CAR NAVIGATION SYSTEMS

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Automobile navigation is a demanding application of digital maps and appears likely to become a common and economically important one. A few systems are commercially available and many prototypes exist. These systems determine location using wheel rotation sensors, solid state compasses, inertial devices (gyros and other novel devices), radio location or some combination of them. Requirements of the source maps depend on the methods used and the user interface, as well as on functions performed in addition to location determination (such as map display, verbal directions, pathfinding and destination finding by address or landmark). Typical map requirements for particular systems include positional accuracy to the order of a car length, detailed street classification, turn restriction data and topological encoding. Creating such digital maps to support navigation is a daunting task. At the time of writing, there are several pilot projects, just a few commercial operations and some fledgling consortia which have as their mission the production of digital maps for navigation or the promulgation of standards for such maps. All systems require faster retrieval than GIS systems have typically provided. Applications using navigation systems include experimental traffic systems, such as traffic congestion reporting and 'sign-post' transmitters and receivers for communicating with on-board navigation systems.

INTRODUCTION

The automobile is becoming a much richer electronic environment for the driver. On-board computers, cellular telephones and vehicle navigation are already available, and real-time traffic information and route guidance have been demonstrated. The market for factory-installed systems appears to be huge. In Japan, Nissan has been selling more than 1000 systems per month as an option on the Nissan Cedric. This option is a combination of navigation system and television (which can only be operated with the vehicle stopped). In Germany, Bosch began to sell the Travelpilot in 1989. In the United States, Etak sold 2000 Navigators over a period of two years. Because electronics are pervading the automobile, a factory-installed navigation option will probably become inexpensive, perhaps less than US $500. As a consequence, demand for and use of digital map data will grow. Market analysts have estimated that sales of navigation systems will grow from US $5 million in 1990 to US $100 million in 1994 (Frost & Sullivan 1989).

Car navigation uses maps intensively. The map must provide information for:

- determining and maintaining the location of the vehicle in relation to features represented on the map;
- displaying a map graphically or generating routing instructions in text or voice;
- linking effectively with infrastructure.

This chapter reviews the current 'state of the art' of digital mapping as regards vehicle navigation and, since it is still in its infancy, some speculations are made about likely future developments. The infancy of the technology is reflected in the meagre

Toyota Petition '743 Exhibit 1043
Page 1 of 11

Fig. 43.2 The Honda Gyrocator screen (courtesy author).

supply of prior research considering the subject and directly related cartography (Petchenik 1989). Marine navigation is not included in this discussion. It has similar requirements and applications and, indeed, was the origin and inspiration for much of the current vehicle navigation technology. However, it differs in many ways from land-based vehicle navigation and warrants separate discussion.

The following sections discuss vehicle navigation systems and methods already in use and how information is displayed graphically, reported textually or by voice. Then applications such as finding destinations and pathfinding are considered. Finally, there is a review of the essential characteristics of digital maps, in so far as navigation and its related functions are concerned. From this, it will become evident that navigation and related applications require a topologically encoded and seamless database, as well as very fast data retrieval.

NAVIGATION

There are only a few vehicle navigation systems commercially available at the time of writing (mid-1990). In the United States, the Etak Navigator has been available since 1985. The Bosch Travelpilot, a derivative of the Etak Navigator, became available in Germany in 1989. Both of these systems are 'after-market' devices, that is, they are installed after manufacture and usually after the end-user purchases the vehicle. In Japan, the Toyota Crown and the Nissan Cedric have offered factory-installed navigation options since 1987 and 1989 respectively. The Etak, Bosch and Nissan systems use dead reckoning and map matching (explained below) but the Toyota system uses only dead reckoning. The map matching systems require topologically encoded digital maps, whereas the Toyota system uses bit-mapped images of paper maps (see Plate 43.1 and Figs. 43.1 and 43.2)

Fig. 43.1 The Nissan Cedric screen (courtesy author).

In addition, there are several experimental systems and 'concept cars' either demonstrating or 'mocking up' navigation systems. In an auto show in Japan in early 1990, more than a dozen

Toyota Petition '743 Exhibit 1043
Page 2 of 11

Fig. 43.3 The Autoguide screen (courtesy Department of Transport).

manufacturers showed such concept cars. This indicates a strong interest in navigation and, by implication, maps for navigation. Examples of experimental systems include the Philips CARIN (Thoone 1987), Clarion NAVI and the UK Autoguide (Catling and Belcher 1989). CARIN and Autoguide present stylized graphic instructions representing the upcoming intersection to the driver (see Fig. 43.3). Only the general principles on which such systems work are known: all the current vendors of navigation systems regard their software and data storage methodology as proprietary and, accordingly, do not reveal details. This is unsurprising because navigation has pushed forward the frontier of map access technology: typically, on-board computers are much less powerful computationally and contain less copious RAM than 'normal' GIS require and, at the same time, demand a faster response rate than available GIS offer. In addition, navigation algorithms and their implementation have involved substantial expenditure. The commercial stakes are high and, accordingly, secrecy prevails on the internal details of each vendor's offerings.

POSITION DETERMINATION

Navigation includes determination of position as well as guidance toward a destination. There are three essentially different technologies used for position determination. These are dead reckoning, radio location and proximity beacon detection. They can be used alone or in combination. Destination finding and guidance towards the destination have various quite different user interfaces.

Dead reckoning and radio location

Dead Reckoning (DR) is the process of computing an updated position from three inputs: details of a prior position; the distance travelled from the prior position; and the heading travelled since that prior position. The Etak Navigator, Bosch Travelpilot and Nissan Cedric all use DR. Figure 43.4 illustrates dead reckoning. To measure the distance travelled, all three use sensors mounted on the wheels. Other systems have tried to use the vehicle's odometer but this is much less accurate.

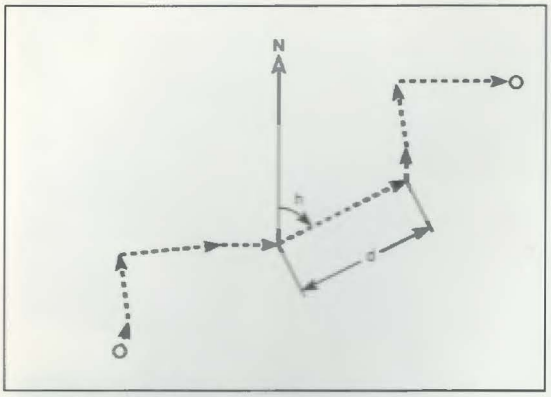

Fig. 43.4 Dead reckoning – computing a new position from heading (h) and distance (d).

For determining the heading, two measurements are taken. An absolute heading estimate is made using a solid-state compass (e.g. see Phillips 1987) and a relative heading is computed from the wheel sensor measurements. A solid state compass (i.e. a two-axis magnetometer) measures two components of the ambient magnetic field; from this the horizontal component of the earth's magnetic field is computed. There are many physical considerations involved such as the magnetic flux focusing effect of the steel in the vehicle and the local magnetic declination. However, all mapping considerations eventually come down to using the approximate position of the vehicle, a model of the earth's magnetic field and the measured magnetic field. An important consideration for in-vehicle applications is dip angle, the angle that the plane of the compass makes with the earth's magnetic field vector. The earth's magnetic field is horizontal only at the magnetic equator, which coincides approximately with the geographical equator. So the compass measures the magnetic field vector projected on to its own plane. While this is normally close to horizontal, local variations in ground slope caused by hills and the road crown may amount to several degrees and affect the compass/magnetic field relationship accordingly. Computation of the heading from compass measurements must take all these effects into consideration.

The difference in the distance travelled on two opposing wheels depends on the change in heading. When travelling straight ahead (i.e. without heading change), the two wheels travel the same distance. When turning, the outside wheel travels further than does that on the inside of the curve. Thus wheel sensor readings yield relative heading information. Again many physical considerations come into play, including wheel base, circumference, radius of curvature of the turn, steering geometry and wheel slip. Taking all these factors into account, however, a new heading can be computed from the prior heading and the difference in distance travelled by the two wheels.

Other sensors are under development or have been demonstrated in experimental systems. These include a gyro turning rate sensor, a vibrating rod turning rate sensor, an inclinometer, a GPS (Global Positioning System) receiver, a LORAN-C receiver and an optical speed sensor.

A gyroscope (more commonly a 'gyro') is a spinning mass and the vehicle's turning rate is measured indirectly by measuring forces resulting from the conservation of momentum; such forces can be experienced by holding a spinning bicycle wheel off the ground and turning it. Large gyros are used in inertial navigation systems common on board ships or aircraft. The vibrating rod sensors also operate on conservation of momentum. An inclinometer measures the angle of inclination of a stationary (or, more generally, a non-accelerating) vehicle and may be used to remove the effects of dip angle on the compass measurement as well as effects of hills on distance travelled. Any acceleration experienced affects the inclinometer so this must also be considered. As a group, the gyro, vibrating rod and inclinometer are all inertial sensors: they depend on the physics of momentum and inertia for their operation. For a survey of such inertial navigation sensors, see Smith (1986).

GPS and LORAN-C are radio location systems. These radio location sensors are not used in dead reckoning. Instead they provide position 'fixes' that are independent of the prior position. They both operate by an on-board receiver and computer comparing signals from multiple transmitters and determining receiver location from known transmitter positions and signal propagation times. The LORAN-C transmitters are based on the ground and the GPS are on a constellation of satellites in orbit. GPS will cover the entire globe when the satellite constellation is completed. French (1986) provides an overview of radio location systems.

Compass and radio location sensors are 'absolute' sensors; in contrast, wheel sensors and

Toyota Petition '743 Exhibit 1043
Page 4 of 11

gyros are 'relative' sensors. Relative sensors give change information and absolute sensors provide information with respect to the earth itself. All sensors, however, suffer characteristic defects. Wheel sensors and gyros have noise and bias. Magnetic compasses measure magnetic anomalies as well as the earth's magnetic field. Radio location (GPS and LORAN) signals are distorted or blocked in highly urbanized areas. Manifestly, the sensor characteristics are important in assessing the accuracy of the estimated position. In addition, however, combining sensors can yield good results even when one sensor is noisy or fails entirely. The Etak method of computing heading, using both a compass and differential wheel sensor measurement, is an example in which the absolute sensor (the compass) suffers no accumulation of error and the relative sensor (the differential odometer) is unaffected by magnetic anomalies – yielding a combined result that is rarely erroneous (Honey, Milnes and Zavoli 1988).

Despite such accurate and resilient methods of deriving heading, the accuracy of a dead reckoned position still also depends on the accuracy of location of the prior position. The ineluctable errors in sensors lead to accumulated error in DR position. In practice, DR alone is insufficient for navigation since the accumulated error will eventually exceed a threshold of usefulness. So occasional fixes are needed, achieved either by human intervention, radio location or map matching. The first of these is tiresome and assumes accuracy on the part of the user; the third method is discussed in detail below. Radio location, however, has characteristic errors that are quite different to those already discussed. These errors do not accumulate over time or distance. Instead, signals are typically received clearly and the error level is the characteristic minimum or, alternatively, there is no position information available. It is, however, possible to dead reckon between radio fixes or, as Etak has done, use radio location (in this case LORAN-C) as just another sensor to be considered in location determination.

Map matching

Map matching is used to remove accumulated error from dead reckoning. The path travelled is determined by dead reckoning or radio location and integrating this with roads and intersections constitutes map matching (see Fig. 43.5). Dead reckoning with map matching is like navigation with absolute sensors in that the error in estimated position does not continue to grow (as it does with use of dead reckoning alone). It differs in that, once lost, the map matching algorithm is unlikely to recover; absolute sensors, on the other hand, may fail for a time or region but, outside that period or region, they have their usual error characteristics.

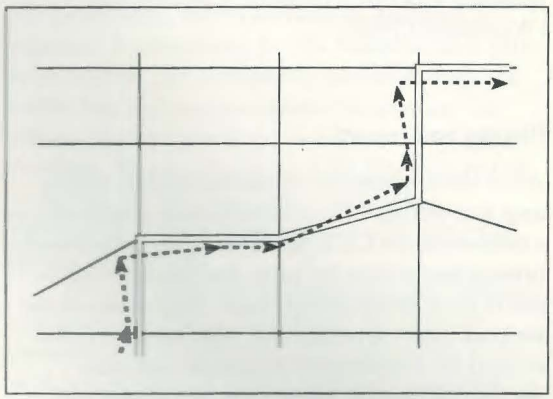

Fig. 43.5 Map matching – identifying a DR path (dashed line) with streets on the map.

By way of an example, one would eventually accumulate significant error using only DR while wandering along city streets. Through comparing the DR path to the map, however, the navigation algorithm can eliminate errors that accumulate from sensor noise. Etak pioneered the map matching approach (see Honey *et al.* 1989) for the Navigator. The Bosch Travelpilot uses the same approach and the Nissan Cedric uses a similar map matching method. Such map matching depends on the driver staying mainly on the roads; it is inappropriate for automatic guidance of a vehicle. In this approach, heading as well as position is determined as an output of map matching and is used for orienting the map displayed to the driver. Experience indicates that the impression given by a map display with a slightly 'wrong' orientation is that the computer is lost or will be soon – somewhat like the impression of a misaligned street name on a printed map. For this reason, map matching methods are used to orient and position the display even for absolute location methods, such as radio location.

Other navigation approaches that have been tried require extensive infrastructure, such as

beacons mounted on traffic signal standards. ALI/SCOUT and Autoguide (Catling and Belcher 1989) are examples of such systems. Such approaches can also be coupled with broadcast traffic information. In Japan, the Advanced Mobile Traffic Information and Communication System (AMTICS) project was a test of such a concept (Tsuzawa and Okamoto 1989). The PATHFINDER project in the Los Angeles region is intended to gather information about alternative routes drivers select when provided with traffic congestion information (Wasielewski 1988).

Display and report

All of the commercially available systems display map and vehicle location information graphically on a dash-mounted CRT. Some work has been done to present instructions by voice, but this approach is still in early development stages. Regardless of the method, safety is paramount. Map displays in this context are a dashboard instrument and must provide the needed information at a glance and must not distract the driver. When audio systems become available, they will also be required to facilitate driving, but not distract the driver's attention. As a result, the human interface must conform to dashboard instrumentation design guidelines. For visual displays, this includes letter and symbol sizes in terms of subtended angle for the driver and readability at a glance. In the case of audio output, sounds must be non-distracting and easily understood.

So far as map displays in cars are concerned, heading-up orientation (i.e. displaying the map so that 'up' on the display is 'ahead' on the ground and hence left and right on the display show features that are left and right of the vehicle respectively) makes the display much simpler to understand and read at a glance. In the Etak Navigator and Bosch Travelpilot, the display is heading up with some hysteresis in the heading adjustment to avoid a 'jumpy' display. The Nissan Cedric permits display at only the four cardinal headings and operates in a 'near heading up' mode. In addition, more generalized views provided through smaller scale map presentations are also quite helpful to a driver for choosing routes or just learning context. All commercially available systems provide generalized views. For a map to be readable at a glance, very

Fig. 43.6 Etak map displays at three scales showing few feature labels (courtesy author).

little annotation is possible. All three of the systems mentioned show only four or five feature labels at one time. Figure 43.6 shows three displays from the Travel pilot at various scales, each showing only a few labels. The labels shown were chosen by an algorithm that favours more important streets, the selected destination street and the street on which the car is currently placed.

Toyota Petition '743 Exhibit 1043
Page 6 of 11

GUIDANCE TOWARDS A DESTINATION

A primary use of navigation systems is in finding the location of destinations, usually specified by street address but also by street intersection or major landmark, and then finding a way to proceed to the destination.

Destination finding

To find a destination, the map database is searched via specially designed indexes and the destination is shown, for example, on the plot with a flashing star. The driver proceeds towards the star and his or her destination, as it was for the Biblical Star of Bethlehem! In-vehicle destination finding is interactive, may lack a keyboard and – because it is interactive – can take advantage of the user's ingenuity. In the Bosch Travelpilot and the Etak Navigator, for example, there are 12 buttons for input and the user only needs to enter a few characters before selecting from a list of possible cities or street names which match what has already been entered. Figure 43.7 shows a destination entry in progress. The user's ingenuity is exploited for recognizing spelling variants, in contrast to the common practice in geocoding software to search for sound-alike or otherwise similar words.

Fig. 43.7 Destination entry to the Etak Navigator.

In the future, business directories ('Yellow Pages') and other lists of destinations will be provided as part of the map. Finding the nearest hardware store or service station is an example of such applications. Detailed business information or advertising could also be provided: for example, restaurant menus may be included. Various experiments are under way to test technical aspects as well as market acceptance of in-vehicle business listings.

Path finding

At the time of writing, only experimental systems such as EVA and CARIN compute recommended paths from the current location to the destination. For pathfinding, the street network topology is required. Furthermore, for the recommended paths to be feasible, the pathfinding algorithm must use traffic flow and turn restriction information; this places a significantly larger burden on the map database. People often expect the guidance system to declare the best route and, ultimately, pathfinding is likely to be a required feature of all navigation systems.

The user interface for the pathfinding function can take many forms. Autoguide, for example, provides only an arrow indicating the action at the next intersection, or a more elaborate graphic for a roundabout. Highlighting the path on a map display is another approach. Two further approaches highlight the path on the map display and offer verbal instructions (Cass 1989).

DIGITAL MAP REQUIREMENTS AND CHARACTERISTICS

A digital map for navigation must meet demanding criteria. It must reside on rugged media, satisfy geometrical requirements imposed by the method of position determination, provide very fast retrieval and use an appropriate coordinate system.

Storage media

The storage medium for all available systems except the Etak Navigator is Compact Disk (CD) (Honey and White 1986). The Navigator uses compact cassette tape. The media and reading device must be sufficiently rugged for vehicle environments and these suffer wide temperature fluctuations and severe vibration. CD players meeting in-vehicle environmental specifications only became available

in 1989 and, being designed some years earlier, the Etak cassette player was made specifically to meet in-vehicle requirements for the application. All such devices are relatively slow for random retrieval; typical average seek time for a CD is 1 second – over 30 times that of a typical hard disk. The Etak cassette tape, which operates at 80 inches per second, has typical seek times of 10 seconds. These relatively slow speeds impose noteworthy challenges and severe constraints for the retrieval software, which are discussed below.

Digital maps also consume considerable space. Each CD holds approximately 600 Mb. This is sufficient in EtakMap format to contain all of the streets, with their names and address ranges, in the United States. Etak's cassette tape holds 3.5 Mb, which is sufficient for approximately the same information as shown in two typical folded paper street maps. Inevitably, the current trend is towards Compact Disk because the speed is workable and the storage available is capacious.

Images, vectors, topology and geometry

The simplest digital map representation to acquire and display is the bit-mapped image. It is also the least informative to the navigation software and most voracious in memory requirements. Map matching systems cannot use such images nor are images useful for destination finding. They only support display and, in any event, only at one scale and in one or a very few orientations: thus an upside-down image would not be readable. This is a severe limitation since most systems display the map with the heading of the vehicle being towards the top of the display, the so-called 'heading-up' orientation described above.

A more useful form of map encoding for navigation software is the vector encoding, in which linear features are encoded as directed line segments (vectors) or sequences of segments (see Egenhofer and Herring 1991 in this volume). This encoding is far more compact but is much more costly to acquire. It can support rudimentary map matching and display as well as variations in scale and orientation. Simply coding vectors (i.e. storing the equivalent of plotter commands) is not, however, sufficient for pathfinding nor is it adequate for sophisticated map matching that uses the network topology in its calculations. On the other hand, a geometrical encoding which includes topology fully supports map matching and display. Map matching requires the geometry of the road network for comparing and matching the dead reckoned path with streets; it also requires the geometry for evaluating possible matches against paths permitted in the road network topology. For example, a road connected to the previously 'occupied' road is more likely to be the one currently occupied by the vehicle than one that is not connected but which is near by.

In addition to applications that directly use topological information from the map, the well-known advantages of topological encoding for error detection and control, consistency of feature attribute assignment and control of digital map maintenance all favour such a method of encoding. Furthermore, topological data can be used to improve retrieval speed, which is quite important and is discussed below. Etak uses a topological encoding that also includes generalized views; these are themselves topological encodings of generalized maps computed from the detailed digital map. These views are used for small scale displays and will be used in the future for pathfinding over large distances. In this case, topology in both the fully detailed map and the generalized maps is required for pathfinding.

Retrieval

There are three different types of map retrieval criteria used in vehicle navigation. The first is window retrieval, which is used to retrieve map data surrounding the vehicle or the destination; these data are used both for map matching and display. Second is retrieval by attributes, such as address or street intersection, for destination finding. The third criterion is topological, which is used in pathfinding.

Map retrieval while driving must keep pace with the vehicle. That is, regardless of the vehicle's speed, map data for all the streets surrounding the vehicle must be in RAM for use by the map matching algorithm. Depending on the scale of the display, all or a selection of streets and other features must be in RAM for display. This is a very difficult requirement to meet given the constraints of in-vehicle systems, particularly the slow speed of mass storage and limits on amount of RAM available. For the Etak Navigator, the mass storage

Toyota Petition '743 Exhibit 1043
Page 8 of 11

is cassette tape and the CPU is an Intel 8088 with 256 Kb RAM. To make retrieval sufficiently fast, Etak organized data so that geographically neighbouring features were usually near by on tape. This reduced the number of searches and the seek time quite dramatically over many GIS implementations.

The constraints for attribute-based retrieval are determined by human factors considerations. The system must find a destination before the user tires of waiting. Typically this constrains the retrieval to 10 seconds or so. Similarly, pathfinding must be fast but probably need not be as fast as destination finding.

Seamless map and coordinate systems

Various coordinate systems have been proposed for use in navigation. Plane projected systems simplify distance and heading computations for dead reckoning and map matching, at least within single map sheets. Complications arise at the seams where projection parameters change. Geodetic coordinates involve more complicated calculations but have the advantage of being seamless, at least over the region that the same approximating ellipsoid is used. The WGS84 ellipsoid is the global reference for GPS (Global Positioning System) and appears likely to be adopted even for systems not using GPS.

For pathfinding, it is necessary to have a connected graph covering the origin, destination and environs. Having unrelated databases for adjacent countries prevents pathfinding from an origin in one country to a destination in another. This means that the map must be topologically seamless, at least at the application software level. Pathfinding software must be able to 'crawl' along the digital street network in a sequence of high level retrieval calls. Seamless topology also simplifies the task of map matching and display algorithms, but these are not quite so dependent on seamlessness.

Digital map production

Providing digital maps meeting the requirements set out above is a huge job and is out of the line of business of automotive electronics suppliers. This fact has impeded development and marketing of navigation systems. Providing electronics alone is not nearly sufficient and mounting a digital mapping effort is expensive and fraught with risk, particularly for companies unfamiliar with the business and technology. Even for companies with considerable experience in digital mapping, the coverage and other requirements for general navigation are daunting. On the other hand, the future navigation market could be huge and the navigation maps are valuable in a multitude of other applications – especially in those countries (like the United States) where provision of large scale and up-to-date mapping has hitherto been sparse.

In the private sector, Etak has produced digital maps for navigation for all major cities in the United States, all of The Netherlands, all of West Germany and various other cities in several countries, including Japan, Argentina, Saudi Arabia, France, England and Hong Kong. Etak sees its business as electronic publishing of digital maps and is building a commercial business accordingly. For source material, Etak uses topographic maps (usually at 1 : 25 000 scale or larger), digital map files, such as TIGER (see Rhind 1991 in this volume), aerial photography, plus various lists of addresses, street names and geographical names and codes. Etak has done some very limited data capture in the field. Navigation Technologies of Santa Clara, California has also produced digital maps for navigation, particularly to support pathfinding for a few metropolitan areas (notably San Francisco Bay and Los Angeles) but has relied much more than Etak on field data capture. TeleAtlas in The Netherlands has produced maps for The Netherlands and has done extensive data capture in the field with specially equipped vehicles. Also, Geographic Data Technologies of Lyme, New Hampshire has provided map data to navigation system developers for US cities. In Japan, Zenrin is providing digital maps containing only major roads to Mazda for its navigation system. Mazda then uses its own manuscripts as the basis for building digital maps.

In the public sector, the Japan Digital Road Map Association (JDRMA) has digitized all of Japan using topographic maps supplied by the government at 1 : 50 000 scale. The Ordnance Survey in Britain has produced the OSCAR data (see Sowton 1991 in this volume) and has provided data for Autoguide covering a corridor between London and Heathrow airport. Several consortia

have been formed with the intent of fostering digital map development in a manner which facilitates widespread use of the products. They are discussed in the following section.

STANDARDS

The blossoming of navigation research has given rise to several standards committees and prototyping projects, including the Society of Automotive Engineers (SAE) Committee on Vehicle Navigation, the JDRMA, DRIVE (Dedicated Road Infrastructure for Vehicle Safety), PANDORA (Prototyping a Navigation Database of Road Network Attributes) and GDF (Geographic Data File). Many of these groups have proposed database content and format standards. None of these standards however has enjoyed market acceptance or even market evaluation, since they are not related to commercially available systems. The interested reader should consult the most recent conference proceedings describing these efforts. At the time of writing, the *Vehicle Navigation & Information Systems Conference (VNIS)*, Toronto, 1989, Conference Record offers over 100 papers describing current projects and consortia and much additional material can be found in RIN (1990).

JDRMA has embarked on a ten-year programme of data collection and dissemination and has completed the first phase, digitizing Japanese major roads for urban areas of 200 000 population or greater at 1 : 25 000 scale and rural areas at 1 : 50 000 scale (Kamijo, Okumura and Kitamura 1989). GDF has defined a three-tiered standard for navigation-related map data, including a data exchange standard (Claussen *et al.* 1989). PANDORA is building a prototype database for a corridor between London and Birmingham (Smith 1989).

A different approach to standards is to agree on a software interface. This is analogous to agreeing to a Basic Input Output System (BIOS) interface for personal computers. Etak has adopted this approach in providing its maps and software for use by vendors of other navigation technology (Alegiani, Buxton and Honey 1989). A software interface standard permits flexibility and innovation in storage and retrieval of data just as BIOS permits flexibility and innovation in hardware design and improvement.

CONCLUSIONS

Vehicle navigation is in its infancy but promises to be a voracious consumer of digital maps and GIS technology. Already there are commercial systems available in the United States, Germany and Japan offering street network topology, destination finding by address, intersection and landmark, head up displays and moving map displays. Navigation by dead reckoning and map matching requires maps with a positional accuracy of a car length and street network topology. Radio location, such as LORAN-C and GPS, are alternatives that have not yet emerged as strong contenders for the consumer market and require maps with coordinate information related to the LORAN or GPS transmitters. In the future, it seems certain that the vehicle will contain facilities for providing a variety of information related to vehicle position, location of facilities and traffic. Digital maps and GIS will necessarily play an important role in bringing about that situation.

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Toyota Petition '743 Exhibit 1043
Page 11 of 11