Analysis of the Use of Digital Road Maps in Vehicle Navigation

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Abstract -- Digital road maps are being used increasingly throughout the world as they become more available. Five major digital road map suppliers are focusing their efforts on producing databases that support vehicle navigation functions. Of a total of 147 vehicle navigation systems in the world, 89 use in-vehicle maps, of which, 35 employ map matching, and 31 offer real-time route guidance. Vehicle navigation systems are limited by the maps they use, so the availability of inexpensive, complete and seamless navigable digital road maps remains as an impediment to the wider use of vehicle navigation systems.

INTRODUCTION

The two key technologies to any land vehicle navigation system are positioning and locating. Positioning technologies such as the Global Positioning System (GPS), dead reckoning (DR), and rate gyros are used to determine positions in co-ordinate space, usually latitude, longitude, and height. Locating technologies determine the vehicle's location relative to land features such as roads and intersections. The only way to accomplish location is through the use of maps. A paper map may be used to find a location given co-ordinates, however in many vehicle navigation systems, a digital road map is used to automate this process.

Digital road maps are the basis for many functions besides locating. Pre-mission route planning and route calculation, *en route* route guidance, address matching, and map matching are all functions that rely on the presence of certain features in digital road maps. Geometric consistency and topological integrity are also essential in any digital road map used for navigation.

There are several mapping companies and organizations that produce and maintain digital road maps. Reviewed in this paper are the major data formats/suppliers being used in vehicle navigation systems, and the navigation functions that they support. Statistics on the use of digital road maps in vehicle navigation systems are used to determine the world-wide situation and to illustrate trends.

SCOPE

The development of vehicle navigation systems is occurring throughout the world, with most of the activity being centerd in North America, Europe, and Japan. Consequently, digital road maps are also being developed in each of these three regions. Interesting strategic alliances are being formed to carry out this engaging task.

Vehicle navigation systems can be broadly classified into fleet management, autonomous, advisory, inventory, and portable systems. Each of these types of systems have unique requirements of a digital road map. These five classifications of systems are described and their particular mapping requirements are discussed.

The data for the statistical analysis in this paper is drawn from the IVHS Navigation Systems Database™ [1]. This Database documents 147 navigation systems in the world that are being or have been developed, patented or demonstrated as a concept. Along with positioning and communications technologies, documentation includes detailed information on the map format and source being used, if any, the feature content of that map, and the map-related functions of that system.

MAP RELATED FUNCTIONS

As mentioned, several functions found in vehicle navigation systems rely on digital road maps. These functions are described and the requirements placed on the digital road maps are outlined. These requirements have been described more fully in [2], [3], [4] and [5].

Address Matching

Often called geocoding, address matching is the process of determining a street address given a latitude and longitude, or vice versa. The algorithms in a vehicle navigation system operate in a position domain (co-ordinates), however, users operate in the location domain (real-world objects). Most people know the address of their destination rather than the co-ordinates, so to navigate to an address, the address must be converted to co-ordinates.

Address matching requires street names and address ranges as attributes of the roads in a digital road map. The roads and intersections in a digital road map must be stored using a co-ordinate system that can be related to the co-ordinates output from positioning systems, such as WGS-84 ellipsoidal or UTM mapping plane co-ordinates. Given a latitude and longitude then, the nearest road in the digital road map is found using a shortest distance

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approach. The address ranges are most often stored for links (road segments) between two adjacent nodes (intersections). A given address is found by linear interpolation between the address numbers of two intersections. Note that different address ranges must be stored for each side of the road.

Ideally, an address match should be better than 15m so that the driver can accurately identify the destination. This is difficult to achieve even with a perfect position. Since address numbers are not distributed evenly along a road link, linear interpolation will not be very accurate. There is no simple method of properly modelling the irregular distributions of addresses along a link to overcome this problem short of storing each individual address as a point at its true location. A plausible alternative is to group similar segments together.

Map Matching

The assumption behind map matching is that the vehicle is on a road. When a positioning system gives co-ordinates that are not exactly on a link in the digital road map, the map matching algorithm finds the nearest link and 'snaps' the vehicle onto that link. As the vehicle travels, changes in direction and distance travelled are used to determine the shape of the route travelled; this shape is used to match the road network in the map.

A good map matching algorithm relies on maps with high positional accuracy, generally better than 30m to minimize incorrect road selections. Also, for map matching to be robust, the links in the map must be topologically correct so that they reflect the real world. If a road travelled is not shown in the map, the algorithm will get confused since it will not consider the route a valid path to travel.

Map matching is considered a pseudo positioning system, in that it can return a position based on the co-ordinates of an intersection or shape point (a node in a link that represents a change in the road direction, but not an intersection), and the azimuth of the road being travelled upon. If the positional accuracy of the map is better than the positioning system accuracy, the position obtained by map matching can be used in the position determination algorithm, whether it be a filter or a weighted mean. For this to occur, the map should have a positional accuracy in the order of 15m. In DR, where sensors are used to measure the distance travelled and the vehicle heading to compute relative change in position, map matching is critical to obtaining absolute vehicle positions. Map matching is also used to smooth the noise in positioning sensors or systems such as GPS. This is especially effective under GPS selective availability (SA), the deliberate degrading of the GPS satellite signal by the US DoD.

Best Route Calculation

In the pre-mission phase of vehicle navigation, a user may wish to plan the route and have assistance in determining the optimal route to travel. A digital road map coupled with a best route calculation algorithm can provide an optimal route based on travel time, travel distance or some other specified criterion. This process is often referred to as pathfinding. The Dijkstra [6] and A* [7], [8] algorithms have both been used for best route calculation in vehicle navigation applications. The results of the best route calculation are turn-by-turn driving instructions from the initial location to the destination. Regardless of the algorithm used, best route calculation is a function that requires a high level of map information.

First of all, the route selected must be valid. The route must not consist of any impossible or illegal turns, or travel the wrong way on one-way roads. To prevent this from happening, the digital road map must have the directionality of each road link and the turn restrictions stored. Turn restrictions are considered 'hard' if it is impossible to turn there, such as from a freeway onto a side street where there is no ramp, or 'soft' if it is just illegal to turn there. In addition to constant 'soft' turn restrictions, there are also time variant turn restrictions that must be accounted for. Some turns that are normally legal, are illegal during rush hours. There are also some cases of time variant directionality to be considered when lane-reversals are implemented.

The criteria for a best route may vary depending on the situation. The most common criteria is to determine the shortest route according to time or distance travelled. Other criteria may be to avoid freeways, avoid certain areas of town, or select the most fuel efficient route for trucks. Each of these criteria require different data to be stored in the digital road map. To calculate the route of shortest distance requires only that the road map be of a consistent scale throughout. The route of shortest travel time would require speed limits or average travel times for each link; this criteria is not very effective if real-time data is not available. Routes that avoid freeways require that roads be classified. Routes that avoid certain areas require that these areas be stored in the map. And routes that are the most fuel efficient for trucks must have road grades stored in the map.

Route Guidance

Once a route has been determined by the driver or the best route algorithm, the navigation system must guide the driver along the route. Route guidance can be given pre-mission or real-time. Pre-mission route guidance consists of a printout of door-to-door turn-by-turn driving instructions that include street names, distances, turns, and landmarks.

Table 1. Database feature content requirements for map-related functions:

Function	Database features required
Address matching	links (roads), names of links, nodes (intersections), co-ordinates of nodes, address ranges between nodes
Map matching	links, nodes, co-ordinates of nodes, correct and complete topology
Pathfinding	link classification, connectivity between nodes, driving and turn restrictions, auxiliary attributes
Route guidance	all address matching and pathfinding features

Real-time route guidance is much more useful, and much more demanding in terms of software. As the vehicle travels, each position must be determined and geocoded to a location in the digital road map in real-time. In this manner, the route guidance algorithm knows where the vehicle is in the route and the direction of travel. Real-time kinematic positioning is normally achieved by using a filter with a state vector consisting of positions and velocities. As a turn or manouever approaches, the algorithm must alert the driver, with audible or visual signals, and then indicate when the manouever is to be performed. If all goes well, the vehicle will continue along the planned route. If the driver misses a turn or manouever, the position reported will result in a location that is off of the planned route. If this occurs, the route guidance algorithm must invoke the pathfinding algorithm to compute a new best route to get from the current location to the destination. Route guidance would then resume along the new route. Real-time route guidance relies on positioning, address matching, pathfinding, and digital road maps.

Each of the four functions discussed relies on specific features in the digital road map database. These database features are summarized for the functions in Table 1. If a digital road map supports pathfinding and route guidance, it is said to be navigable.

TYPES OF NAVIGATION SYSTEMS AND SPECIFIC MAPPING NEEDS

As vehicle navigation systems have been documented and analyzed, four main classifications of have arisen: fleet management systems, including dispatch systems; autonomous systems; advisory systems, which receive real-time traffic congestion information; and inventory systems that are used for collecting road-related information [1]. Inventory systems do not have extensive navigation systems for the driver, so they will not be discussed in the context of this paper. The main difference between advisory and autonomous systems is the presence of a communications link for receiving traffic congestion and auxiliary information. Advisory and autonomous systems use digital road maps in much the same manner, so they are discussed together. Portable systems are a subset of autonomous systems that are not fixed or permanently mounted to the vehicle. Many new portable systems have been developed over the past year, so they will be discussed separately. The mapping requirements for each of these types of systems is described below.

Fleet Management

A dispatch or control center with a digital road map lies at the heart of every fleet management system. The vehicles being tracked may or may not have a digital road map on board, depending on the use of the system. Systems that are for tracking stolen vehicles do not need mapping within the vehicle, however emergency vehicle dispatch systems benefit greatly from having route guidance available in the vehicle, which requires an in-vehicle map.

The dispatch or control center is usually used to track all of the fleet vehicles on a map. This requires position reporting via a communications link, and then address matching. In cases where vehicle allocation is concerned, such as shipping or emergency vehicles, allocation algorithms involving multiple vehicles and multiple destinations are required. Although this algorithm will be much more complex than the single vehicle-single destination example, the requirements of the digital road map remain the same. If the vehicles have an on board map and best route calculation and guidance software, the dispatch center may just do the vehicle allocation, send the destinations to the vehicles, and then the individual vehicles would compute how to best get to the destinations. Otherwise, the allocation algorithm would include best route calculation and send the whole route to the vehicle being dispatched.

Autonomous and Advisory

Autonomous navigation systems are for stand alone vehicles and are concerned with aiding the driver in getting to the destination. These systems can be completely autonomous, relying solely on the positioning systems and digital road map on board, or they can involve communications links for obtaining up-to-date traffic congestion and accident information. The latter type of system is classified as an advisory system.

Advisory systems are more effective in avoiding traffic problems because of the real-time information provided. However, this type of system requires an infrastructure of traffic monitoring and reporting. This in turn requires a control center with a digital map for maintaining all of the congestion information, and also a communications infrastructure for the dissemination of the traffic congestion information. Once the vehicle has received the real-time data, the road links affected must be considered in the best route selection algorithm. In order to do this, the time variant traffic data must be integrated with the static digital road map either directly or indirectly. Usually, the affected links are given an impedance value as an attribute that makes it less desirable to use in the best route calculation algorithm.

Portable

A navigation system that is not fixed to the vehicle is considered portable. The simplest example of a portable navigation system is a GPS receiver that has the ability to store and recall way-points. When a way-point is selected as a destination, the bearing and the distance to that way-point is given, and the user must travel in that general direction to get to the destination. These systems are known as way-point systems, and generally cost less than US $1,000. Way-point systems do not require digital road maps, and hence, do not support address or map matching, pathfinding, or turn-by-turn route guidance. Most of the portable systems available today are way-point systems.

There are a few vehicle navigation systems being developed that do provide some of the mapping functions discussed. These systems are typically based on a portable computer and a GPS receiver. Portable navigation systems can be used in a home, office, or place of lodging to do route planning and route calculation. Since portable navigation systems travel with the person, they can be used in any vehicle, whether it be a personal vehicle, a rental car or a company vehicle. This type of personal navigator is akin to the personal data assistant (PDA), and indeed could be combined with a PDA.

MAJOR DIGITAL ROAD MAP SUPPLIERS

There are five mapping suppliers that are predominant in vehicle navigation systems: JDRMA, Etak, NavTech, EGT, and the European data pool. These five data suppliers, their origins, and their database formats will be discussed. The functions supported by each of the five main data suppliers are summarized in Table 2. The use of the data formats and functions found in the 147 systems in the Database are summarized in Table 3.

JDRMA

The Japan Digital Road Map Association (JDRMA) [9] is a consortium of Japanese companies involved in vehicle navigation. Member companies, 82 in all, include Toyota Motor Corporation, Summitomo Electric Industries Ltd., Mazda Motor Corporation, Sanyo Electric Company Ltd., Mitsubishi Electric Corporation, Nissan Motor Co., Pioneer Electronics, Suzuki Motor Co., Sony Corporation, Nippondenso Co., and Toshiba. In 1988, the JDRMA released the first Digital Road Map (DRM) of Japan, which was derived from 1:50,000 and 1:25,000 topographical maps. Each member of the JDRMA has access to the DRM format and data. Typically, a company takes the DRM data and converts it into a proprietary structure for use in their own vehicle navigation system. By June of 1993, more than 150,000 vehicles on the road in Japan had been equipped with a navigation system that uses the DRM or some derivative.

A specialized group called the Navigation Systems Research Association (NSRA) takes the DRM data and puts it onto a CD-ROM in a format known as Naviken. Most of the member companies of the NSRA are also members of the JDRMA. Each of these companies builds navigation systems that use the Naviken CD-ROM directly, so the CDs are interchangeable between systems.

As of March 1993, the two gigabyte DRM covered approximately 1.1 million kilometres of roads in Japan; virtually all of the urban and rural areas have complete coverage. Efforts continue to upgrade the detail of the DRM to the 1:25,000 level. Currently, all cities with a population greater than 100,000 are digitized at this higher level of detail. In addition to increasing the level of detail, the JDRMA maintains the DRM by adding newly constructed and modified roads. Updated versions of the DRM are released at the end of March each year.

The DRM does not contain any turn restriction information. Companies that wanted to add pathfinding to their navigation systems had to modify the DRM database. Often these companies would add the turn restriction data as well as traveller information in the form of digital yellow pages. Recently, legislation was introduced in Japan to prevent vehicle navigation systems from directing traffic away from the congested main roads to the side streets. This has resulted in an increased number of navigation systems that simply plot the vehicle position on the map display.

Etak

Etak Corporation of Menlo Park, California, is a digital map company that focuses on producing and distributing highly accurate digital road maps known as EtakMaps [10]. Etak has been producing digital road maps for ten years, starting with the maps for the Etak Navigator vehicle navigation system in the early eighties.

EtakMaps are available in two formats: MapAccess and MapBase. MapAccess is a proprietary binary format that is optimized for storage space and display speed.

Table 2. Map-related functions supported by major digital road map formats/suppliers

Function	DRM	EtakMap	NavTech	GDF/EDP	EGT
Address matching	Yes	Yes	Yes	Yes	Yes
Map matching	Yes	Yes	Yes	Yes	Yes
Pathfinding	No[1]	No[2]	Yes	Yes	Yes
Route guidance	No[1]	No[2]	Yes	Yes	Yes

1 - The JDRMA does not include restrictions in the DRM data, however, many companies have included these functions by either ignoring restrictions, or adding them to the database themselves.
2 - Etak has produced maps with restrictions that support pathfinding, however, coverage is only available on a custom basis at this time.

MapBase is a non-proprietary ASCII format that can be imported into most commercially available Geographic Information System (GIS) packages for use and modification. The MapAccess data requires less than one-tenth the storage space of MapBase. Although the MapAccess format is proprietary, Etak provides a library of software development tools for Value Added Resellers (VARs) that wish to develop applications using these EtakMaps. Etak VARs include Blaupunkt Werke GmbH. of Germany, Clarion Co. of Japan, and PacTel Teletrac Systems Inc., OCS Technologies, Radio Satellite Integrators Inc., and Trimble Navigation of California.

The coverage for EtakMaps is extensive. All of the United States is covered in one of the versions of EtakMaps. Over 100 major metropolitan areas are covered in EtakMap Version 3 or 3.4, which have an accuracy equivalent to 1:24,000 scale topographic maps. All of the rural areas in between the cities are covered by EtakMap Version Connect, which has an accuracy equivalent to 1:100,000 scale maps. Additionally, Etak has coverage in France, Germany, Japan, Canada, Hong Kong, and The Netherlands. In France, all cities with populations of more than 100,000 plus the major interconnecting roads are covered. In Germany, the same applies, but for cities with populations of more than 50,000. For Japan, Etak has taken the DRM format, which meets Etak's standards of positional accuracy, and converted it into the EtakMap format. Etak has acquired the Statistics Canada Area Master Files (AMF) for use as a starting basemap in Canada. Varying levels of coverage are available for the other countries mentioned.

Version 3, 3.4, and Connect EtakMaps do not support pathfinding. Etak has developed Version 4 EtakMaps which do support pathfinding, however, coverage is only available in a few areas, or on a custom basis.

NavTech

Navigation Technologies Inc. (NavTech) of Sunnyvale, California, is a producer and provider of fully navigable digital road maps known as NavTech maps. NavTech has developed their databases from the beginning to support navigation functions such as map matching, pathfinding, and route guidance [11]. NavTech's strategic partners include Philips International B.V. and European Geographic Technologies B.V. (EGT) of The Netherlands, Motorola Inc. and SEI Information Technology of Chicago, Nippondenso Ltd. and Zexel Corporation of Japan, and the American Automobile Association (AAA). Philips, Motorola, Nippondenso, and Zexel are developing vehicle navigation systems, SEI develops software for creating and using NavTech databases, EGT is a mapping company in Europe, and the AAA provides driver information services.

The first NavTech databases were released in 1991. Currently, NavTech databases are available for about a dozen major US cities including San Francisco, Los Angeles, Chicago, Washington D.C., Orlando, and Miami. NavTech has an aggressive schedule for producing and releasing additional databases over the next two years. Software development tools that access NavTech proprietary maps are available through SEI.

Data sources used in NavTech databases include aerial photos, local base maps, AAA-collected data, and field work [12]. The databases are cross-checked with other data sources such as ZIP + 4 files, state departments of transportation, and other Federal, state, county, and municipal sources. The completed NavTech databases are guaranteed to be 97% complete and accurate both in position (better than 15m) and in the correctness of the restrictions and geometry of the road network.

NavTech maps have been used in the AAA DriverGuide kiosk system that provides users with written door-to-door turn-by-turn driving instructions. Vehicle navigation systems that use NavTech maps are the Zexel NAVMATE (offered on the '94 Oldsmobile 88 LSS) and the Motorola Advanced Traveller Information System (ATIS). Nippondenso has demonstrated their system (normally based on DRM) with NavTech maps.

GDF, EGT, and European data pool

In Europe, the development of digital road maps was driven by the requirements of vehicle navigation systems.

Table 3. Statistics on the number of vehicle navigation systems[1] employing various map formats and functions

	Map Database Suppliers/Formats									
	DRM	EtakMap	NavTech	GDF/EDP	EGT	Other	MM[2]	AM[2]	BRC[2]	RG[2]
Used	12	9	3	4	1	63	35	36	29	30
Optional	0	0	0	0	0	0	0	1	1	1
Proposed	0	0	0	0	0	0	1	0	0	1
Total	12	9	3	4	1	63	36	37	30	32
Percentage of 147 total systems	8%	6%	2%	3%	1%	43%	24%	25%	20%	22%
Percentage of 89 systems with in-vehicle maps	13%	10%	3%	4%	1%	48%	40%	42%	34%	36%

1 - Systems developed between 1976 and 1993.
2 - MM--map matching, AM--address matching, BRC--best route calculation, RG--route guidance

Both Bosch and Philips were developing systems in the mid-eighties, namely the Blaupunkt Travelpilot and the CARIN respectively. These systems were both based on map matching and relied on high quality digital road maps, of which there were none at the time. The Digital Electronic Mapping of European Territory (DEMETER) project was commenced jointly by Philips and Bosch to create common technical specifications for a digital road database for vehicle navigation purposes. The result was the Geographic Data File (GDF) Version 1.0, released in October 1988 [13].

The Dedicated Road Infrastructure for Vehicle Safety in Europe (DRIVE), funded by the EC, formed the Task Force European Digital Road Map (TFEDRM) to oversee the subsequent development of GDF. At this phase of development, Daimler-Benz GmbH. of Germany, Renault of France, Tele Atlas International B.V. of The Netherlands, and Intergraph Corp. of Alabama joined the consortium. Benz and Renault are car manufacturers, Tele Atlas is a map producer, and Intergraph is a major GIS vendor. The work by TFEDRM resulted in GDF Version 2.0, which was released in January 1992. Since then, GDF has been updated to Version 2.1.

Since GDF maps can contain extensive information, vehicle navigation system manufacturers generally use only a subset of the available data for their system. The manufacturer takes the required data and puts it into a proprietary data format that has been optimized for use in their system. Rather than being a format for direct end use, GDF takes the role of being a data pool and exchange format. Bosch, Tele Atlas, and Etak have in fact signed a co-operative agreement to create a pool of digital road map data for all of Europe; this project is known as the European data pool [14]. EGT has declined to join the data pool, opting to map all of Europe on their own [15]. This rift is likely due to the fact that EGT's partner NavTech and Bosch's partner Etak are competitors in the U.S..

EGT maps will cover all of Germany and France by the end of 1994, along with parts of Italy. Austria, Switzerland, and Benelux are the next priorities, followed by the U.K.. Scandinavia and eastern Europe may eventually be mapped as well. EGT has licensed NavTech database management technology for mapping, and can supply maps in the GDF, NavTech and DRM formats. EGT supplies the databases for the Philips CARIN system, and has the potential to supply data for any system based on NavTech, DRM or GDF derived maps.

The European data pool's objective is to complete a digital road map of all of Europe within two years. A country is considered complete if a minimum 50% of the population is covered by the map. Bosch has primary responsibility for Germany; Etak has been allocated the U.K., Switzerland, and Austria; and Tele Atlas will cover Benelux and Italy. The data pool is looking for other partners to map France, Spain, Portugal, and the Scandinavian countries. The Blaupunkt Travelpilot is the first system on the market that will use the data pool maps. The data pool uses GDF as their storage and exchange format, so the Travelpilot and the other systems that used GDF are shown under the GDF/EDP heading in Table 3.

Both the data pool and EGT have focused on the vehicle navigation and GIS markets for their maps. Also, both map suppliers are including high-level route guidance support features, such as turn restrictions and one-way streets, in their maps.

Others

Out of the 147 systems in the IVHS Navigation Systems Database™, there are 89 that have in-vehicle mapping functions. The map suppliers discussed above account for just 26 of the 89 systems, so there are 63 systems that use

Table 4. Statistics on the use of various map formats and functions in selected regions of the world

	Map Database Suppliers/Formats									
	DRM	**EtakMap**	**NavTech**	**EDP/GDF**	**EGT**	**Other**	**MM[2]**	**AM[2]**	**BRC[2]**	**RG[2]**
North America	0	6	3	0	0	28	8	8	4	5
Out of 36[1]	0%	17%	8%	0%	0%	78%	22%	22%	11%	14%
Japan	12	1	0	0	0	16	17	14	13	13
Out of 29[1]	41%	3%	0%	0%	0%	55%	59%	48%	45%	45%
Europe	0	2	0	4	1	19	10	15	13	13
Out of 24[1]	0%	8%	0%	17%	4%	79%	42%	63%	54%	54%
Total	12	9	3	4	1	63	35	37	30	31
Out of 89[1]	13%	10%	3%	4%	1%	71%	39%	42%	34%	35%

1 - Systems developed between 1976 and 1993 that have vehicle maps, excluding proposed functions. May not add up to 100% due to some systems using multiple formats.
2 - MM--map matching, AM--address matching, BRC--best route calculation, RG--route guidance

some other type of map. Some maps are developed by the system producers, while others are acquired from map suppliers such as Geographic Data Technology (GDT) of New Hampshire, DeLorme Mapping of Maine, MapInfo of New York, GeoSystems of Pennsylvania, Roadnet Technologies Inc. of Maryland, and Thomas Bros. Maps of California.

There are 68 fleet management systems identified in the Database. By definition, the dispatch center of each fleet management systems must have a map. The maps in the dispatch centers are usually custom made for the user based on the application and region of operation. The maps can be derived from various sources and suppliers, or they can be obtained from existing GIS installations that show the road network.

Map Use Analysis

As shown in Table 4, twelve of 89 systems use DRM derived maps in the vehicle, nine use EtakMaps, three use NavTech maps, four use GDF derived maps, one uses maps supplied by EGT, and 63 use maps from some other source. Of those same 89 systems, 35 employ map matching, 37 perform address matching, 30 compute best routes, and 31 offer real-time route guidance. Since the route guidance function requires address matching and best route calculation, all three of these functions are usually found together on a system. Map matching is not a pre-requisite to any of the other systems, but it is usually employed along with the other three functions.

Most fleet management systems are primarily for position reporting and monitoring rather than allocation, so the maps used do not require a high level of intelligence. In some cases, simple rastor maps are used as the backdrop for vehicle tracking. There are 29 of the 68 fleet management systems that have maps in the vehicle in addition to the dispatch center map, but none of these systems provide pathfinding nor route guidance based on the in-vehicle map.

There are 39 autonomous systems, of which nine are considered portable. Of the 30 remaining autonomous systems, 28 have in-vehicle maps. Just twelve of the 28 map-based autonomous systems use map matching and only five have both the pathfinding and route guidance functions.

Out of the 26 advisory systems, 24 have in-vehicle maps. All but one of the 24 map-based advisory systems offer pathfinding and route guidance, while 19 of the 24 use map matching. It is apparent that the advisory systems have been designed to take advantage of the availability of the real-time traffic congestion information. On the one system that does not offer best route calculation, the congested areas are marked on the map display and the user is left to determine the best route visually.

Finally, of the nine portable autonomous systems, only three use maps. The other six are simple way-point GPS receivers with no mapping functions. None of the three systems with maps use map matching nor offer best route calculation and route guidance. The maps are simply used to display the vehicle's position.

Future Trends

There are two phases of mapping that become apparent from the preceding discussion. The first phase focused on producing digital road maps to support map and address matching. Nearly all of the U.S., Europe, and Japan have been mapped at this level by the JDRMA, Etak, Bosch, and others. The second phase is to produce navigable digital road maps that support pathfinding and route guidance. NavTech is well underway with this phase in the U.S., while Etak is poised to upgrade their existing maps when as the market matures. EGT and the European data pool have both set the objective to complete a fully navigable European digital road map within two years. As navigable digital road maps are completed for the U.S. and Europe, the market for pathfinding vehicle navigation systems should flourish. As more vehicles are equipped with pathfinding and route guidance systems, the price for the navigable digital road maps should decrease due to the strong competition in both of these markets.

The situation in Japan is slightly different due to the limitations in traffic re-direction. In the past year nearly a dozen new Japanese systems have been introduced that are simple map display systems. These systems typically have a GPS receiver and an output screen that plots the vehicle's position on the digital road map. The user is left to determine the best route visually and follow that course. Only a few of these newly developed systems combine dead reckoning sensors with GPS. Systems based solely on GPS and maps are susceptible to signal blockage in urban canyons and tree covered areas. This is a severe limitation to any vehicle navigation system for use in a large metropolitan area.

Another trend that is beginning to manifest itself is the move by system manufacturers to provide support for digital road maps from multiple sources. The CARIN can use data from GDF, DRM or NavTech maps, the Travelpilot uses EtakMaps and GDF maps, and the Nippondenso system can use DRM or NavTech maps. Strategic alliances are the key to providing support for other map formats, which opens the doors to the other major markets. It is much more cost effective to develop data filters or software to support existing map formats rather than re-map the other regions of the world.

Finally, the development of portable navigation systems that are map-based should increase with the availability of less expensive, more intelligent digital road maps. It shouldn't be too long before we see a map-based personal navigation assistant (PNA) that supports pathfinding and route guidance as well as the business card directory and daily planner functions found in typical PDAs.

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