacts a similar wedge attached to the horizontal locking bar with angled contact so that when the vertical bar slides down, the horizontal bar slides across (Figure 5.7). Also attached to the horizontal locking bars are locking "tappets" that slide into a notch on a vertical bar, preventing its movement. The following logic, provided by the locking bed, is required to prevent a collision between the two trains shown in Figure 5.7.

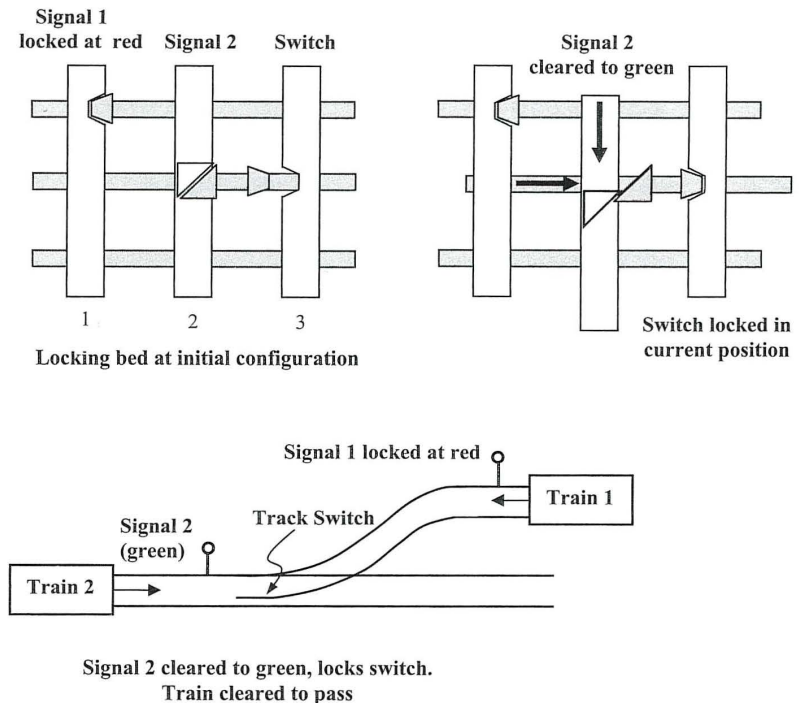


FIGURE 5.7. Simplified example of a mechanical locking bed. Signal 2 has been activated and locks the switch, preventing it from being altered.

1. Signal 1 is locked at red and stops Train 1. Signal 2 is activated by the operator with a lever and cleared to green. The lever also slides vertical bar 2 in the locking down position.

2. The triangular wedge on vertical bar 2 contacts a similar wedge on the horizontal locking bar, forcing it to slide to the right.

3. A locking tappet attached to the horizontal locking bar slides into a notch on vertical bar 3, locking the switch into its current position. The through train safely continues. The switch cannot be accidentally changed underneath the passing train.

A very complex sequence of interlocking can be obtained by attaching multiple triangular wedges to each vertical bar that activate multiple horizontal locking bars. And each horizontal bar can have multiple tappets that lock multiple signals or switches.

The locking bed for the levers shown in Figure 5.5 is shown in Figure 5.8.

#### INTERLOCKING LOGIC IS COMPLICATED

Consider the simple track layout shown in Figure 5.9. Signals 1 and 2 are in their default state of “stop” and directed at approaching Trains 1 and 2. The track switch is in its normal position, allowing trains to pass from A to B.

For Train 2 to safely pass through the switch to point B, the following interlocking has to occur. The switch is thrown to allow Train 2 to proceed safely through the branch. A separate circuit verifies that the switch completed its movement successfully. Signal 1 is locked at “stop.” Signal 2 can now change and allow Train 2 to pass. The interlocking logic must also guard against the switch accidentally being changed underneath the passing train. Additional logic is required to coordinate distant signals and different combinations of train directions. The logic becomes intensely complicated when tracks merge, cross multiple tracks, move in both directions, and so on, as shown in Figure 5.10.

Surprisingly, even after electric signals were used to activate distant signals and switches, the mechanical interlocking bed was still used for many years to supply the interlocking logic.

When direct mechanical linkages were eliminated and replaced with electric signals, shoulder-high levers were no longer needed to activate

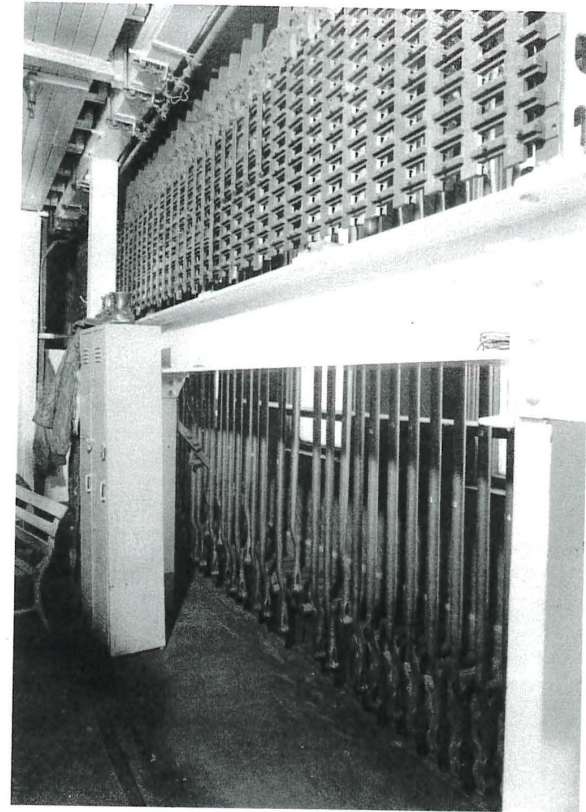


FIGURE 5.8. The locking bed for Wilson Tower; see levers in Figure 5.5.  
*Photo by Jack Boucher, Library of Congress.*

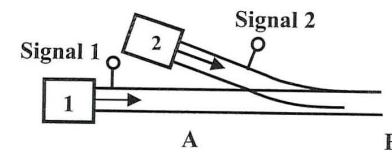


FIGURE 5.9. Simple track switch used to illustrate interlocking logic.

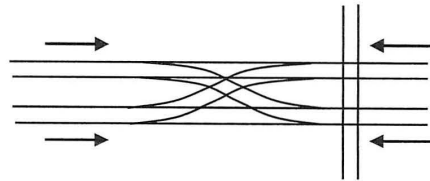


FIGURE 5.10. Example of tracks that require complex interlocking logic.

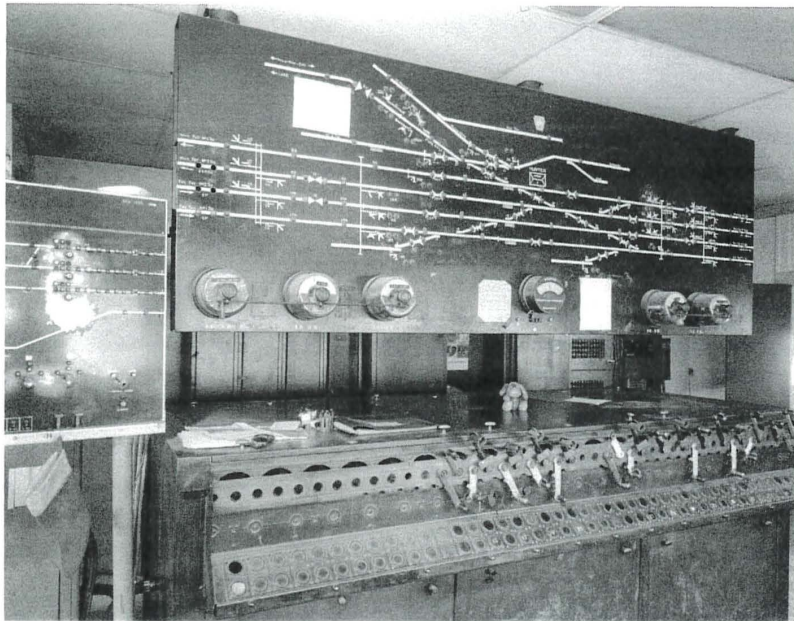


FIGURE 5.11. Interlocking control panel for Pennsylvania Railroad, Hunter Interlocking Tower, Newark, New Jersey. Behind the levers is the horizontal mechanical locking bed. *Historic American Engineering Record; Library of Congress.*

track switches several hundred feet away. Smaller hand levers were still used to operate the mechanical interlocking bed (Figure 5.11).

### GRAND CENTRAL TERMINAL

The most complex electrical interlocking machine with a mechanical locking bed was installed in 1913 in New York's Grand Central Terminal. There were 145 separate tracks at Grand Central: 41 tracks on

the upper level, 22 on the lower level, and 62 tracks for train storage. The trains were routed to 67 platforms. Grand Central Terminal was the largest train station in the world at the time.<sup>9</sup> Underneath Park Avenue, the 67 tracks from the 67 platforms merged into 4 tracks that entered and exited the station. Controlling about 1,200 train movements per day (today 1,500), concentrated in the 4 hours of rush hour, were 238 track switches and 570 signals. The upper-lever interlocking machine had 400 levers, and the lower-level machine had 376.

When they were 5.3 miles (8.5 km) from Grand Central, arriving trains were announced by telephone in the control tower. About 30 blocks from the terminal, the train would light a bulb on the control panel. The train director placed each arriving train by calling out lever numbers. An operator (controlling 40 levers) rotated each lever called. The position of each train changed on the control panel, and the director called out another number until the train was correctly placed.

It took about 20 levers (sometimes up to 60) in the correct sequence to park an average train. The levers were mechanically interlocked so they could not be pulled out of sequence. "Imagine a piano whose keys could be so interlocked that each note of each piece had to be played in its proper order."<sup>10</sup> The interlocking machine at Grand Central remained in operation until 1993, when it was finally replaced by modern computer controls.

### THE ELECTRIC RELAY

The mechanical locking bed was eventually replaced with electric relays. (Recall that a relay is an electrical on-off switch; see Figure 5.3.) One electrical relay can activate many other electrical relays, each controlling a circuit to activate or deactivate any complex sequence of signals and switches as needed. An elaborate interlocking can involve hundreds, even thousands, of relays.

In 1925, the Interstate Commerce Commission (ICC) reported 7,023 interlocking plants in the United States, with 930 electrical and the rest mechanical. An all-electric interlocking was first used in 1907, but new installations were not widespread until the 1920s. A 2007 survey by the Federal Railroad Administration (FRA) indicated nearly 14,000 interlockings, with only 110 being manually operated. The last all-mechanical

TABLE 5.1  
Survey of Interlockings in England, circa 2003

| Interlocking Type | Approximate No. | Estimated Average Age |
|-------------------|-----------------|-----------------------|
| Mechanical        | 600             | 75                    |
| Relay-based       | 850             | 25                    |
| Computer-based    | 250             | 7                     |

interlocking tower (Ridgely Tower in Illinois), complete with levers and pipes, was deactivated in 2010.

Every electrically controlled track switch and signal required a power circuit to operate the device and a control circuit to process the interlocking logic. The control circuit was wired to perhaps hundreds of relays with complex interconnections to create the control logic. Starting in the 1980s, the control circuits were replaced by a microprocessor. One microprocessor could replace hundreds of relays and greatly reduce installation costs. The microprocessor computer logic was identical to the mechanical interlocking logic from a century earlier.

In a layout begging for computerization, the New York Subway System in 2004 had 856 track miles (1,378 km), 11,646 track circuits, 327,156 relays, and 198 interlockings (70% of the interlockings were all relay, 30% older style electro-mechanical or electro-pneumatic, and 1 solid state). The New York City Transit (NYCT) transports more than 5 million commuters per day and averages 1 “apparent” signal failure every 10 hours. To get a train moving within 10 minutes, NYCT has a crew of nearly 1,000 to maintain signals.

A 2003 U.K. SURVEY gives some insight into the life expectancy of older railroad technology, at least in England. It estimated that there were about 1,700 interlockings in the United Kingdom at the time (Table 5.1).

#### INTERLOCKING ON THE NORTHEAST CORRIDOR

The Northeast Corridor (NEC) operates in the most densely populated part of America—a 456-mile (734-km) route connecting Washington, D.C., Baltimore, Philadelphia, New York City, and Boston. The

NEC has been historically and remains the busiest, most technologically advanced, and only example of a high-speed train in America.

In 1975, this busiest train route in America had 124 manned interlockings on its 456 route miles. About 5% of the track miles are interlocking. The trains were handed off from interlocking to interlocking, in what was effectively a manual block system.

As the Northeast Corridor was slowly modernized for high-speed traffic, the number of interlockings changed very little. Instead, they were reconfigured and automated. The mechanical interlocking beds survived for a surprisingly long time on the NEC. In 1975, there were 104; by 1986, there were 25 and just 2 in 2002.

Why are there so many interlockings on the NEC? There are hundreds of bridges on the NEC. Tunnels leave and enter Baltimore and New York City. To reduce costs, four tracks converge to two before crossing a bridge or entering a tunnel, and then diverge back to four upon leaving. Most stations and yards have multiple tracks entering and leaving. Other tracks also need to cross the NEC.

Before modernization, the tracks on the Northeast Corridor were mostly laid out in the mid-nineteenth century and optimized for traffic patterns in the 1940s—the last time the now-bankrupt Pennsylvania Railroad had money for major improvements. In the mid-1970s, there was a hodgepodge of tracks along the NEC, with routes having two, four, or six tracks, depending on the location and population density.

One example of knotted train movements caused by a 100-year-old layout is Harold Interlocking, a 2-mile (3.2-km) complex in Queens, New York. Harold Interlocking is adjacent to Sunnyside Yard and just east of the East River tunnels. The interlocking is nearly identical to its 1908 layout (Figure 5.12).

On the west end of Harold Interlocking are four tracks from the four tunnels crossing the East River from Pennsylvania Station (marked with a “T” on Figure 5.12). During the morning rush hour, all eight tracks converge into four tunnels, and in the evening the process reverses. During rush hour, more than 40 trains per hour are sorted by Harold Interlocking.

A mechanical interlocking machine operated Harold Interlocking until 1990. Twenty-eight hundred relays were needed to duplicate and auto-

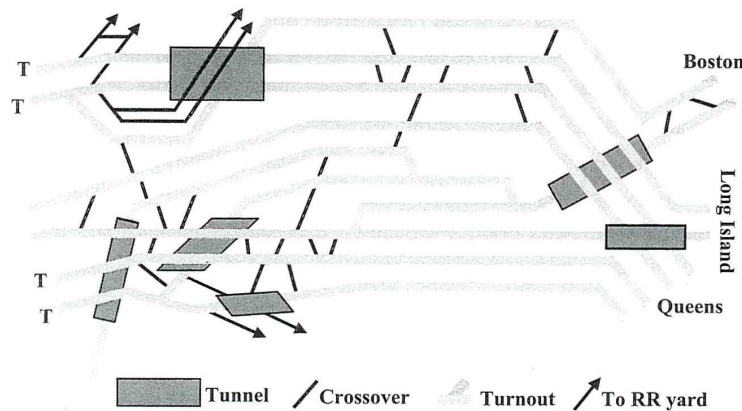


FIGURE 5.12. Harold Interlocking is located in Queens, New York, just across the East River. This interlocking sorts out commuter and Amtrak trains going to and from Pennsylvania Station. "T" indicates tracks coming from the East River tunnels.

mate the operators and mechanical locking bed controlling the switches, signals, remote signals, verification circuits, locking, and interlocking.

All interlockings on the Northwest Corridor were reconfigured to speed up passage of the high-speed passenger trains. Abandoned tracks and tracks in disrepair caused nonsensical switching patterns. For example, passenger trains had to slow and switch tracks just to slow and switch back all within the same interlock.

Reconfigured interlocks involved eliminating track crossovers for passenger trains or redesigning the interlocking so that crossovers could occur at higher speeds—up to 80 mph (129 km/h). A high-speed train forced to negotiate 124 automated interlockings is reason enough to explain the problems of high-speed rail on the Northeast Corridor.

Europe and Japan (and an increasing number of other countries) build new high-speed rail without interlockings. The new tracks are dedicated to the high-speed trains and are not shared with slower-speed commuter trains. They do not have to contend with 100-year-old tunnels and bridges and curves laid out for train speeds in 1850. The Northeast Corridor is a nineteenth-century system adopted for twenty-first-century use.

Another nineteenth-century problem involves road crossings. Unlike other high-speed trains around the world, the NEC is actually crossed by automotive traffic—a serious safety hazard. By 1986, all 34 road crossings between Washington, D.C., and New Haven had been removed. From New Haven to Boston, 11 road crossings remain, including 5 mandated by Congress.<sup>11</sup> Currently, the 150-mph (241-km/h) Acela slows down to 100 mph (161 km/h) at all road crossings.

### CENTRALIZED TRAFFIC CONTROL

With electric relay systems the hand levers that operated the mechanical locking bed could finally be eliminated and the interlockings could be remotely controlled. Remote-controlled signals and interlocks led to centralized traffic control (CTC). The train crew drives the train following signals and/or instructions from the dispatcher. CTC reduces human error and the number of signalmen at interlocks.

The first "running meet" is believed to have occurred on a CTC track in 1927. In a running meet, one train is routed off the main track and onto a siding so that the two trains pass each other in opposite directions without stopping.

Today the busiest, most important main line tracks, including the tracks involved in the September 12, 2008, Los Angeles collision (see Chapter 2), are controlled by centralized traffic control.<sup>12</sup>

The railroad industry can increase throughput by adding more track or by using a better signal system. A common problem is operating 79-mph (127-km/h) passenger trains and 40-mph (64-km/h) freight trains on the same tracks. Coordinating meets and passes becomes problematic. With better traffic control the trains travel at higher speeds, are spaced closer, have running meets, and spend less time waiting to pass each other.

When a double-track system needed new ties and rail, it was more cost-effective to upgrade one of the tracks with CTC and use part of the second track for sidings. This reduced maintenance costs (and real estate taxes) while increasing throughput. In 1957, New York Central installed centralized traffic control on the 163 miles (262 km) of routes between Buffalo and Cleveland. Four tracks were replaced with 2 CTC tracks with crossovers every 7 miles (11 km). The entire stretch was controlled by just

2 dispatchers sitting in front of their control panels. Freight train speeds were increased from 30 to 60 mph (from 48 to 97 km/h). Automatic train stops (discussed later) were also added. At the time New York Central boldly stated this was the safest route in the world.

Often one track upgraded with CTC replaced two tracks without CTC. The standard centralized track control installation consists of a single main line track with sidings spaced perhaps every 25 miles (40 km) for lightly traveled routes and up to every 5 miles (8 km) for busier track. Interlockings are installed at the ends of sidings to control train meets. Typically, block signals are used to safely space trains in between sidings.

Computer analysis of actual train movements in the late 1990s concluded practical, safe limits for two-way traffic on a single track in dark territory, a single track with automatic block signals, and a single track with CTC as 15 MGT (million gross tons per year), 35 MGT, and 75 MGT respectively.<sup>13</sup> In all cases sidings were available for train meets.

A traditional CTC control board (Figure 5.13) consisted of a schematic of the track with lights showing the location of track switches, signals, and trains. Underneath were two rows of toggles and a row of buttons. The dispatcher set the correct route through the interlock by first setting the track switches and then the track signals. The system logic would not allow settings that collided trains. The buttons started a sequence of events corresponding to the levers' settings. Banks of relays in the control board verified the current position of signals and switches in the field, made the required changes, and verified that the changes had, in fact, taken place. A typical track switch motor required 7 seconds to unlock, move the switch, and relock.

In 1937, a technological advancement reduced the dispatcher's task to pushing only two buttons: the train's entrance and exit points through the track network. After the entrance point was selected, the control panel would light up all possible safe routes allowed by the relay circuit logic. The dispatcher selected the final route by pushing the button identifying the correct exit point. The relay circuits would automatically check for conflicting train routes and correctly set all the track switches and signals between the entrance and exit points. The push button entrance-

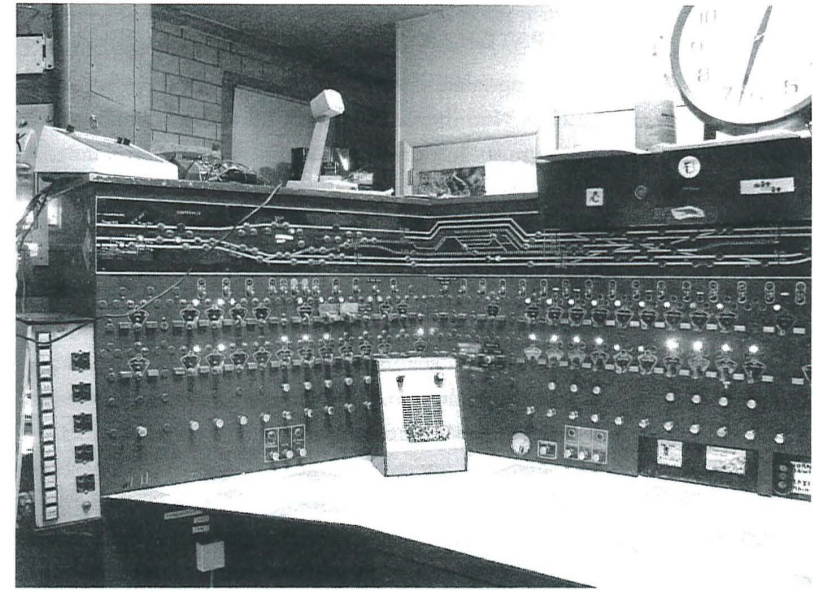


FIGURE 5.13. Active Union Switch and Signal CTC machine at Amtrak's THORN Tower. Although many of these systems still exist, a computer screen is more common today.

exit technology remains the standard today. More recently, the computer allows the dispatcher to program multiple trains in sequence.

Traditionally, dispatching was done from one or two desks with dispatchers communicating by telegraph with signalmen located near the tracks. As electronic controls and communications improved, the CTC centers slowly grew into the computerized centers they are today.

Mergers and computerization encouraged larger regional and eventually centralized dispatching for the entire train network. Today BNSF maintains the largest centralized dispatching facility in the United States, employing 533 dispatchers to cover 98 desks in its Network Operations Center located in Fort Worth, Texas. BSNF operates 6,400 locomotives on about 32,000 route miles (51,500 km) with 50,000 track miles (80,500 km). (Two miles of triple track is 2 miles of route and 6 miles of track. Most routes are single tracked.)

### THE DISPATCHER

Whether in signaled or dark territory, all train traffic is controlled by a dispatcher. Nothing moves without the dispatcher's permission. The dispatcher grants authority to enter the main track, plans train meets, allows higher-priority trains to pass slower trains, and sorts out trains crossing at junctions.

The level of responsibility (and associated job stress) is very obvious—trains are commonly routed for head-on, rear-end, or crossing collisions. The dispatcher's job is to keep the trains moving at a safe distance from each other. A routine slowly develops as new trains enter the dispatcher's territory at about the same rate as others leave. Everything must be adjusted, however, when unexpected delays occur.

Equipment, track, signal, and communication failures can all cause delays, as can weather, vandalism, crew changes, switching in the yard, track obstructions, and, of course, accidents. Trains must be routed around maintenance crews required to inspect and repair track—both activities with their own unexpected delays.

The dispatcher must monitor the location of all trains, track inspectors, maintenance crews, and hazardous material. The dispatcher must adjust for different train speeds, the train crew's hours of work (12 hours maximum), location of relief crews, and the weather; even the number of locomotives and number of cars will alter train speeds up and down steep grades.

Even ordinary train movements can require extensive activity for the dispatcher. In Chapter 9 four locomotives repeatedly go back and forth and on and off the main track to pick up their train, reposition the locomotives at the head of the train, move off the main track for oncoming traffic, and couple to their helper locomotives. After 5 hours, the train has advanced only 19 miles (30 km).

Computer software helps the dispatcher keep track of everything, even in dark territory—but this help is somewhat muted because he or she is then expected to supervise more trains.

Despite the responsibilities of the job, dispatcher-caused accidents are rare. A 1995 FRA study found only five reportable accidents caused by dispatchers during a three-year period. Even then, in four of the five

accidents the train crew incorrectly repeated their instructions, and the dispatcher failed to notice.

Any potential dispatcher error should be flagged by a computer. Information is continuously presented to the dispatcher, who should be able to correct any mistake at a later time. For the train crew, missing a signal during minutes (or even seconds) of distraction is not as easily corrected.

### CENTRALIZED TRAFFIC CONTROL ON THE NORTHEAST CORRIDOR

On the Northeast Corridor the trains are powered by electricity instead of diesel engines. Electrification played out differently in America than in the rest of the world. Up until World War II, the electric NEC was the most advanced railroad system in the world. After World War II, dieselization took over in the United States. Prosperous Americans loved their cars and spread out into suburbia with their new federally built highway system. The bombed-out economies of Europe and Japan could not afford millions of cars—their people were going to move by train or not at all. American electric train technology fell by the wayside and the Northeast Corridor fell into disrepair until modernized with today's dominant foreign technology.

Electricity is the most efficient way to operate trains. Even in 1914, when the first 70-mile (113-km) stretch was electrified, burning coal in a power plant created twice the horsepower generated by burning coal in a steam locomotive firebox. A large pile of burning coal with a huge chimney at a power plant can burn hotter and more efficiently than a small pile inside a locomotive. A steam locomotive consumes coal even when idling or coasting. An electric motor has less friction than all the moving parts in a steam or diesel engine. Also, an electric train does not have to carry around fuel, a fuel tank, an engine, and a bigger frame for all the added weight. Today all high-speed trains in the world operating above 125 mph (201 km/h) are electric for these reasons and others. The initial costs, however, are roughly double for the added electric infrastructure.

Once the travel time between two destinations comes down to three hours or so, all over the world trains compete successfully with planes and

dominate the market. Profitability, especially in the case of high-speed electric trains, requires a minimum population density to work. Such population concentrations exist in Japan, Europe, and the NEC in America.<sup>14</sup>

IN ADDITION TO MOVING TRAINS AROUND, dispatchers on the Northeast Corridor must also move electricity around. On the NEC traffic control is called Centralized Electrification Traffic Control, or CETC. CETC controls the trains and regulates the flow of electric power, balances the loads, shuts down sections for maintenance, and monitors electric switches, circuit breakers, transformers, and other power controls.

This is no trivial matter. With more than 1,800 trains operating on the NEC per day, mostly concentrated at rush hour, power demands are constantly changing. Depending on the time of day and the number of trains on the tracks, electric power is constantly being turned on and off, adjusted, and balanced in the network with electric switches in the interlocking towers.

Most of the Northeast Corridor has the same electrical layout as it did when first electrified in the 1930s. In fact, quite a bit of the original electrical equipment has survived into the twenty-first century.

Alternating current (AC) is more efficiently transmitted over long distances at high voltages. Since electrical resistance is fixed, increasing voltage results in lower current (per Ohm's Law, voltage = current  $\times$  resistance). Reduced current decreases the power losses caused by the flowing electrons rubbing on each other.

On the Northeast Corridor power plants supply 13,200 volts increased to 132,000 volts with transformers for more efficient transmission. The voltage is then decreased with more transformers to 11,000 volts in 67 substations every 7–10 miles (11–16 km) for the conductor wire. The pantograph rubs on the conductor wire and supplies power to the train. Additional transformers on the trains further step down the voltage from 11,000 to the 625 volts used by the motors.<sup>15</sup> For safety, only 36 volts, supplied from batteries, is used inside the crew compartment for signal equipment.

The 132,000 volts is not supplied directly to the conductor wire because arcing will damage the pantograph and/or electric switches. Arcing is a high-temperature electron discharge across a gap. If the contacts

of a switch (or between the pantograph and conductor wire) are separated by a small gap, the electricity will jump the gap like a tiny bolt of lightning, with temperatures as high as 9,000°F (4,982°C). Electric switches are required to isolate sections for maintenance. Each track has four redundant conductor wires switched on and off as needed; an entire substation can be shut off and bypassed.

Today the electric power loads on the Northeast Corridor are balanced with computers. In the 1930s and for many years afterward, current, voltage, and power calculations were solved with a mini electric panel that mimicked the real thing. Any adjustment to the big grid would first be tested on a mini panel located in the Central Load Dispatching Office in Philadelphia. After any load change, acceptable current and voltage levels were checked on the mini panel with portable meters.

THROUGHOUT THE 1980s, the Northeast Corridor was being modernized in preparation for high-speed trains. This was and remains a massive project. The rails had to be upgraded and the roadbed stabilized. Hundreds of 100-year-old bridges and a few tunnels had to be brought up to modern safety standards or replaced, and the signals had to be updated.

In 1975, just 25% of the track was signaled for traffic in both directions. Eventually, the Northeast Corridor evolved into mostly three tracks signaled for bidirectional movement. All the interlocking logic had to be redesigned. In 1987, the interlocking control towers were slowly being automated and connected to a central dispatcher. Beginning with a 110-mile (177.02-km) stretch from Philadelphia to Wilmington, Delaware, in the spring of 1987, Centralized Electrification Traffic Control was gradually introduced on the NEC. The 124 manually operating interlockings slowly became modernized, automated, and connected to 1 of 3 control centers (Philadelphia, New York City, or Boston). Today the NEC is controlled by 19 dispatchers in 3 control centers aided by an occasional operator in a tower.

#### PEAK COLLISION PERIOD

In the early part of the twentieth century, the collision rate reached its zenith. This period also coincides with record railroad passenger traffic. Between 1906 and 1921, there were 26,297 head-on or

rear-end collisions, resulting in 4,326 fatalities—almost 1,400 collisions and 270 fatalities per year. The average passenger fatality rate for this period was about 2.2 fatalities per 100 million passenger miles traveled. Contemporary rates today are 0.034 per 100 million for intercity travel and 0.02 per 100 million for commuter trains.

### EARLY TRAIN CONTROL

Automatic controls to prevent collisions began more than 100 years ago. Mechanical train stops were first used on Boston transit trains in 1901. A mechanical trip would trigger a valve on the train that activated the emergency airbrake system.

Somewhat surprisingly, mechanical stops remain in use on the New York, Chicago, Boston, Philadelphia, and Toronto transit systems. (As of 2004, the New York Transit subway system's 856 miles [1,378 km] had 11,646 blocks protected by track circuits and automatic train stops.) A short mechanical arm, called a trip stop, is pneumatically or electrically raised beside the rail when a signal shows the next block is occupied. The trip stop strikes a trip cock on the train that evacuates the air in the brake line and triggers emergency braking.

Passenger trains began experimenting with mechanical train stops and installed more than 100 miles (161 km) on 3 stretches between 1913 and 1919. Because of wear and track-shifting under heavy freight trains, mechanical stops for freight trains were less effective.

Electric automatic train stops came next. An alternate current in a coil creates an alternating magnetic field. The changing magnetic field will "induce" (without contact) an AC current in a second coil attached to the locomotive, the basic principle of a transformer. This AC current, now inside the locomotive, can be used to activate the brakes.

In 1922, after extensive studies and congressional hearings, the ICC ordered 49 railroad companies (expanded to 93 railroads in 1925) to install automatic train stops (ATSs) or other safety devices on at least one major line by the end of 1925. The railroad companies resisted this order furiously, with much justification. It was impossible back then to design a device that safely stopped long and heavy freight trains and light passenger trains. Braking is not a precise process and varies greatly with the condition of the rails and the length and weight of the train. Chapter 6

explores the difficulties of precise stopping even with modern technology. Also, a sudden emergency stop can derail a heavy freight train.

Because the ICC regulated prices and would usually not allow increases, the railroads had trouble justifying any extra costs unless it improved operations. Forced stops, when merely slowing would suffice, played havoc with schedules. After emergency braking depleted the air, it could take up to 45 minutes to re-pressurize the airbrakes and many more minutes regaining lost speed. At that time even the Brotherhood of Locomotive Engineers (the engineers' union) argued that automatic devices would decrease safety as the engineers became over-reliant on them and paid less attention.

These arguments went on for years. Meanwhile, the number of passenger deaths dropped significantly (mostly from reduced ridership) while fatalities at road crossings tripled between 1923 and 1927. In 1928, the ICC stopped demanding train controls on additional routes, concluding that more lives could be saved by spending more money on signals at road crossings.

The Pennsylvania Railroad (PRR), always a technological leader, began widespread use of automatic cab signals. Automatic cab signals moved the trackside signals (called wayside signals) inside the locomotive cab. This was done by sending pulses of current into the rails. The pulses could be displayed as signals inside the cab. With cab signals now located on the engineer's control panel (with a whistle announcing changes) it was extremely difficult for a conscious engineer to miss a signal even during inclement weather. The PRR demonstrated that cab signals were just as safe as train controls, and the ICC allowed Union Pacific, PRR, and others to substitute cab signals for automatic train stops in the late 1920s.

Actually, it is a far more confusing story. After ATS or ACS was added, it was not necessarily easy to get permission for removal, and remnants of these safety features still exist today. In general, the ICC allowed removal of ATS and ACS when passenger service ended on that route.

### SPEEDY PASSENGER TRAINS IN THE 1930S

Speed limits eventually placed on the streamliners introduced in the 1930s are an important part of the train control and signal story. The same rules limit passenger train speed today.

The first official record of more than 100 mph (161 km/h) occurred in 1892, when a U.S. steam-powered train averaged 112.5 mph (181 km/h) for 1 mile. The record was broken in 1903 with a brief burst of 124 mph (199 km/h). Short runs are less meaningful than sustained longer runs. For this reason an international railway study identified speed records for 15 distances ranging from less than 25 miles (40 km) to greater than 3,000 miles (4,828 km).

Speed records began falling in the mid-1930s with the introduction of diesel-powered high-speed trains, the Burlington's Zephyr being the first of many. In 1936, the United States held the record in 12 of the 15 categories and dominated until Japan developed Bullet trains in the 1960s. (The current record for a conventional passenger train is 357.2 mph [575 km/h], made during an experimental test run on a modified TGV French passenger train in 2007.)

The Burlington lost 60% of its passengers between 1926 and 1931. Besides the Great Depression, one of the reasons was, of course, the automobile. Starting in 1901 with 15,000 cars, the number increased 10 times every 7 years. By 1933, there were 55,000 locomotives pulling nearly 52,000 passenger cars trying to compete with 25 million cars.

Burlington's innovative (and risky) plan was to build a lighter, faster, stylish passenger train. The Zephyr, with its art deco design, had many innovative "firsts": the first aerodynamic streamlined design, the first high-speed train powered by a diesel engine, and the first lightweight train—about half the normal weight. Wind tunnel testing showed a streamliner could reach 100 mph (161 km/h), whereas a conventional train with the same horsepower could only obtain 75 mph (121 km/h).<sup>16</sup>

On May 26, 1934, the Zephyr was introduced to the public on its publicity-filled, record-breaking run. Although only briefly hitting 115.2 mph (185 km/h), the Zephyr reduced the travel time between Denver and Chicago from 25 to 13 hours and averaged 77.75 mph (125 km/h) for 1,017 miles (1,636 km)—the longest nonstop train ride ever. Just 2 years later, the same run was completed at 83.3 mph (134 km/h).

Because of the intense public attention on the Zephyr's maiden trip, Burlington went to extraordinary means to avoid any mishaps. All other trains were parked along the entire route, and flagmen protected every road crossing. To prevent tampering, track switches were spiked shut.

Speed limits were posted on difficult curves. Today modern technology creates similar protection for Amtrak's high-speed Acela.

The Zephyr was a sensation wherever it appeared. In 1934, the Zephyr starred in its own Hollywood movie, *The Silver Streak*. The Zephyr, the "hero" of the movie, raced across the continent transporting an iron lung for a medical emergency.

The new schedule between Minneapolis and Chicago had diesels making the trip 3.5 hours faster than steam engines and 115 minutes faster than Amtrak trains today. In 1935, revenue doubled for the Zephyr and operating costs were about half. By 1938, 90 streamliners were in service across the nation.

### THE RULES CHANGE AGAIN

On April 25, 1946, two passenger trains collided, killing 45. A trainmaster on the Advance Flyer thought he saw something dragging under the train. Since dragging equipment can derail a train, the trainmaster promptly ordered the Advance Flyer stopped 28 miles (45 km) southwest of Chicago. Unfortunately, 90 seconds later the Exposition Flyer, traveling at about 75 mph (121 km/h), collided into the stopped Advanced Flyer (Figure 5.14).

A signal light 1,100 feet (335 m) east of the stopped train indicated red for "stop." A second signal 5,150 feet (1,570 km) farther indicated yellow for "slow down." The investigators determined that the yellow light was visible nearly 2 miles (3.21 km) from the stopped train. The engineer of the colliding train stated that he saw both lights, but at 85 mph (137 km/h) the train was traveling too fast to stop before hitting the Advance Flyer. The investigation did not favor the colliding engineer's story.

Several test runs were conducted to determine the train's stopping

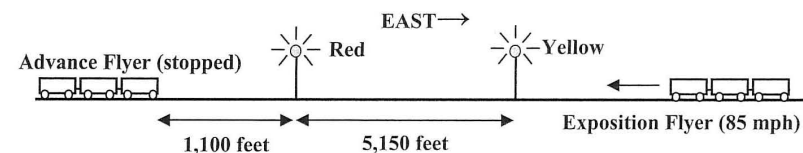


FIGURE 5.14. Collision on April 25, 1947.

distance. Representing the shortest possible warning consistent with the engineer's story, it was possible the yellow warning light came on just as the Exposition Flyer passed the signal. Braking for the third test began at 80 mph (129 km/h) at the yellow signal light. The test train stopped in 5,191 feet (1,582 m), still 1,329 feet (405 m) short of the collision site. Repeating this test at 85 mph (137 km/h) the test train took an additional 360 feet (110 m) to stop. Emergency brakes were used during the final test. The test train stopped in a smoky, sparking 3,300 feet (1,005 m). As a result of this particularly bad collision, the ICC altered the haphazard rules first made in 1922 (and frequently waived) concerning automatic train controls.

IN 1947, the ICC passed new rules requiring automatic block signals for all freight trains operating above 49 mph (79 km/h) and passenger trains operating above 59 mph (95 km/h). This rule affected about 18,000 miles (28,968 km) of track. Additionally, all passenger trains operating above 79 mph (127 km/h) (about 27,000 miles [43,452 km] of track) now required train controls (i.e., automatic train stops or automatic cab signals). These rules are still in place today.

The ICC expected expanded use of train controls. Although train controls were added to about 5,000 miles (8,046 km) of track, most railroads, in the face of declining passengers, simply lowered operating speeds to comply. The decline of passenger trains in the United States accelerated. The number of intercity trains plunged from 20,000 in 1929, to 2,500 in 1954, and to about 450 in 1970, when Amtrak took over. Today in the United States high-speed trains are being studied for many locations, but only a few passenger trains currently operate above 79 mph (127 km/h). The Northeast Corridor is the most important example.

In 1951, the Pennsylvania Railroad continued innovating and developed automatic train control (ATC) to regulate train speeds. It added ATC to passenger trains already equipped with automatic cab signals. ATC took the electric pulses sent in the rail for automatic cab signals one step further. The coded track pulses creating signals inside the cab were developed to apply the brakes if the engineer did not respond to a warning light and whistle within 6 to 8 seconds. Speeds of 20, 30, and 45 mph (32, 48, and 72 km/h) were enforced. Today ATC on the Northeast Cor-

TABLE 5.2  
Federal Railroad Administration Surveys of Train Control Use,  
1993 and 2007

|             | Total Track Miles (1993) | Total Track Miles (2007) |
|-------------|--------------------------|--------------------------|
| ACS         | 3,964                    | 5,303                    |
| ATS         | 1,780                    | 2,095                    |
| ACS/ATS     | 90                       | 310                      |
| ACS/ATC     | 1,554                    | 2,106                    |
| ACS/ATC/ATS | 2,455                    | 419                      |
| Total       | 9,843                    | 10,233                   |

ridor has evolved into a more advanced system known as Positive Train Control (PTC; see Chapter 6).

Automatic train control differs from automatic train stops. Automatic train control enforces the speed limit but will not precisely stop the train because the signal is received randomly in a long section of track. Also, it takes 3 to 5 seconds for the changed signal to appear in the cab, and the engineer is allowed 6 to 8 seconds to respond. ATC can enforce any speed except zero. The slowest speed enforced is 20 mph (32 km/h). Trains with ATC can still travel past a signal at speeds below 20 mph.

With ATS the engineer has 6 seconds to acknowledge the alarm before the train's brakes are applied. Because braking is not a precise and repeatable process (especially on heavy freight trains), the designers allow overriding of the automatic stop by merely pressing a button to acknowledge the alarm. This gives final judgment to the engineer (to account for all the variability associated with a long, heavy freight train) and reintroduces the possibility of human error.

Despite the near disappearance of fast trains, remnants of train controls still remain (Table 5.2). ATS, ATC, and ACS (automatic cab signals) are often used in combination.

#### TRAINS PROTECTED BY CTC, ABS, ACS, AND ATS COLLIDE

On July 2, 1997, two Union Pacific freight trains collided in spite of both being protected by a centralized traffic control system, automatic cab signals, and automatic train stops.

This busy section of Kansas main line track averaged 60 to 75 trains per day. Train 1 passed a signal indicating “do not exceed 40 mph (64 km/h).” Just 2.4 miles (3.8 km) later, a second signal warned Train 1 to slow to 30 mph (48 km/h). The dispatcher remotely threw a switch directing Train 1 onto a siding to allow a second oncoming train to pass. After the 6,400-foot (1,951-m)-long train entered the 13,500-foot (4,115-m)-long siding, a third signal warned Train 1 to stop at the next signal. Two-and-a-half (4 km) miles later, at the end of the siding, a fourth signal ordered Train 1 to stop and wait for oncoming Train 2 to pass on the main track.

The collision occurred at 2:23 a.m. and killed the engineer of Train 1. The investigators concluded that the engineer fell asleep somewhere in the siding. The engineer was sufficiently awake to acknowledge the alarm from the automatic cab signals after each signal changed. He did not slow the train, however, when entering the siding.

Even though the automatic train stop did activate the train’s brakes, the train was moving too fast to stop. The sleeping engineer woke up when the brakes were automatically applied. Exact speeds were not recorded because the event recorder was destroyed in the collision and fire.

Operating rules for these two freight trains (and all trains) require the engineer to call out all signals to the conductor. The conductor, sick in the lavatory for 20 minutes, missed all callouts. The colliding train struck the sixth car of the second train, derailing 15 cars. The subsequent fire engulfed the derailed cars and locomotives of both trains.

The focus of the 1947 Chicago collision investigation was completely different from the one in this 1997 accident. In 1947, the investigation centered on proving that the train could have easily stopped and concluded that the engineer missed the yellow and red signals. Clearly, the engineer missed the signals in the 1997 accident. In a relatively modern development, the investigators sympathetically view the human potential for error and do not even assess safe stopping distances.<sup>17</sup> In the case of this accident, the investigators focused on the engineer’s sleep patterns, changing schedules, “the rhythmic sound and motion produced by the locomotives,”<sup>18</sup> the lack of sensory stimulation inside

the cab at night, and Union Pacific’s existing operator fatigue education program.

The National Transportation Safety Board also recommended developing Positive Train Control, designed to prevent such accidents. PTC is the subject of the following chapter.