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ASSESSMENT OF POSITIONING AND NAVIGATION TECHNOLOGIES FOR INTELLIGENT TRANSPORTATION SYSTEMS

Prepared for

TRANSPORT CANADA
R & D Directorate
Safety and Security Group
26-B, Tower C
330 Sparks Street
Ottawa, Ontario, K1A 0N5
Canada

AND

INDUSTRY CANADA, Aerospace and Defense Branch
235 Queen Street
Room 604-C
Ottawa, Ontario, K1A 0H5
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by

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15. Abstract

Terrestrial and satellite positioning and navigation technologies are documented. Also, systems-products being developed worldwide, are described. Conclusions and recommendations are listed, along with a strategy for a Canadian participation in the area.

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15. Résumé

Les technologies terrestes et satellites de positionnement et de navigation sont documentées. De plus, les systèmes/produits dèveloppés mondialement sont dècrit. Conclusions et recommendations sont listées avec une stragédie pour une participation canadienne dans ce domaine

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DISCLAIMER

The contents of this report reflect the views of the authors and not necessarily the official views or opinions of the Research and Development Directorate of Transport Canada, or the Aerospace and Defense Branch of Industry Canada.

NOTE

This report is one of the following series of reports produced under the joint Industry Canada/Transport Canada study into: "Strategy for the Development of an ITS Industrial Base in Canada". The reports to be produced in this series include:

1. Assessment of Communications Needs and Standard for ITS by: A. Waltho Engineering
2. Assessment of Geographic Information Systems (GIS) Technologies for ITS by: Intergraph Canada
3. Assessment of Positioning and Navigation Technologies for ITS by: IDI Ltd.
4. Assessment of Sensor Technologies for ITS by: IBI Group
5. Assessment of Display Technologies for ITS by: IBI Group
6. Assessment of System Integration and Intelligent Software for ITS by: IBI Group
7. Assessment of FM Sub-Carrier Broadcast Technology Applications for ITS by: Lapp-Hancock Associates Ltd. and L-P Tardif & Associates (Sponsored by: Transport Canada, Heritage Canada, Canadian Association of Broadcasters and Canadian Broadcasting Corporation.)
8. Review of the Canadian Role in ITS Standards Development by: E.R. Case and Associates (Produced for: Transport Development Centre-TDC, of Transport Canada.)
9. Benefit-Cost Assessment of ITS Implementation in Canada by: IBI Group, SNC-Lavalin, Parviainen & Associated, A. Waltho Engineering, Richard Ravergiu (Produced for: Transportation Development Centre - TDC of Transport Canada)
10. Assessment of the Demand, Markets and Commercial Development of Global ITS Industry by: SRI Consulting
11. Strategy for the Development of an ITS Industrial Base in Canada by: Delphi Systems Inc.

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EXECUTIVE SUMMARY

The following executive summary is structured around the conclusions and recommendations made for the seven parts of the report in Chapter 26. The chief issues have been selected and are given immediately below.

ITS AND NAVIGATION RELATED TECHNOLOGIES

Intelligent Transportation Systems (ITS) is the new and emerging multi-billion dollar market over the next decade. The opportunities for Canadian companies are large for a combined Canadian and export market scenario.

The following general summary and conclusions are made vis-à-vis the role for positioning and navigation related technologies in Intelligent Transportation Systems:

1. Positioning and navigation is regarded as one of the key enabling technologies, along with communications, computers and mobile information databases, in the development of ITS products.
2. Canadian activities in positioning and navigation, as well as mapping, have always been ranked at an international level and thus there is a solid foundation upon which to develop an ITS related industry utilizing this expertise.
3. Positioning and navigation hardware components are chiefly being manufactured outside of Canada by large international conglomerates; Canadian firms are largely performing system integration and software development.

The following general recommendations are made vis-à-vis navigation and ITS:

1. Industry Canada and Transport Canada regard positioning and navigation (including digital map databases) as strategic to the economic development of Canadian Industry and initiate a focused program in this strategic domain.
2. Industry Canada and other Government Agencies support Canadian firms to create strategic alliances with local and international firms for the express purpose of developing ITS Navigation Systems related products for the domestic and international markets.

SATELLITE RADIO FREQUENCY (SRF) BASED POSITIONING SYSTEMS

The following main summary and conclusion items form the basis for recommendations dealing with satellite-based positioning systems:

1. Canada has numerous GPS product developers and system integrators who have and are developing a host of GPS related applications and are poised to introduce their products in the about to take off GPS market (see list in Chapter 3).
2. The two impediments to international exportation of Canadian GPS technology is the slowness of acceptance in Canada of this technology and the apparent inability of Canadian concerns to purchase it.

3. LEO systems are being launched as infrastructures with alliances made with solution providers - who will resell time and build applications for end users. Canadian firms have the possibility to be strategically positioned (via Teleglobe Canada and Orbcomm Canada) to be system integrators and solution providers of LEO-based positioning and communications systems worldwide.
4. Canadian firms have an entry into global personal communications technology via Northern Telecom and Aerospace Ltd. who are participants in Odyssey.

Recommendations emanating from the above conclusions regarding GPS, GEOs, LEOs, MEOs and HEOs are the following:

1. Given Canada's prowess in GPS in both the governmental and corporate sectors, Industry Canada should foster innovative programs for getting this space-based technology into products for Canadian consumption and then for the export market. The specific sectors to be targeted are high-lighted in the GPS conclusions in the body of the report.
2. Given Canada's leadership in GEOs via the MSAT of Telesat and TMI, coupled with the wholesaler network in place (Bell Mobility in Montreal, Glentel in Vancouver, and InfoSat in Burnaby), Industry Canada should work with the private sector in creating products that utilize GEOs.
3. Given Canada's leadership in LEOs via Orbcomm Canada and Teleglobe Canada, Industry Canada should work with the private sector in creating products that utilize LEOs. These are exportable, because these same LEOs orbit the entire Earth and are used by some 75 other jurisdictions (wholesalers) around the world.

TERRESTRIAL RADIO FREQUENCY (TRF) BASED POSITIONING SYSTEMS

The following main summary and conclusion items form the basis for recommendations dealing with terrestrial-based positioning systems:

1. Terrestrial paging-based communications and positioning systems are numerous and present a huge opportunity for Canadian firms, however, the competition is high.
2. Canada has a promising development of cellular positioning in Cell-loc, Calgary. There soon may be a ruling in the United States by the FCC, (911 cellular communications), that may require the position-location of the mobile caller to be known, i.e., its coordinates computed.
3. Given the soon to be available digital maps in Canada, the above mentioned new positioning technologies have all the necessary components - positioning, communications (uses a standard cellular phone or communications modem) and maps for product development.

Recommendations emanating from the above conclusions regarding terrestrial RF based positioning systems are as follows:

1. Industry Canada should support the relevant firms mentioned immediately above in exploring ways in which to integrate mobile communication of data and positioning (locating) information into future paging related products.

2. Industry Canada, in concert with the Canadian telecommunication companies, and the developers of positioning by cellular, (Cel-loc, Calgary) foster the development of applications of this core technology to an array of products for end users.

DIGITAL MAP DATABASES IN SUPPORT OF TRACKING AND NAVIGATION

The following main summary and conclusion items form the basis for recommendations dealing with digital map databases:

1. Locations relative to physical features are given by maps and thus are an indispensable component of ITS navigation systems along with the coordinates from positioning sensors.
2. The development of a seamless database of the Canadian road network is about to take shape as several governmental organizations and firms are poised to take advantage of the opportunity. The main federal agencies are Geomatics Canada, Canada Post and Statistics Canada. The provinces which has shown leadership are Ontario, British Columbia, Alberta and Saskatchewan.
3. Mapping firms poised to supply seamless Canadian road network databases are Etak (owned by Sony) and NavTech (partially owned by AAA and Phillips)- both have established offices in Toronto in 1996.
4. The first opportunity for Canadian firms is to participate as sub-contractors in the development and preparation of the basic road network data for the major data holders listed immediately above.
5. The second opportunity for Canadian firms is to make strategic alliances with one of the two main suppliers - Etak or NavTech, and use their data to develop application specific products and deal with end users.

The main recommendation related to the mapping area is the following:

1. Industry Canada declare that the soon to be created databases of the Canadian Single Line Road Network be regarded as a strategic data source upon which to develop ITS related products. IC and related agencies should foster the development of products by Canadian firms working in strategic alliances with international firms with the aim to launch their products in Canada but gain growth through exports.

SENSORS FOR RELATIVE POSITION DETERMINATION

The following main summary and conclusion items form the basis for recommendations dealing with dead reckoning relative positioning sensors:

1. Rate gyros require an initial reference heading and are extremely useful in ITS navigation systems for determining the change in heading of a vehicle.
2. Fiber Optic Gyros (FOG), with a decrease in cost, offer the greatest potential for future heading sensors. Vibration gyros are currently the lowest in cost and are being used in a number of automobile makes and models. Low cost sensors will most likely be manufactured in Japan due to their high level of electronic manufacturing capabilities. Delco and Rockwell

are manufacturing gyros aimed at the automotive industry in the US. Bosch and British Aerospace and producing low cost gyros in Europe.

3. Japanese technology is apt to dominate low cost AVL systems in the future. They have had a much wider acceptance in Japan and they are much further ahead in terms of commercialization. Canadian companies will likely not be involved with the manufacturing of gyros, but may incorporate them into custom navigation systems.
4. Many commercial navigation applications will be met using GPS alone, but significant number will need integration with dead reckoning or with inertial units.
5. For inertial units to be accepted in ITS circles, the target cost per axis for the automotive industry will have to be several dollars each; so that for a pair of two-axis units, two for rate gyros and two for accelerometers, the total cost will be about $25 in large quantities. Low cost inertial systems could be used to supplement GPS for AVL applications if the cost becomes low enough.

The following recommendations are made vis-à-vis relative positioning sensors:

1. As dead reckoning sensors are not manufactured in Canada, strategic alliances need to be made with international developers of this technology to assist system integrators, and Industry Canada should support Canadian firms in establishing these relationships.
2. Industry Canada is encouraged to sponsor market studies for determining the use of the up coming, low cost inertial navigation units(INUs) and how they can be integrated with GPS to develop products for new markets.

ITS NAVIGATION SYSTEMS BEING BUILT WORLDWIDE

The following main summary and conclusion items form the basis for recommendations dealing with ITS Navigation systems being built worldwide:

1. Japan is the leader in the development of Autonomous type systems with over 20 systems, while the USA is second with under 10 systems developed. Canada's position is weak in the development of such systems, however, the opportunity exits for Canadian firms to make alliances with Japanese and US firms to implement these systems now that the Canadian road network database will be available sometime in 1997-8 time frame.
2. Again Japan leads the world in the development of Advisory type systems with over 25, Europe follows with about ten and the USA trails with about 5. Canadian firms need to make alliances with companies from these three areas for both domestics implementation and then exportation to other parts of the world.
3. United States leads the world in the development of Fleet Management type systems. Europe is second and Canadian firms have been reasonably active in this domain. Japan is gearing up for entrance into this type of system via their autonomous and advisory type systems in which they have been very strong.

4. The Canadian opportunity is in the development and implementation of Fleet Management types of systems coupled with innovative use of new communications systems like GEOs and LEOs, cellular and two way paging.
5. The large United States showing in the category of Inventory type systems is due to GPS manufacturers producing hand held GPS-GIS units for coordinate tagging information. Canada has a reasonable showing which indicates that this is an area in which Canadian firms can compete domestically; expanding these products to the international market is where the growth will be.
6. United States firms dominate the development of the portable systems. Canadian firms should forge alliances with US firms and write software for specialized applications. Integrating GPS and GIS into palmtop and laptop computers is another niche for Canadian firms.
7. After the USA and Japan, Canada along with Germany and the UK are prominent developers of these types of ITS Navigation systems.

Recommendations for ITS Navigation systems are the following:

1. Industry Canada support market research for the purpose of developing of new systems for markets not covered by existing ITS navigation systems. As well, market research should be performed with an eye to match existing ITS Navigation systems to ready made markets in Canada and internationally.
2. Industry Canada declare ITS navigation systems (about 200 active products worldwide) as valuable ingredients for solving ITS related problems and support their introduction into ITS in Canada and for export.

Industry Canada foster the dissemination of information on ITS Navigation systems being built worldwide to Canadian firms so that they are aware of opportunities and competition.

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Part I: Introduction to Intelligent Transportation Systems and Navigation Related Technologies

1. INTRODUCTION

1.1. Objectives

The objectives of this study are the following:

- assess positioning-navigation technologies and systems used around the world;
- identify producers of these technologies in Canada and in other countries;
- perform an information synthesis;
- prepare a report in hard copy ; and
- present the report and study findings to Industry Canada, Transport Canada, and others interested in ITS.

1.2. Focus of Study and Report

The research focuses on analyzing the technical specifications and marketplace applications of positioning and navigation technologies such as GPS receivers, dead reckoning sensors, and inertial devices. The study analyses how each sensor computes a position and what applications the device is best suited for. Furthermore, IDI Ltd. will collect data on how each device is being used in industry and by whom the devices are being used. Although this last task is difficult, it should be possible to succeed to the extent that the data supports and molds the analysis of what applications a certain technology is suited for.

In addition to GPS, DGPS, dead reckoning, and inertial technology, several other techniques are used to determine position, for example, terrestrial RF methods such as cellular, AM/FM, paging and infrared beacons. Furthermore, the emerging mobile satellite constellations such as Geostationary Earth Orbit (GEO's), Medium Earth Orbit (MEO's), Low Earth Orbit (LEO's), and Highly Eccentric Orbit (HEO's) satellite systems provide competition to GPS for applications that do not require 30 meter or better accuracy. Although this proposed study will focus on GPS, dead reckoning, and inertial techniques, it will also document these other positioning and navigation methods and their accompanying devices. Map databases of the road network are also included as they related directly to tracking and navigation.

Specifically, the report is structured to contain the following elements:

- description of the technologies and methods for positioning and navigation;
- assessment of technology trends around the world;
- discussion of issues related to standards and protocols;
- the need for North American cooperation in order to achieve compatibility and inter-operability of systems; and
- recommendations for improving Canada's competitiveness in the global market place and opportunities for penetration in the international arena.

1.3. REPORT OUTLINE

The report is organized into seven parts with Part I devoted to an introduction while Part VII contains the conclusions and recommendations. The following is a list of the intermediate parts of the report with a brief description of the researched positioning and navigation devices and technologies.

1.3.1. Part II: Satellite Radio Frequency (SRF) Based Positioning Systems

1.3.1.1. *Global Positioning System (GPS)*

GPS is a satellite positioning system developed by the US Department of Defense. The system is available to civilian users under certain accuracy and reliability constraints. In general, signals received from four satellites by the on-board receiver are enough to determine the vehicle position to about 30 meters. Differential GPS (DGPS), which will also be studied, can improve this accuracy to between one and ten meters.

1.3.1.2. *Radio Determination Satellite Service (RDSS)*

These are non-GPS based satellite tracking systems having a symbiotic relationship between positioning and communications; the satellites are used for both positioning and communication. There are four basic varieties of RDSS; namely Geostationary Earth Orbit satellites (GEO's), Medium Earth Orbit (MEO's), Low Earth Orbit (LEO's), and Highly Eccentric Orbit (HEO's) satellites. GEO positioning is available right now, whereas MEO's, LEO's, and HEO's are emerging systems, some of which will possess positioning capability.

1.3.2. Part III: Terrestrial Radio Frequency (TRF)

Systems that use TRF technique receive radio frequency signals from a number of towers scattered throughout the area of operation of the system. The time-difference of arrival of the incoming signals from several TRF towers determine the exact position of the vehicle, which can then be reported to the driver or control center via a communications link. Examples of such radio-frequency-based techniques include Omega, Loran C, and Decca. The more recent systems have utilized paging, cellular and AM/FM radio signals as alternative methods of obtaining the coordinates of a vehicle. Cellular based positioning is the exiting new frontier with several new systems being worked upon.

1.3.3. Part IV: Digital Map Databases in Support of Tracking and Navigation

1.3.3.1. *Map Databases*

Digital map databases are used to define the location of a vehicle in the real world via plotting the mathematical coordinates determined by say GPS on the outline of the street network. Extensive databases have been developed first in Japan and now in Europe and the USA. Canada has made a good start but availability, cost and jurisdictional issues have impeded the development of systems around these map databases. Activities in these regions are addressed and compared in this part of the report.

A map supplier in the USA has estimated that it takes an original $700 million investment to cover the entire US with navigable grade of map and a $300 million annual budget to maintain it.

1.3.3.2. *Map Matching (MM)*

This is a technique used to determine the location of a vehicle on a map with respect to street names, addresses and geometry of the road network. The vehicle's path is correlated with the graph of the road network, and the coordinates of identifiable features such as intersections are used to position the vehicle. This and other mapping related techniques are discussed in the report.

1.3.4. Part V: Sensors for Relative Position Determination

1.3.4.1. *Dead Reckoning (DR)*

DR includes the compass, rate gyro, odometer, and speedometer. These devices determine the distance traveled, speed, heading and heading change of a moving vehicle. The accuracy of such sensors is fairly high over short periods of time, but they require assistance by absolute positioning devices (e.g., GPS and map matching) over longer periods to control error accumulation.

1.3.4.2. *Inertial Navigation System (INS)*

INS is comprised of three accelerometers and three gyroscopes. Inertial systems are capable of data capture at very high rates with very high levels of relative accuracy. Nevertheless, the absolute accuracy decreases over time so aiding sensors such as GPS are needed. Once thought to be too expensive for everyday navigation, INS sensors are now being developed by former military contractors for the civilian automotive market and thus for ITS applications.

1.3.5. Part VI: ITS Navigation Systems Being Built Worldwide

There are at least 300 individual ITS navigation system products being developed worldwide by over 200 companies. For example, in Japan there are about 60 systems built to date and sales during the last decade have reached about 1.3 million at prices ranging initially from $10K for each unit to the present $1.5K per unit. These systems are built around an interesting selection of positioning devices and map assemblies. The five basic types of systems are described in this part of the report along with the country of origin, references to the companies who have produced these systems.

2. POSITIONING, NAVIGATION AND INTELLIGENT TRANSPORTATION SYSTEMS

2.1. Intelligent Transportation Systems (ITS)

Intelligent Transportation Systems (ITS) supersedes the old term Intelligent Vehicle-Highway Systems (IVHS). It is meant to encompass all modes of transportation in a systems sense, by people on foot, in buses and those in vehicles. ITS related systems are understood to be intelligent and operate in a automatic, efficient and economical manner.

These intelligent mobile information systems have the following three market segments:

- Advanced Traveler Information Services (ATIS);
- Advanced Vehicle Control Systems (AVCS), and
- Commercial Vehicle Operations (CVO).

ATIS systems are meant for all travelers, whether they are on foot, in buses or driving their own vehicles. They may even be traveling in a combination mode, namely drive-park-commute. Traffic, weather and parking information are integral components of ATIS systems. Even the digital yellow pages become integrated with these mobile information systems.

AVCS are systems of the future, i.e., the beginning of the next century will be the dawn of convoys of vehicles taken under the control of a command center where well-tuned and appropriately equipped vehicles will travel swiftly from one transportation node to another. They will exit these controlled corridors and then travel along their own local routes in a customary fashion. The recent anti-collision type systems are part of this group.

The CVO sector is the fasted growing as there are large savings to be made. One ITS navigation system (1 of 300) alone has sold into 13,000 trucks and orders are on the books for 30,000 more sales over the next five years. AVI (Automatic Vehicle Identification) is an integral part of these systems.

All three classes of ITS systems mentioned above must have some sort of positioning, communications and mapping associated with them in order for them to function. In the past, communications devices were part of these systems, but the question: where is the vehicle? could not be answered. Now, with GPS and a multitude of other positioning devices, it is possible to pinpoint the coordinates of a vehicle and determine its location with the aid of a map onboard the vehicle or at the dispatch center.

Hence, it is clear that positioning, navigation and map databases are important components of ITS systems-the market for which is growing rapidly.

2.2. ITS Markets

In 1992 IVHS America (presently known as the Intelligent Transportation Society of America) released the "Strategic Plan for Intelligent Vehicle-Highway Systems in the United States".

Charged by the Department of Transportation to develop a guide to development and deployment of ITS in the USA, ITS America set out to enlist the entire ITS community to aid in the completion of a realistic vision document. With the assistance of industry, the strategic plan forecast the markets for ITS products to the year 2012.

The consumer market was differentiated from the public 'market' and the private company market. The public market included government expenditures on ITS R&D. The private company market involved private sector development expenditures. The consumer market was divided into three segments; Advanced Traveler Information Services (ATIS), Advanced Vehicle Control Systems (AVCS), and Commercial Vehicle Operations (CVO).

Analysts estimated the cumulative expenditures on ITS in the U.S. would reach $210 Billion (in 1991 U.S. dollars) by the year 2012. It was estimated consumer spending would represent the majority of the market totaling some $170 Billion. ATIS products were expected to claim the lion share, capturing 60% of the consumer dollar.

Figure 2-1 illustrates the anticipated annual consumer spending on ITS products as envisioned by the ITS Strategic Plan.

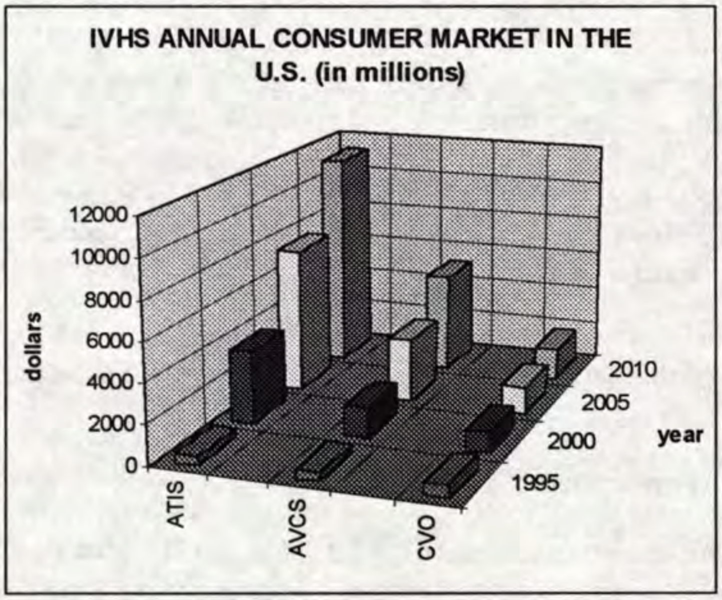

Figure 2-1: 1992 Estimates by ITS America

2.2.1. Wide Range Among Recent Forecasts

In the four years that have elapsed since the release of the ITS Strategic Plan, market information has proven to be fragmented. The lack of market forecast consensus among major industry participants in the ITS marketplace is indicative of an emerging market. As late as the end of 1995, the executive director of the Intelligent Transportation Society of America, Mr. James Costantino, stated that the agency still used consumer market forecasts derived from the 1992 Strategic Plan [Albert, 1996].

In contrast, major industry players like Lockheed Martin Corporation believe ITS markets to be potentially 3 times as large. In June 1995, an executive with Lockheed Martin publicly stated that the company expected that $650 billion will be invested in the intelligent transportation marketplace throughout North America over the next 20 years [Newswire, 1995a].

Contributors to the 1992 ITS Strategic Plan like the Battelle Memorial Institute have subsequently increased their market forecasts. In an interview with PR Newswire in December 1995, Battelle officials estimated the ITS market to be 70% higher than earlier predicted [Newswire, 1995b].

The possibility that the U.S. government would not maintain funding for ITS development was not considered in the market forecasts of 1992. Recent budget controversies in Congress have illustrated the fragile nature of government funding sponsorship of future ITS initiatives. In a recent interview the executive director of the Intelligent Transportation Society of America, or ITS America, commented that the "emphasis on private financing of "intelligent transportation" systems is growing under the Republican controlled Congress... I don't see a major federal program on the horizon... The federal role is important because by financing some traffic centers and research, the government sends a "message" to private industry that "we care about this program." Congress's seven year plan to balance the budget would nearly eliminate ITS spending, by contrast." [Karr,1996].

The impact to consumer markets in the U.S. of decreased government funding of ITS R&D is unknown. It is probable consumer markets would require longer to reach industry forecasts, as consistent government financial support tends to facilitate increased willingness among the private sector to invest in R&D which helps drive the growth of markets. Hopefully the new Market Research Task Force within ITS America will undertake to consider the American market implications of disruptions in federal financing.

At the time of writing this report, Stanford Research International, Menlo Park, CA were preparing an estimate of the size of the ITS market in Canada. It will be interesting to find out whether the "one tenth of the USA" factor holds in this context

2.2.2. Extensive 1995 Forecasts

Perhaps the most extensive market analysis of ITS related activity since the 1992 Strategic Plan was carried out recently on behalf of the American National Academy of Public Administration (NAPA) and National Research Council (NRC). Released in May 1995, their report culminated a joint study of the future of the Global Positioning System. Mandated by the National Defense Authorization Act for Fiscal Year 1994, the study addressed the future management and funding of the GPS program. During the study, NAPA surveyed 59 companies operating in the GPS related hardware and services industry. The survey results provide a recent indicator for ITS market forecasts.

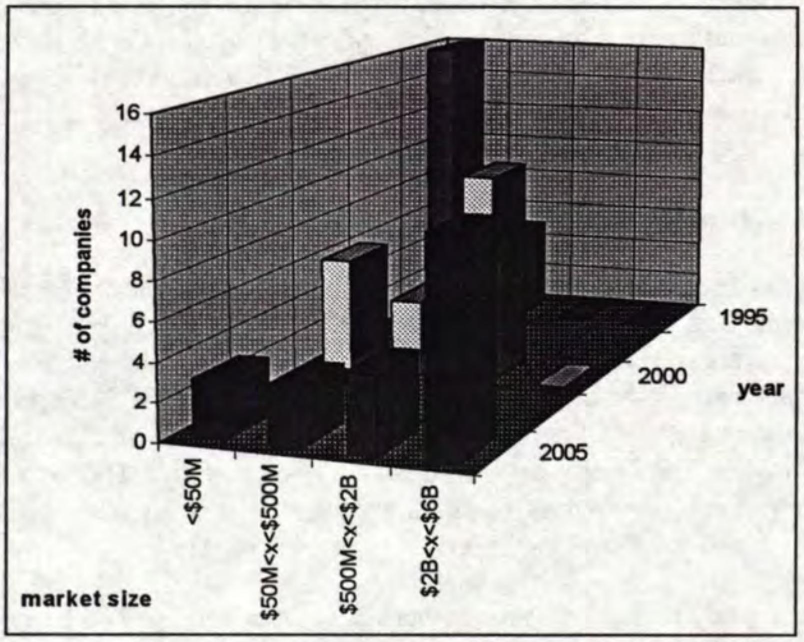

Figure 2-2: US Market for Land Transportation Products Using GPS

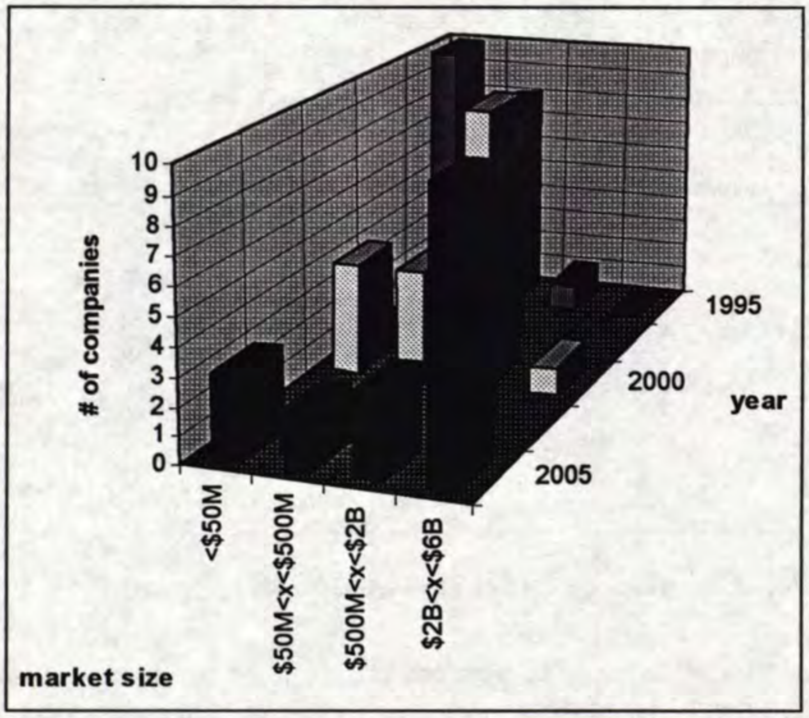

Figure 2-3: Market (Non-U.S.) for Land Transportation Products Using GPS

Survey respondents categorized themselves by the user community they serve, which makes direct comparison of survey results to the 1992 Strategic Plan somewhat obtuse, but useful nonetheless. Of particular interest were those who serve the 'land transportation' market segment. Twentyfour of the 59 respondents indicated land transportation as their primary market segment. The following two figures summarize the market size estimates for the GPS related products and services sector within the land transportation market for the U.S. market (Figure 2-2)and the rest of the globe (Figure 2-3). The 24 respondents were asked to estimate the annual size of their primary market segment given 5 ranges between $0 and $6 billion U.S.

2.2.3. ITS Market Indicators

The size similarities between American and international markets are clear. However the size of individual niche markets (e.g., in vehicle navigation systems) is not indicated by the NAPA survey. There are industry analysts who offer subjective estimates on certain niche areas. Robert French of R. L. French & Associates suggested in the October 1995 issue of GPS World that cumulative U.S. sales of automobile navigation systems will, by 2005, catch those of Japan. French predicts that by 2005, 3 - 5 million units per year will be sold in each country. By 2010 to 2015 French predicts market penetration of automobile navigation systems will reach 50% in both countries, as well as in Europe [Krakiwsky and French, 1995].

The NAPA/NRC joint study of 1995 presents other indicators of future ITS markets. In a study by the consulting firm Booz, Allen, & Hamilton the projected market size of the land transportation segment was considerably larger than those of either aircraft or marine. The consulting report presents the North American cumulative market for GPS based products between the years 1994 to 2003. Figure 2-4 summarizes the market size in units sold for the land, air, and marine segments.

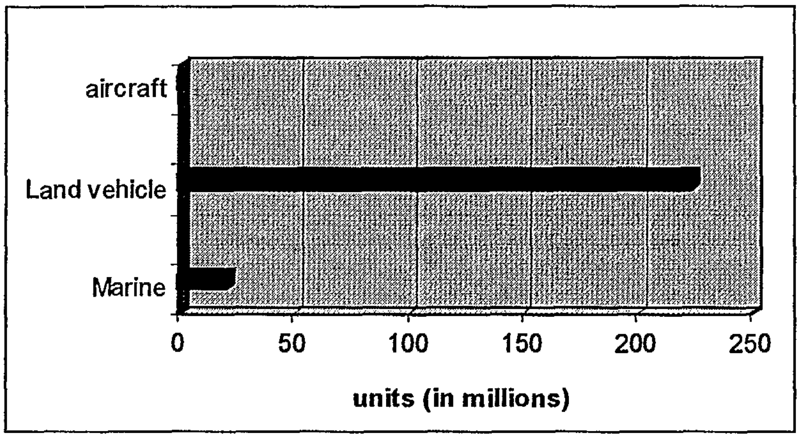

Figure 2-4: Cumulative Market 1994-2003 for GPS Based Products

In summary, there exists a wide range of opinions concerning the future size of ITS markets. Restricting any market research is the reality that industry players and government agencies place different perspectives on the marketplace: industry tends to migrate to end user applications, and government to the categories enshrined in the 1992 Strategic Plan. By all accounts the market potential of intelligent transportation technologies is significant. Unfortunately, analysts utilizing secondary research are currently limited to interpreting indicators like those from the NAPA/NRC joint study of 1995. There is relief in sight, however, as according to the December 1995 issue of

ITS America News, the Coordinating Council has accepted the new Market Research Task Force's proposed charter and action plan. Their report is eagerly awaited, and should prove to be a seminal work.

Insofar as the ITS market in Canada is concerned, we await the results of the SRI study. Nevertheless, exportation is vital to Canada, hence the importance of knowing the US and global market sizes cited above.

2.3. References

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Part II: Satellite Radio Frequency (RF) Based Positioning Systems

3. GLOBAL SATELLITE POSITIONING SYSTEM (GPS)

3.1. System Description

The Global Positioning System (GPS) is the first truly global utility offering positioning and navigation information to land, marine and airborne users anywhere on Earth, 24 hours per day and in most weather conditions. It is free of charge to all users, but is owned and operated by the United States Department of Defense (DOD) at an initial cost of $15 Billion dollars to the US tax payer. Nevertheless, millions of civilian users worldwide use this new utility as the 24 satellites enveloping the Earth at an altitude of 20,000 km send signals downwards at 1.6 GHz. Shown in Figure 3-1 is a GPS satellite.

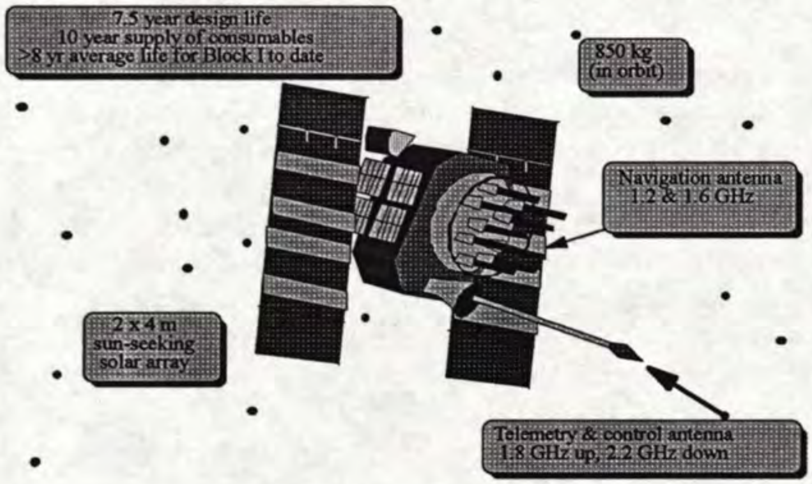
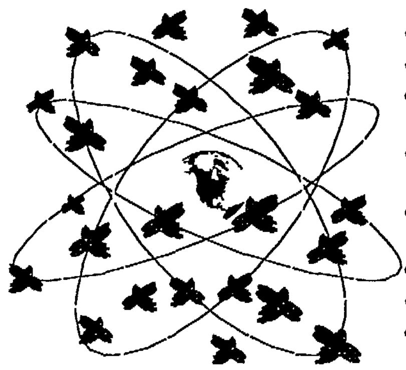


Figure 3-1: GPS Satellite

These satellites are configured in a bird cage pattern such that at all times a user can receive signals from at least four satellites at a time (Figure 3-2). For precise applications requiring decimetre accuracy it is usually a requirement to track five or more satellites simultaneously. There are several short periods during each day when there are less that five satellites in view over an elevation of 12°. This can be amplified if satellites become unhealthy or are turned off for maintenance.

When multiple satellites are in view, one can measure the ranges from roving receivers to the GPS satellites thereby making it possible to compute the coordinates (latitude, longitude, height and time or Cartesian X, Y, Z, and time.) of each receiver (Figure 3-3).

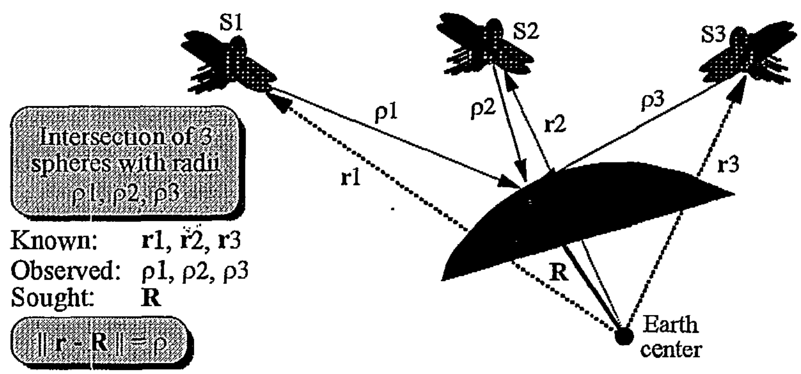
- 24 active satellites
- Six orbital planes
- Altitude of 20,000 km
- Orbital period of 12 hours
- All weather performance
- Global coverage 24 hours per day
- At least four satellites visible
- IOC declared early 1994



- High accuracy 3D positioning
- Velocity vector and time outputs
- Global coverage and continuous availability
- Passive service; unlimited number of users
- No direct user charges for service
- No infrastructure is needed
- Availability of low cost receivers
- Military and civil applications

Figure 3-2: :GPS Constellation and Characteristics

With a GPS receiver (now costing as little as a few hundred dollars), you can receive data on the positions of the satellites, make measurements of the ranges to them, process the information, and compute coordinates and velocity vector (heading and speed) as frequently as every second (some high performance GPS receivers can compute positions at a rate of 10 Hz or higher). This capability has revolutionized the positioning and navigation market place and GPS related products have mushroomed all over the world to fulfill the needs of an expanding position-related industry, which in North America is conservatively estimated to be $20 billion over the next decade.



A minimum of three satellites are needed for the 3D position unknowns. A fourth satellite is needed to solve for the GPS receiver clock bias as well. A 2D solution can be obtained by using only three satellites.

Figure 3-3: Ranging to GPS Satellites

There are some pitfalls to this panacea. First, GPS is a military system, hence it is viewed with a great deal of skepticism by the European community, who have been threatening for the past decade to launch a purely civilian positioning and navigation satellite system. Nevertheless, companies from all over the world have literally jumped on the bandwagon and have invested heavily in building GPS receivers and related products - albeit using a US military system. Secondly, the system accuracy is purposely degraded under a DOD action called SA (Selective

Availability) so that one cannot compute in real-time their coordinates and velocity vector to a high degree of accuracy. The effect of SA is to degrade the ephemeris of the satellites, as well as dithering the satellite clock thereby adding unwanted noise - all of which seriously degrades the results. There is further discussion later in this chapter on the possibility of S/A being turned off in the near future.

There are basically two classes of service in autonomous mode:

1. Precise Positioning Service (PPS) is available for Military use only and the positional accuracy is about 8 meters 50% of the time; and
2. Standard Positioning Service (SPS) is available for civilian use and the positional accuracy is about 50 meters 50% of the time or 100 meters 95% of the time The elevation is less accurate at 150 meters 95% of the time.

It should be noted that it is not uncommon to witness changes of 100 to 200 metres in the coordinates of a stationary receiver over a 20 minute period while using the SPS.

Before advancing further in our discussions, let us enunciate the simple principle upon which GPS positioning is based. Given the measured ranges to at least four satellites, along with the coordinates of these observed satellites (received in the message), it is possible to write four equations in terms of the known ranges and four unknowns - the three coordinates of the receiver and one time parameter. The time parameter (fourth unknown) is necessary so that the clock in the receiver can be corrected into the GPS time system. GPS receivers usually have inexpensive quartz clocks that drift and thus a mathematically-based correction is needed to compensate for the shortcut made in the hardware. If only a two dimensional solution is required (latitude and longitude), then only three ranges to three satellites need to be observed - noting that the time parameter still needs to be included as an additional unknown in the solution - hence a total of three. Clearly, if ranges to more that four satellites are made, then an over-determined solution can be made, thereby improving the quality of the solution. Even under these favorable circumstances, the accuracy achievable of the SPS is about 30 to 50 metres.

The aim of differential GPS (DGPS) is improve the accuracy to about the 1 -10 metre range. This is achieved by setting up a monitor station over a point of known coordinates and continuously computing its coordinates (Figure 3-4). The excursion of these coordinates from the known values is a direct measure of the effect that SA is having on ones solution. To undo the effect of SA, one simply has to reprocess the range data at the monitor station where the corrections to the ranges and the clock are made knowing the coordinates of the monitoring station. In other words, one determines what corrections to the ranges are necessary in order to get the known coordinates of the monitoring station. In practice, the rate of change of the satellite range corrections are also computed. These range corrections and changes, along with satellite ID, are then transmitted by a communications device to a remote user, who then uses them to correct their own ranges made at the remote cite. In this way a DGPS accuracy of 1-10 m can be achieved in near real-time which a latency of only a few seconds. The reason that this technique works is that the DOD induced errors are satellite-based, and these errors effect both the monitor station and remote stations almost identically as the inter-station separation is small compared to the 20,000 km altitude of the satellite; in other words what happens at the monitor, also happens at the remote as far as positional errors are concerned.

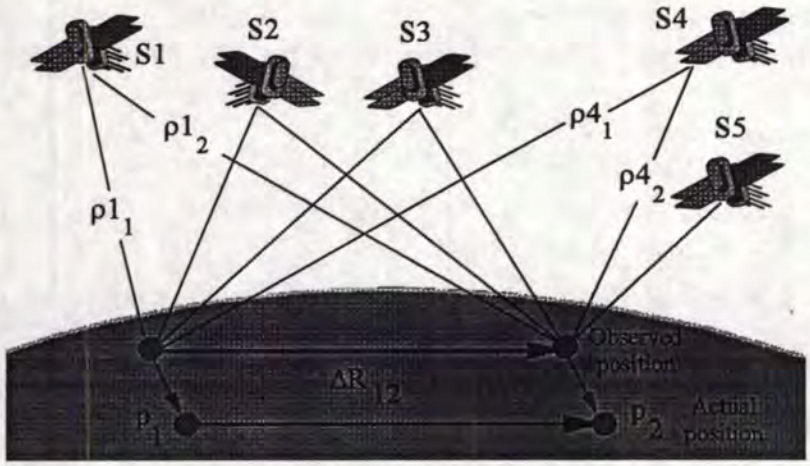


Figure 3-4: Differential GPS Positioning

Many communications technologies have been used to send the corrections to the users. Some of the most common are terrestrial UHF/VHF devices, geostationary satellites, Coast Guard beacon transmitters, and more recently the FM sub-carrier frequency (57 KHz). The latter communications technique is proving to be the most cost effective as local FM radio stations have the rights to sell about 20% of their transmitting power for the purpose of sending data. Pinpoint, Toronto has signed contracts with numerous private FM stations across Canada to disseminate GPS range correction data. Differential Corrections Inc., California has signed a contract with CBC to use their infrastructure. Both firms also have plans to send traffic information to drivers using the same technology. All that is needed is a receiver - looks exactly like a pager - to obtain the correction data which is then fed directly into a DGPS ready receiver which automatically corrects the range measurements and yields a solution accurate to the 1-10 m level. A local communications device can also be installed like a Data Radio product but a license must be obtained from the federal DOC to operate the device.

The Coast Guard system is being established along coastal areas in North America. This system is being provided free to the user. The system accuracy was supposed to be degraded compared to the commercial services, however comparable accuracies are being reported. The Corp. of Engineers are also setting up service along some of the major inland water ways in the US as well. This has extended DGPS service west of the Mississippi some 400 miles. A number of groups are lobbying to extend this service to other areas as well, such as the western part of the continent. CSI of Calgary has capitalized on this opportunity by manufacturing a black box containing a beacon communications device coupled with a GPS board. Their main buyers are the agricultural industry in the USA.

Who needs an accuracy of 1-10 m? Firms involved with regional and wide area tracking of trucks may not, but an ambulance service responsible for navigating to an address of a 911 emergency call (heart attack victim) does. Also, coordinate tagging of road related information such as curb-lines, catch basins, roadside obstructions, valves and the like need to be performed to an accuracy commensurate with DGPS standards. Geographic Information Systems (GIS) containing coordinate tagged data need DGPS. The agricultural industry are sold on this DGPS for scientific and precision farming. As users become more familiar with GPS they will naturally demand a higher accuracy.

3.2. WADGPS (WIDE AREA DGPS)

The absolute navigation accuracy achievable from the GPS system is dependent upon the accuracy of the pseudorange and delta-range corrections. The measurements are affected by the GPS system errors, such as ephemeris, clock and Selective Availability (SA); atmospheric effects (ionosphere and troposphere); and receiver errors (noise, vehicle dynamics, and multipath). WADGPS can be used to eliminate or reduce these effects.

WADGPS includes a limited number of DGPS reference sites widely distributed across the country, each equipped with GPS and communications equipment. By using a WADGPS mathematical algorithm, the user is able to combine the various DGPS corrections received from the different reference stations to produce a locally-valid single set of DGPS corrections. The algorithm accounts for the spatial decorrelation of GPS error sources over the large separation distances between the user and the respective WADGPS reference sites. There are a number of algorithms proposed by various authors and organizations. These have been divided into two classifications [Abousalem, 1996], namely:

- Measurement domain algorithms; and
- State-space domain algorithms.

Measurement domain algorithms provide a DGPS network corrections computed as the weighted mean of the various DGPS reference station corrections. These algorithms are relatively simple and require just a few DGPS reference stations. A disadvantage of such algorithms, however, is that the accuracy of the computed corrections degrades with the distance from the network centroid [Mueller, 1994]. A commercial FM sub-carrier DGPS correction supplier, ACCQPOINT, uses the measurement domain method to provide positioning accuracy of 1-5 m.

State-space domain algorithms, on the other hand, provide highly accurate baseline-independent corrections using a number of DGPS reference stations equipped with dual frequency GPS receivers and complex software. The complexity of state-space domain algorithms comes from estimating (modeling) the individual error sources. An example of state-space domain algorithms would be the one developed by the Geodetic Survey of Canada which employs a single-layer ionospheric model in conjunction with precise satellite ephemeris and clock data obtained from the Canadian Active Control System (CACS) (Gao et al., 1995). DCI, another FM sub-carrier provider has recently announced that they are now employing a state spaced solution as well.

Shown in Figure 3-5 is a schematic of a WADGPS infrastructure. The system contains the following components:

- Real Time Active Control Points (RTACP),

- Real Time Master Active Control Station (RTMACS),
- Virtual Active Control Points (VACP),
- Integrity Monitor Stations (IMS),
- Central Monitor Station (CM), and
- various communication links.

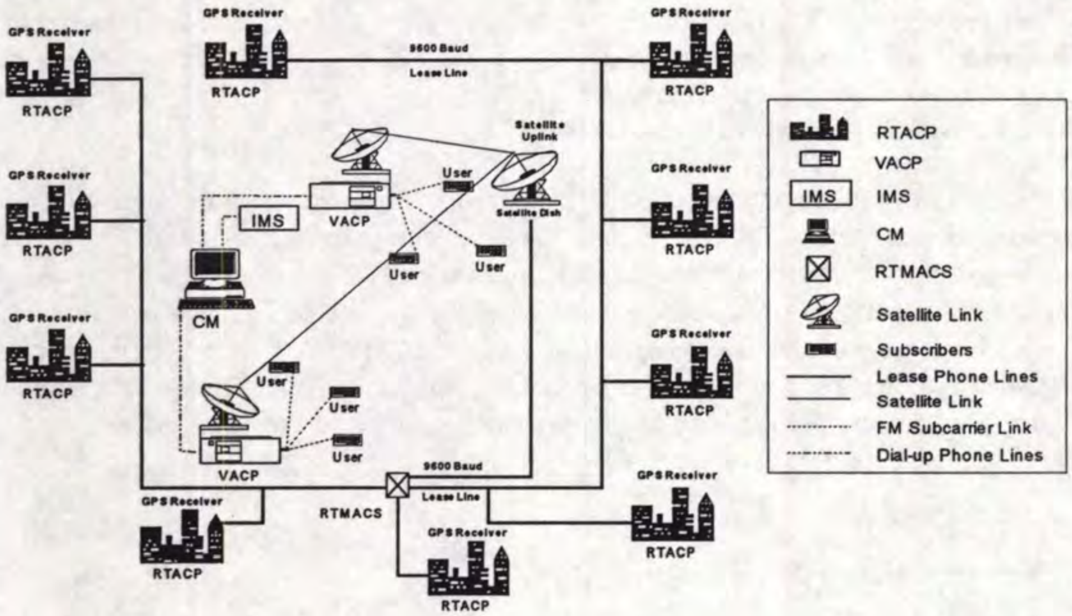


Figure 3-5: WADGPS Overview

3.2.1. Canadian Active Control System (CACS)

Canadian Active Control System (CACS) is a GPS tracking network which currently consists of eight remotely controlled stations across Canada. Each station of the network is equipped with a dual frequency Rogue GPS receiver, which can track up to eight satellites in view, and an external atomic frequency standard clock (a hydrogen maser at Algonquin and Rubidium and Cesium at other stations). Data is transferred to the processing centre in Ottawa (Master Active Control Station (MACS)) via ground or satellite communication links.

Two main objectives for this system are: a) to establish and provide direct link to Canadian Space Reference System (CSRS); and b) to improve effectiveness and precision of GPS applications. Tasks include providing fiducial reference, computing precise GPS satellite orbits, monitoring GPS performance and integrity and facilitating differential GPS and other services. More details about the system can be found in Kouba et al (1993).

A number of approaches have been proposed in literature for Wide Area Differential GPS (WADGPS). The existing methods, however, virtually can be classified either as the state space approach or the measurement approach. The former is a vector approach which attempts to separate the errors into GPS orbit, clock (including SA), as well as atmospheric delays while the latter is a scalar approach which provides only a lumping correction. From the accuracy point of view, the state space approach is more promising than the measurement approach. To achieve this high accuracy, precise modeling and separation of GPS orbit, clock and atmospheric delay errors is required by the state space approach which needs much more complicated algorithms and computer time. Another advantage for the state space approach is that the method virtually has no limitation for the distance between the users to the reference stations of the network.

CACS-based WADGPS is planned to provide a nation-wide WADGPS service, and thus it seems natural to choose the state space approach in order to achieve the highest accuracy from WADGPS to satisfy various positioning and navigation requirements in the future. Therefore, the CACS-based WADGPS consists of three core tasks: precise generation of differential orbit, clock and ionospheric corrections. The research and development regarding the use of CACS for WADGPS have been focused on this baseline at Geodetic Survey Division since late 1992. More about the CACS's WADGPS can be found in Kouba et al. (1994) and Gao et al. (1995).

Stations in the CACS network are located at the following locations:

Site	Latitude	Longitude
Algonquin Park, Ont.	N 45 57	W 78 04
St. John's Nfld.	N 45 35	W 52 41
Yellowknife, NWT	N 62 29	W 114 29
Albert Head, (Victoria) B.C.	N 48 23	W 123 29
Penticton, B.C.	N 49 19	W 119 37
Churchill, Man.	N 58 45	W 94 05
William's Lake, B.C.	N 52 14	W 122 10
Schefferville, Que.	N 54 48	W 66 48

ACP raw observational data for the first 5 sites are generally available on-line 6 hours after midnight (UT) and maintained on-line for a period of six weeks. Older data is available on request.

The ephemeris data is computed in the International Earth Rotation Service (IERS) Terrestrial Reference Frame (ITRF) which agrees with NAD83 (CSRS) within 0.2 ppm. The ephemeris data is provided as daily files and are available within 2 to 5 days following the observations.

Precise offsets between individual satellite clocks and the CACS reference clock are computed for satellite arcs visible in Canada based on the precise ephemerides and observational data from CACS stations. Satellite clock corrections are available for each individual satellite for a 24 hour period at 30 second intervals (this can be interpolated to 1 sec). They are typically available within a week following the observations.

For example, Canadian software which can use this data directly in post-processing is available from NRCan or commercially such as Jupiter from Pulsearch Navigation Systems.

The data was initially free over the Internet, however the following charges are now applicable (these values were supplied at the time this report was written and are subject to change):

- ACP raw observational data: $30/day/station
- Precise Ephemerides: $10/24 hour period
- Precise Clock Corrections: $20/24 hrs (Canadian coverage) & $60/24 hrs (global coverage)

Using CACS dual frequency observational data, precise ephemerides and observing sessions of upwards of 4 hours, it is potentially possible to obtain cm level 3D positions relative to the national fiducial network, with baseline determination to less than 0.1 ppm.

Using a standalone GPS receiver with raw pseudoranges and precise ephemeris, clock corrections and an ionospheric model it is possible to obtain metre level results.

Orthometic heights are limited to the accuracy of the geoid which ranges from 10 cm to about 100 cm absolute accuracy.

The GPS integrity and performance are monitored through analysis of data acquired through continuous tracking. There is always the possible threat the US DOD could shut the system down, though this is highly unlikely.

If real-time processing was not a strict requirement for WADGPS, the CACS-based WADGPS could have been considered operational now, because the precise orbits and clock products have been available since late 1992 plus the most recently available ionospheric grid model. Both dual and single frequency users can perform sub-meter level positioning in a post mode using these differential corrections. It was the intention that NRCan would form a joint venture with industry partners to launch a real-time system that would be operational by the end of 1995. This joint venture did not materialize.

British Columbia has commenced a province wide initiative in conjunction with NRCan. They plan on delivering a real-time service using M-SAT of TMI Communications Inc., Ottawa.

Extensive analysis has been done at the Geodetic Survey Division to validate the positioning accuracy using CACS's post precise orbits and post clock corrections. Sub-meter positioning accuracy has consistently been achieved using these corrections. Analysis has also been done to use the predicted orbits to simulate the generation of real-time orbit and clock corrections.

Results indicate that the positioning errors in the simulated real-time mode using the 24-hour predicted orbits has an RMS of about 1 m.

3.2.2. CBN (Canadian Base Network) / HPN (High Precision Network)

All CBN pillars are easily accessed by 2 wheel drive. Pillars are placed on government owned highway rights-of-way or very near to them. The density of the CBN is at approximately 175 km south of latitude 56. Each site has been tested for GPS observing suitability. This is a passive system with no fee for access.

The 3 dimensional positions relative to one another will be well known. Differential horizontal positions of each station at no more than 200 km spacing will be accurate to the cm level (i.e., 3D (Cartesian) accuracy, 1 cm @ 95% confidence relative and absolute)

The network consists of permanent monumented control points. Each CBN pillar consists of a 14" diameter steel pipe with a cone driving point, pounded to a full 35' or to refusal. The pipe has been filled with concrete to within 3" of the top of the pipe. A stainless steel plate with a force centering plug is attached to the top.

Testing to date indicates that this type of pillar is stable at the 1 mm level. Periodic re-observation campaign's are planned to assess relative stability and plate tectonics.

The CBN will be integrated to the CACS and will provide a high precision foothold point for future projects that wish to use GPS. As more ACSMs are integrated into the NAD83 (CSRS) fiducial network, the spacing between high precision points may decrease. At present, south of latitude 56, no location is more than 125 km away from at least one CBN point. Positions will be known to the cm level (relative and fiducial), but they may be inconsistent with local adjacent control monuments unless direct observation ties are undertaken.

Currently the CBN consists of 10 newly installed pillars and 12 existing pillars. The existing pillars consist of one pillar from each of the 3 EDM calibration baselines (Lethbridge, Calgary, Edmonton & Grand Prairie), one pillar in the Calgary area Marker Farm, temporary ACP Priddis, Calgary HPN marker adjacent to Geodetic Survey marker Kathy, the monolith marker at the Kananaskis ski hill and four pillars from Edmonton area GPS validation basenet.

3.3. LDGPS (Local DGPS)

Local DGPS systems have been the earliest types of systems implemented to provide GPS corrections. Initially, these systems only transmitted pseudorange corrections in RTCM SC104 format. Early expectations of system accuracy were in the order of 5-10 m. This accuracy was greatly improved with accurate pseudoranges, both at the reference station and the remote, sometimes yielding accuracies near the meter level. This is sufficient for many GIS accuracies but is far from being acceptable for legal, geodetic and engineering land applications.

During the last year a number of manufacturers have developed RTK and RT-20 technology using carrier phase observations. RTK typically requires dual frequency receivers to reliably fix the ambiguities and yield cm level accuracies. RT-20 technology has been developed using precise pseudroranges and carrier phase measurements using single frequency receivers. Accuracies in the order of 20 cm are achievable and a double difference float solution is employed rather than fixing the ambiguities.

RTK and RT20 methods require that carrier phase data is sent every 1-3 seconds on average. The RT20 methodology intersperses RTCM pseudorange corrections in the data, such that a single communications link can be used for both types of GPS applications.

To date, all GPS manufacturers have kept their carrier phase messages proprietary, such that the base and remote receivers must be from the same manufacturer. A minimum of 4800 baud is required to transmit the data at a sufficient rate.

RTK methodology requires that the ambiguities must be fixed prior to carrying on an accurate survey, if loss of lock has occurred. The time to resolve these ambiguities depends on the receiver technology, number of satellites being tracked, multipath, ionosphere and the communications link. Maximum distances of 10 km were recommended in the past, but that distance is being increased over time.

The majority of systems used to date have been setup for individual company use. ACCQPOINT has recently announced and have begun to deploy two systems, namely:

- RTK FM; and
- FARM FM.

RTK FM uses Trimble 4000 SSI's at the reference stations and is intended for urban applications requiring cm level accuracies. An overview of the system is shown in Figure 3-6. FARM FM uses NovAtel RT-20 receivers and is intended for agriculture applications requiring 20 cm accuracies. These stations will be upgraded to RT-2 in the latter part of 1996 and will provide dual frequency carrier phase observations.

The main advantages of the system are:

- the user does not have to purchase his own base station;
- the user does not have to acquire a new radio frequency;
- the radio stations typically emit 50,000 to 100,000 watts of power or more; and
- the radio transmission towers are typically located on the top of hills or high office towers.

The main disadvantages of the system are:

- only Trimble and NovAtel receivers are currently supported;
- coverage is limited to the coverage of the radio station (will not be available in many rural areas); and
- operating range is limited to 10-30 km of the reference site.

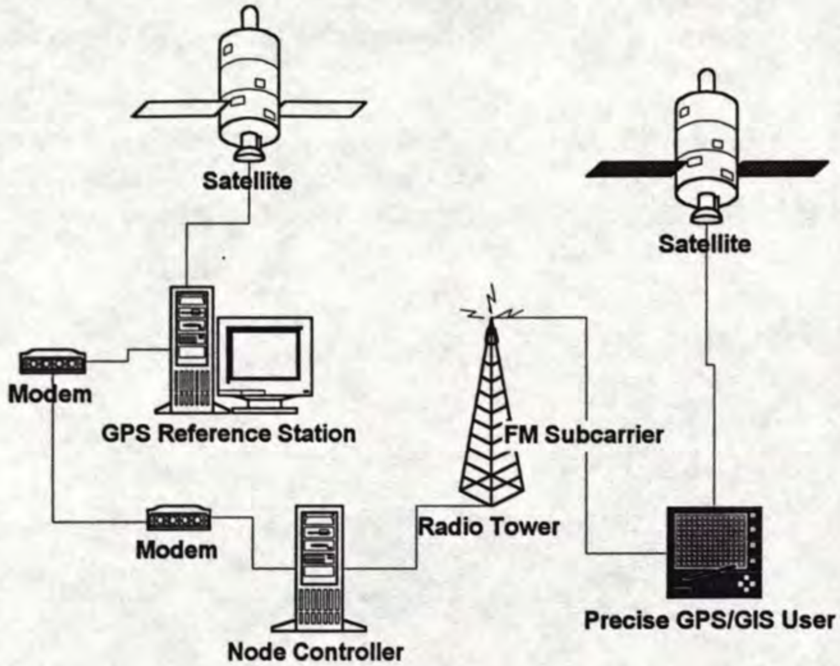


Figure 3-6: LDGPS System Components

3.4. GPS PLAYERS AND RECEIVER COSTS

The GPS industry has been advancing at an explosive pace over the past several years. Great strides have been made to reduce the size, power consumption and cost of GPS systems. Some projections in terms of cost are given in Figure 3-7. The GPS industry is starting to shake out, somewhat similar to the PC industry in the late 1980's.

The industry is being divided into several categories, namely:

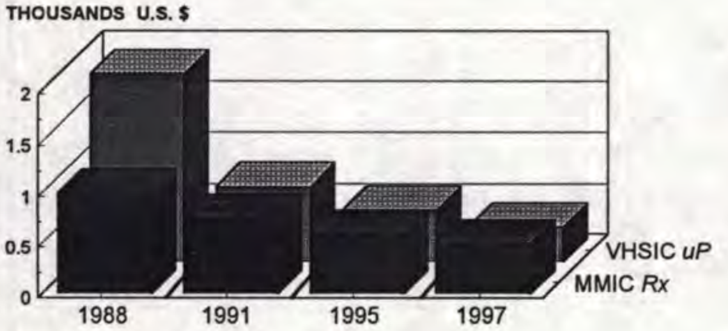
- OEM board manufacturers;
- GPS product developers and manufacturers; and
- System integrators.

In Canada there are two GPS OEM manufacturers, Canadian Marconi and NovAtel Communications. Canadian Marconi has concentrated mainly on the aircraft industry in the past and have worked closely with GEC Plessy and Honeywell. They have recently released a low cost OEM board aimed at GPS product manufacturers, as well as a GPS-dead reckoning unit for positioning in tree covered areas and urban canyons.

NovAtel also produces OEM GPS boards, but have stayed focused on high precision applications. Much of their success has been in the aviation industry as well. Pulsearch Navigation Systems (PNS) is a Canadian company that has developed several products around NovAtel's OEM board sets.

Communication Systems International (CSI) have developed a product that integrates a low cost GPS board set from Motorola with a beacon receiver that receives RTCM corrections from the Coast Guard differential service.

A number of other Canadian product developers and system integrators exist, namely: TMI, Ottawa; Premier, Calgary; Piccodas, Toronto; Challenger Surveys, Calgary; GeoSurv, Ottawa; AVLIS, Sarnia; AVeL, Quebec; Pelorus, Calgary; DataTrax, Calgary and Usher, Edmonton. This seems to be the area that Canadian companies are best suited to fill.



Pacific Monolithics GPS receiver chip set
- AM0205B $232.00 US
- CV0207B $410.00
- AM0202 $143.00

Figure 3-7: Projected GPS Chip-set Costs

In the USA the large electronic companies such as Motorola and Rockwell are focusing on providing low cost board and chip sets to other product developers. They are both also pursuing the automotive industry. Both companies have contracts with the Big 3 car companies in the area of safety and security where cellular phones and GPS receivers are being bundled.

Companies such as Trimble and Ashtech are pursuing both the OEM market and internal products. Trimble has been a recognized leader in the past. Magellan has been purchased by Orbcomm who are launching LEO's. The Canadian connection here is that Teleglobe Canada of Montreal has a 50% equity interest in Orbcomm USA which owns Orbcomm Canada, Montreal. Magellan has pursued both the OEM and products business. Magellan has been a leader in driving down the price of hand held GPS receivers aimed at the consumer market. Wal-Mart and K-Mart are now selling units with a list price of $199 (they were on sale in Christmas 1995 in Alaska for $161).

The Japanese industry has focused on the automotive and marine industries. Their low cost manufacturing capabilities will provide severe competition for Canadian and US manufacturers. These manufacturers are looking to Mexico as a low cost manufacturing strategy.

Over 1.2 million land navigation systems have been sold in Japan to date. This is in comparison to 10,000 land navigation systems in Europe or North America. This difference is expected to disappear by the year 2005 when it is estimated that between 3 and 5 million systems will have been sold per area. By 2010-2015, 50 % of new cars will be factory equipped with navigation systems.

3.5. GPS POLITICAL ISSUES

The NAPA panel recommends the following goals for GPS, including augmentations funded by the US. government, and urges that they be adopted. The goals are:

- Protect the security of the United States and its allies and seek to counter or limit the hostile use of the system by others.
- Maintain an efficient, effective, dual-use geo-positioning capability providing responsive, highly accurate, and reliable positioning, velocity, and timing information worldwide.
- Maintain US. leadership in GPS technology by encouraging its evolution, growth, and commercial applications.
- Maintain GPS as a global resource by considering international interests and concerns in GPS governance and management.
- Establish policies governing the availability, use, and funding of GPS that are - and are seen to be - stable, consistent, and workable for all major users of the system.
- Provide a flexible management structure capable of adapting rapidly to changing technical and international circumstances.
- Consistent with other national goals, limit the overall burden on the US. Taxpayer.

In short, GPS goals should aim to protect national security, encourage commercial growth, and foster international acceptance and continued US. leadership in this field.

NAPA Panel Recommendations conclude that GPS is the basis for a truly global positioning and navigation system. Included are the following:

- The United States should issue a clear and concise policy statement at the highest level that reasserts the US. commitment to provide permanent international access to the GPS signal and that states the US. intention to consider foreign interests in the future evolution of GPS.
- The United States should formulate an explicit strategy to increase international acceptance and use of GPS that reassures foreign users of the reliability, credibility, and consistency of the United States as a provider.
- The US. Government should encourage and participate in developing and organizing a global navigation network with GPS as its foundation, and with appropriate arrangements for governance, management and funding.

The most important actions the United States can take to enhance its position are to:

- Keep the civil GPS signal free of direct user charges and available to all.
- Turn Selective Availability to zero immediately and deactivate it after three years.
- Broaden civil agency participation in GPS governance.

- Provide a forum for international parties to voice their needs, interests, and concerns.

The NAPA panel recommends that:

- Congress and the administration treat the current basic GPS as a public good, paid for through general revenues.
- Congress and the administration refrain from imposing a receiver tax and impose no special fee or tax on private differential systems.
- The cost of the Coast Guard's and FAA's augmentations of GPS and related systems should be covered by the appropriate trust funds without raiding fees.

The following is an excerpt of a Bill that was supposedly signed by US President Bill Clinton the end of February. This information was contained on a news group on the Internet.

Bill HR1530

SEC. 279. GLOBAL POSITIONING SYSTEM

(a) CONDITIONAL PROHIBITION ON USE OF SELECTIVE AVAILABILITY FEATURE- Except as provided in subsection (b), after May 1, 1996, the Secretary of Defense may not (through use of the feature known as `selective availability') deny access of non-Department of Defense users to the full capabilities of the Global Positioning System.

(b) PLAN- Subsection (a) shall cease to apply upon submission by the Secretary of Defense to the Committee on Armed Services of the Senate and the Committee on National Security of the House of Representatives of a plan for enhancement of the Global Positioning System that provides for:

- *the development and acquisition of effective capabilities to deny hostile military forces the ability to use the Global Positioning System without hindering the ability of United States military forces and civil users to have access to and use of the system, together with a specific date by which those capabilities could be operational; and*
- *the development and acquisition of receivers for the Global Positioning System and other techniques for weapons and weapon systems that provide substantially improved resistance to jamming and other forms of electronic interference or disruption, together with a specific date by which those receivers and other techniques could be operational with United States military forces.*

One must wait and see if S/A is actually turned off or if the military devises some other method to impede accuracy.

Shown in Figure 3-8 are the potential accuracies achievable with S/A turned off. These just involve using code measurements in an autonomous mode. It is believed by many that differential services will still be required by many applications requiring higher accuracies. There will also be concern with many groups such as the aircraft industry that will require differential service due the threat of degradation.

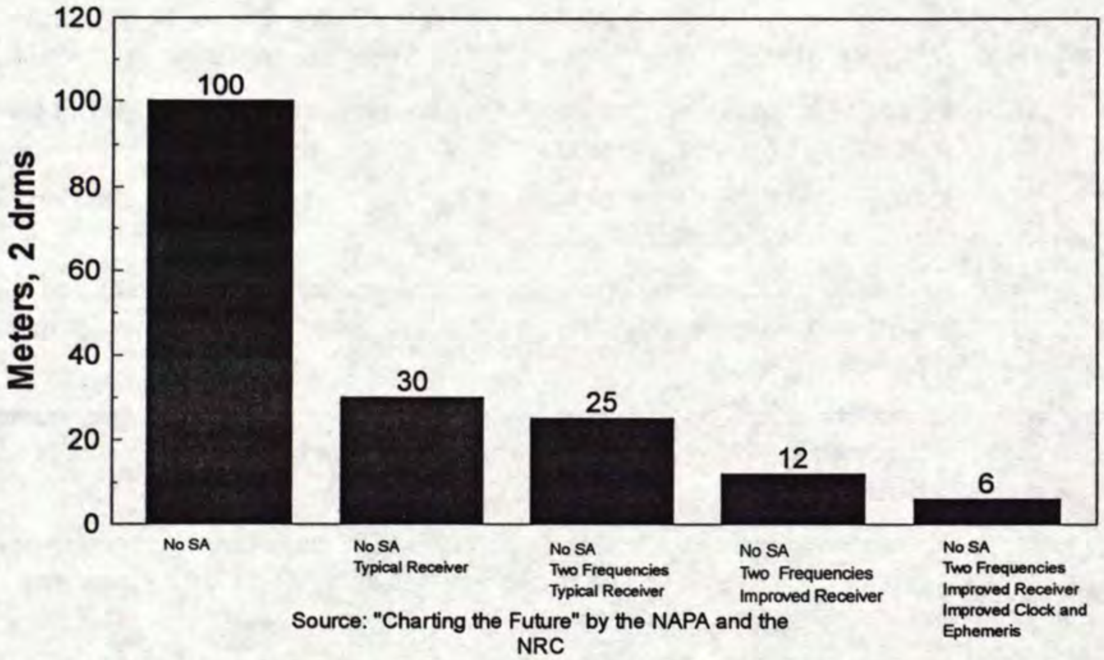


Figure 3-8: Accuracy Resulting from Recommended Improvements and Enhancements

Shown in Figure 3-9 is the current plan for the launching of GPS satellites in the future. Contracts are being pursued in the US for these future deliverables.

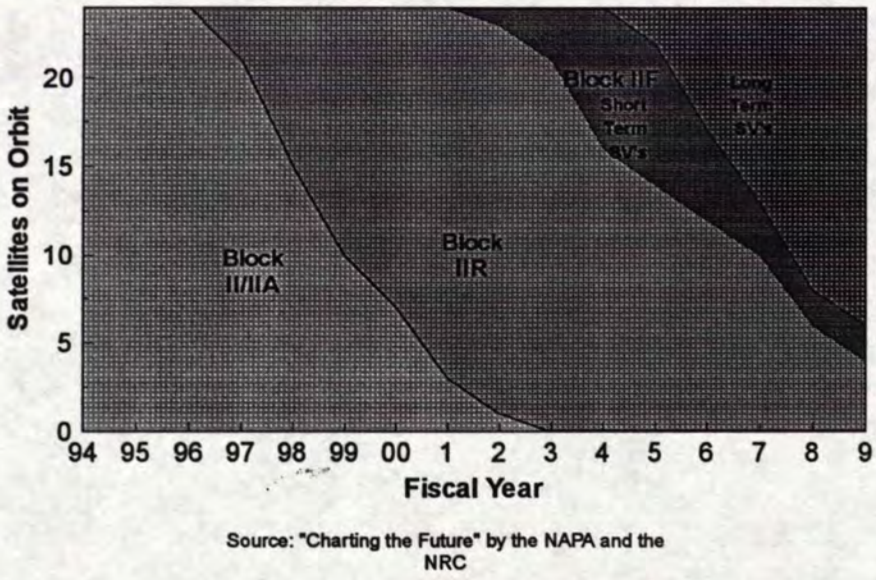


Figure 3-9: Current Plan for Satellite Replacement

3.6. Summary And Conclusions

- Standards, protocols and interfacing issues for GPS have been handled well by the navigation and electronics industry and few impediments to development if any exist.
- Compatibility and inter-operability within NAFTA countries is automatic as GPS is truly a global positioning utility allowing for GPS related products to operate anywhere in the world.
- Canada has unusual strength in the GPS education and research arena as it has two world class universities (The University of Calgary and University of New Brunswick).
- Canada has two GPS manufactures in Canadian Marconi and NovAtel which adds considerable strength to the various Canadian GPS teams.
- Canada has numerous GPS product developers and system integrators who have and are developing a host of GPS related applications and are poised to introduce their products in the about to take off GPS market.
- Canadian firms have more than the required level of expertise and products to meet domestic needs, but often the Canadian launching pad for these products is not being supported or is not available. The NRC-IRAP program is an exception to this rule.
- The two impediments to international exportation of Canadian GPS technology is the slowness of acceptance in Canada of this technology and the apparent inability of Canadian concerns to purchase it.
- The slow market development in Canada for GPS products has caused Canadian firms to seek USA and international markets, thereby adding high costs of marketing to their overall budgets. This fact places high importance in supporting these firms in international marketing initiatives.

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4. GLOBAL SATELLITE POSITIONING SYSTEM (GNSS)

4.1. INTRODUCTION

The acronym GNSS was coined by the ICAO Future Air Navigation Systems (FANS) committee who's mandate is to designate systems that meet the ICAO requirements for a primary standalone navigation systems in the 21st century. The international community has adopted a broader interpretation of GNSS to mean global navigation note only for applications in the air, but also in the marine and land environments. GNSS is intended to distinguish generic satellite positioning and navigation from GPS and GLONASS-military owned systems. In other words, when Europeans and Japanese address civilian based satellite positioning and navigation systems, it is to GNSS which they refer. This begs the question-how then does GNSS differ from GPS? To answer this question, one must state first that there are two GNSS systems-GNSS1 and GNSS2; each will be described immediately below.

At this juncture it would suffice to say that GNSS1 doesn't differ a whole lot from GPS as it is essentially GPS augmented with geostationary (GEO) communications satellite overlays. The time frame given for the development of GNSS1 is 1994-99, while GNSS2 will be studied and analyzed over the period 1994-97, with its design and development taking place later; it would replace GNSS1 in about 10 to 15 years.

GNSS2, however, would be a new satellite system but be backward compatible with GPS. The reasoning behind this characteristic is that the millions of GPS receivers that will have already been deployed will be useable with GNSS2. In this way, the GPS and GLONASS systems along with their respective military control would thereby be by-passed, a worrisome problem for many nations.

4.2. GNSS LEADERSHIP

GNSS is being spearheaded by a European Tripartite Group consisting of the following political and scientific parties [Tytgat, 1995]:

- European Commission which is looking after the political and institutional matters;
- European Space Agency is responsible for the implementation; and
- Eurocontrol is charged with validation and certification of GNSS.

This mandate flows from the following treaties:

- "The Common Market" 1957 Treaty of Rome which is aimed at the creation of a single market for Europe:
- Creation of a political European union via the Treaty of Maastricht 1993; and
- Creation of the United States of Europe initiative-a new Intergovernmental Conference 1996.

In 1992 a turning point in the Commission's Transportation Policy was reached when the following needs were defined:

- develop a single market for transportation services;
- develop a navigation system that is free from unnecessary restrictions;
- improve the competitiveness, financial performance, and efficiency of transport in the region and globally;
- improve the functioning and quality of transport systems, including safety, reliability and passenger comfort; and
- introduce measures for the protection of the environment.

Another large and important player in GNSS is EUGIN-standing for European Union Group of Institutes of Navigation [Bouche, 1995]. The institutes of navigation that are presently members are from France, Germany, Italy, Netherlands, Nordic countries and the United Kingdom. The role for EUGIN is to promote a decentralized ownership and regional operation of GNSS. A small number of autonomous-interoperating subsystems, owned and operated by major players from the Far East, Europe, USA and the Arab Nations is envisioned by this organization.

Hence, a new initiative has been born-the Global Navigation Satellite System (GNSS) Program of the Tripartite Group mentioned above. Part and parcel to this initiative is the development of a European Radio Navigation Plan (ERNP). To be clear, this initiative is in response to a large global-civilian market for navigation related products for the land, marine and air environments [Lechner, 1995]. GPS-military based or not-has shown the way.

4.3. GNSS1

GNSS1 is regarded as a stepping stone to GNSS2. GNSS1 is an extension to GPS and GLONASS. The sorts of augmentation required by GPS is generally agreed upon by the international community to be the following [Forssell, 1995]:

- supplementing GPS positioning with communications via geostationary communications satellites (GEO);
- adding a ranging capability to the GEOs (R-GEO);
- improving GPS receiver capability with receiver autonomous integrity monitoring (RAIM);
- adding a ground integrity channel (GIC);
- combining R-GEO with GIC (RGIC); and
- offering wide are differential GPS corrections (WADGPS).

The above requirements have arisen from the domain of air navigation. When one considers the evolving needs of the marine and land ITS sectors, they also become relevant to these sectors. Smart ship navigation near obstacles at sea and for harbor entry are convincing examples. On the other hand, real-time steering control in agricultural vehicle navigation and by high speed convoys of vehicles on super highways of the future have similar needs to the aviation sector.

Immediate reliability and integrity related needs in the land navigation sector is the requirement for fool proof navigation and route guidance of emergency vehicles to the exact address of a 911 call; the liability issue is the driving force behind this need. Clearly, the era of the simple use of GPS positioning alone for all applications is over; employing DOPS (Dilution of Precision) as the sole means of measuring the accuracy and reliability of positioning and navigation is inadequate. Industry is demanding more and it is up to the navigation community to deliver; hence the need for GNSS.

GNSS1 is similar to the United States FAA (Federal Aviation Administration) system in that, for both cases GPS is augmented with GEOs. The GEOs are four INMARSAT-III satellites positioned appropriately positioned in longitude, a pair to cover each continent. In Europe, the two GEOs will be positioned over the Indian Ocean (IOR) and the east Atlantic (AOR-E). In the USA the positioning will done over the west Atlantic (AOR-W) and the Pacific (PO-R). The system architecture for GNSS1 is shown in Figure .

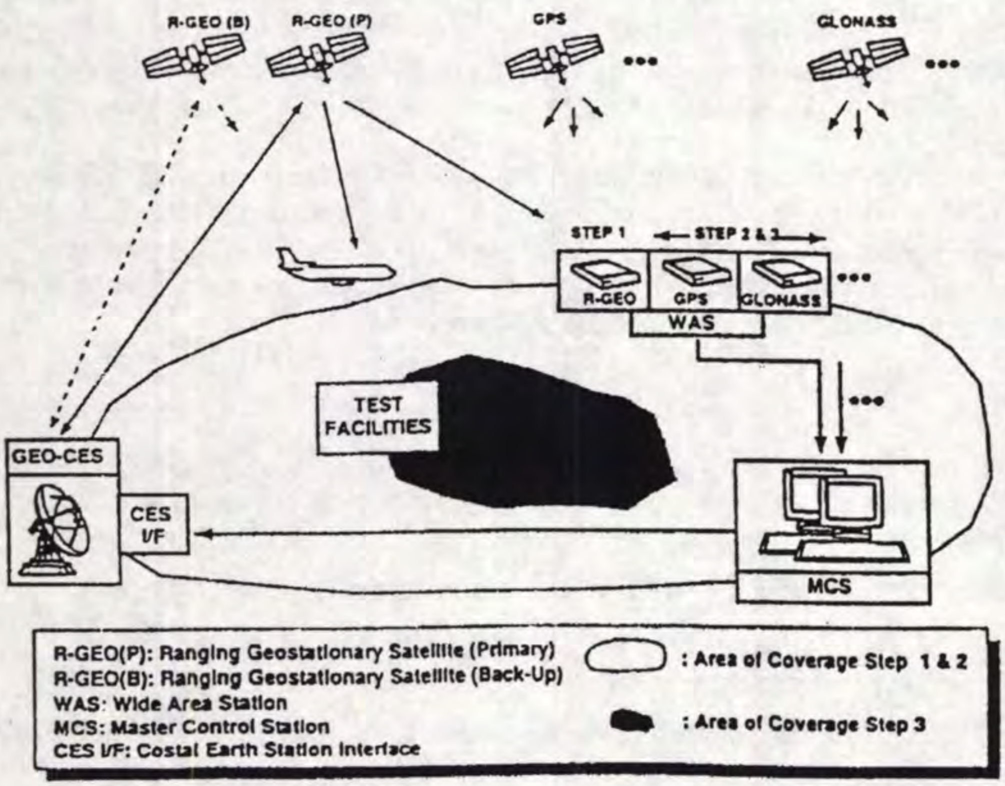

Figure 4-1: GNSS1 Overview

The Tripartite Group has created a new organization to nurture GNSS1 into existence, namely the European Geostationary Navigation Overlay Service (EGNOS). The two IMARSAT-III GEO navigation transponders will be managed for the Group by France Telecom and Deutsche Bundespost Telekom.

EGNOS plans for GNSS1 are as follows:

- Initial Operational Capability (IOC) Phase 1996 to 2000; validation trails, development of certification requirements and user segment;

- Full Operational Capability (FOC) Phase 1998 to 2002; when fully deployed FOC will meet sole means air navigation.

4.4. GNSS2

Forssell [1995]states that GNSS2 is expected to differ significantly form GNSS1. GNSS1 is being used as a means to solve the initial problems of GPS and GLONASS and in the course of doing so valuable knowledge will be gained in the domain of satellite positioning and navigation. GNSS2 is expected to be under civilian control and is being aimed at meeting the needs of the civilian community in all three domains-land (including railways), marine, air and space for the period 2005 to 2020. It will include enhancements in communications broadcasting of e.g., traffic and weather information.

Some of the important design issues currently being investigated for GNSS2 are the following:

- backward compatibility with GPS so that user equipment can be utilized;
- continued use of communications satellites; GEOs, as well as LEOs and MEOs to improve angle of signal reception for countries of high latitudes and urban areas of high buildings; and
- constellation optimization and frequency management.

Bouche [1995] believes GNSS2 should be designed with the following principles in mind:

- GNSS2 should be composed of a small number of automous-interoperating subsystems, owned and operated by countries in major regions of the world, e.g., Far East, Europe, USA, Arab Nations.
- The GPS signal structure should be maintained thereby allowing for the operation of exiting GPS equipment with GNSS2.
- Monopolies can be avoided by allowing the regions to introduce enhancements without violating interoperability.
- As satellite navigation represents a global infrastructure (e.g., GPS being the first truly global utility), the cost of which should be removed as a burden to the taxpayers and a charge levied as for any utility.

Figure 4-2 and Figure 4-3 represent how the EUGIN envisions GNSS2, first as a European contribution, and secondly as a group of regions joining together to own and operate this new system of the 21st century.

The vision for GNSS2 extends beyond Europe to include inter-regional cooperation with Russia, Japan, North African Area and the Arabian Peninsula, Africa, and the United States. Canada was inadvertently missed from the list, which says something about their perception of the size of our market. Nevertheless, it would have been correct to include Canada as it contributes real dollars to the European Space Agency-moneys which are being used on GNSS.

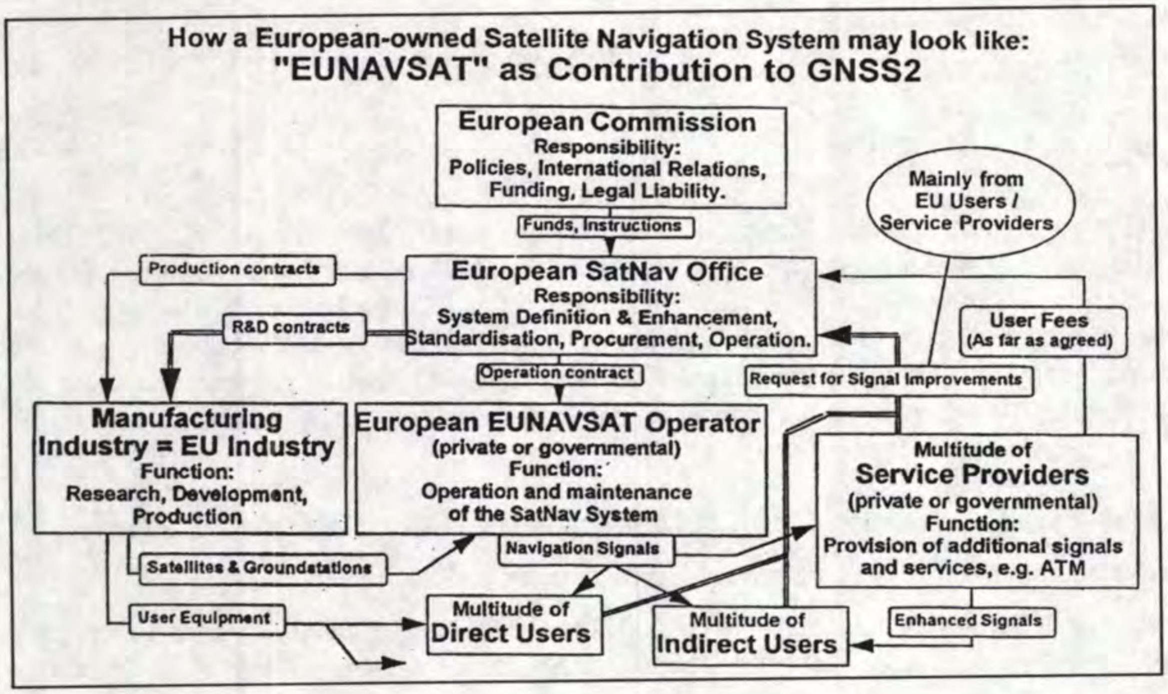

Figure 4-2: Proposed European Organization of GNSS2

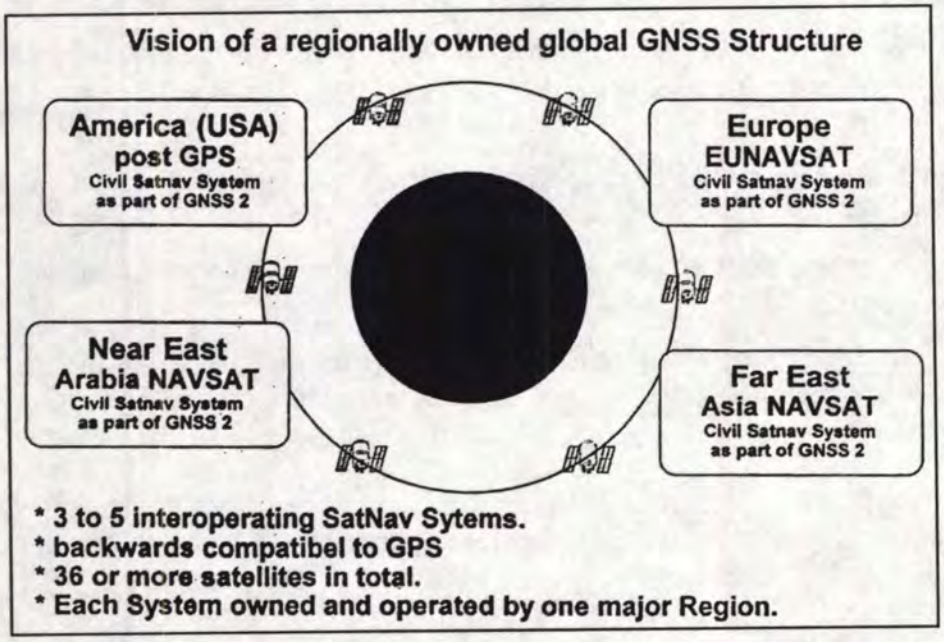

Figure 4-3: Vision of a Regionally Owned Global GNSS Structure

4.5. Summary and Conclusions

The following are important Canadian issues related to the Global Navigation Satellite System (GNSS):

- Canada contributes financially via the Canadian Space Agency to the European Space Agency who is a lead player in GNSS, thereby making it possible for Canadian companies to be involved in this new space positioning and communications effort.
- GNSS is a longer term initiative (circa 2000-2005), however, considerable funds are presently being expended on design and studies and some level of Canadian presence is required. Industry Canada should partner with the Canadian Space Agency to look into this matter and create the opportunity for Canadian firms to participate.
- GNSS will be backward compatible with GPS - meaning that somehow it will be possible to leverage all the GPS equipment and applications over to GNSS.
- GNSS will be regionally owned and operated by the civilian community; this begs the questions "what should the Canadian involvement be ?". Finding the answer to this question is an initiative that Industry Canada should support.
- Canadian positioning and navigation needs both domestically and internationally for exportation of our products makes an involvement in GNSS essential.

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5. GEOSTATIONARY EARTH ORBIT (GEO) SATELLITE POSITIONING SYSTEMS

5.1. INTRODUCTION

To date, most satellite communications systems involve geo synchronous satellites, but few constellations offer inherent positioning (and tracking) in addition to communications. In order to have position/tracking capability, the satellite constellation must be designed for mobile communications and positioning. Most GEO's are not meant for mobile communications; most traditional GEO's are meant for stationary communications links. For example, in order to offer live television feeds from remote locations, significant preparation is involved and the remote terminal must remain in a constant position. However, with mobile satellite networks an earth terminal can travel large distances and maintain communications with the satellite network. Satellites that have mobile communications capability have the potential to offer inherent positioning and tracking.

Orbiting at altitudes of 36,000 kilometers in synchronization with the earth's rotation, GEO satellites remain approximately over the same locations on the earth's surface near the equator. Due to their vast distance above the earth, they require relatively large antennas, at the earth mobile terminal, to send and receive signals, making the equipment somewhat bulky. This technology is effective for AVLN applications that require wide-area coverage; however, the equipment and services are relatively costly. A typical Mobile Terminal (MT) is about 18"x12"x4" and weighs three or four pounds. Qualcomm and AMSC sell their MT's for about US$5,000.

Inmarsat, one of the first providers to enter the satellite business, offers worldwide coverage except in the extreme polar regions. Inmarsat employs four satellites with the following services: Inmarsat A/B, which handles voice , telex, and data: Inmarsat M, which handles voice and offers fax and data capability; Inmarsat C, which handles telex and data messaging; and Inmarsat E, which provides the EPIRB (Emergency Position Indication Radio Beacon) distress signal. Inmarsat has also been used as an interim solution for those AVLN applications awaiting future communications satellite launches. Inmarsat has not offered inherent positioning, but they are launching new satellites that will offer a kind of quasi GPS service. This new Inmarsat service, called GPS Overlay is described in the sequel..

Another provider, AMSC, offers a service called Sky-Cell. Signals are carried in the L-band which operates on frequency of 1635-1600.5 MHz at 300 bits per second (bps) from the subscriber to the satellite and 1530-1559 MHz at 600 bps from the satellite to the subscriber. Coverage includes the continental Untied States with 200 miles of coastal water, Puerto Rico, and the Virgin Islands. AMSC does not offer inherent positioning yet. However, they plan to in the future. At the present their MT's are equipped to work with GPS receivers.

One of AMSC's partners, TMI communications, owns the MSAT satellite (yet to be launched), which is a twin of AMSC's Sky-Cell satellite; this will give each service provider a back-up system. Each backup can support as many as 3,200 radio channels.

AVLN systems that use GEO inherent positioning include Qualcomm's OmniTRACS (and its French relative, Alcatel-Qualcomm's Euteltracs), TMI's Roadkit, and AMSC's Sky-Cell Fleet

Management. These systems offer inherent positioning services but can also be interfaced to external positioning device (GPS sensors, for example) for more accurate positioning. Some other geostationary satellite communications-based systems without inherent positioning services that can accommodate GPS or other positioning sensors are the SNEC VTS (SNEC, France), GEC-Marconi's Star-Track, an airport vehicle tracker from GP&C (Sweden), and Rockwell's Satellite Communication System.

5.2. Generic Geostationary (GEO) Satellite Positioning

Although Geostationary satellites are primarily used for communications, it is also possible to use GEOs to obtain location information about a mobile vehicle. Positioning is achieved by ranging to two communications satellites using a technology called Radio Determination Satellite Service (RDSS). A signal is sent from the primary satellite to the mobile terminal on earth; the signal is sent back to both of the satellites. Each satellite receives the signal at a different time. This time difference of arrival combined with the round trip range information allows for calculation of the position of the mobile terminal on earth. The position calculation is done at the management control station and transmitted via satellite to the mobile terminal. Typically these position/tracking type of systems utilize a directional antenna that alternately tracks a primary and a ranger satellite. Each mobile terminal consists of an antenna, communications terminal, and display/data-entry terminal. The positioning accuracy is dependent upon the angular separation of the satellites and can typically be 250 metres for good geometry and 400-2000 metres for poor geometry.

The following sections describe systems which use the RDSS technology.

5.2.1. QUALCOMM OmniTRACS System

QUALCOMM does not have its own space vehicles; it leases time on existing geostationary communications satellites. It provides coverage of the continental United States; in Europe, coverage is achieved through the Eutelsat Satellites. Also, coverage is available in Canada, Mexico, Brazil, and Japan. QUALCOMM provides inherent positioning as part of its service (typical accuracy is 250 to 2000 meters).

OmniTRACS is the biggest selling long haul trucking tracking system in the world with over 100,000 installations. Qualm's system is an Automatic Satellite Position Reporting (QASPR) type of AVL system. The positioning technique uses the original OmniTRACS TDMA (Time Division Multiple Access) timing signal formats in the forward and return link directions. An auxiliary, low power, forward link signal through a second satellite (Ranger) is used to derive distance values to be used in calculating the coordinates of the vehicle. The derived latitude and longitude are then received at the Network Management Centre (NMC). The coordinates of the two satellites are determined by observations from fixed platforms with known coordinates. The equipment used is identical to the mobile terminal hardware. The system is intended for long haul trucking fleets. In the third quarter of 1993 the Irving operations in Maritime Canada signed a contract with Cancom (a Canadian company who markets the system in Canada) to track their trucks.

In April 1993, QUALCOMM reported revenues of US$36.8 million for its second quarter, up US$10.5 million from the year before. QUALCOMM has taken over many of Geostar's customers since that firm went bankrupt including a US$6 million contract with KLLM Transport, Jackson, Mississippi. QUALCOMM has taken over assets from Motorola's Coverage Plus network and Comdata's DriverLink/24 and intends to sell its service to Motorola's former customers -- about 10,000 vehicles. J.B. Hunt is using the system on 4000 of their vehicles. Leaman Tank Lines, Pennsylvania, is fitting the system to 1,500 trucks. Most of OmniTRACS customers are in the United States, however the system is also operational in Canada, Europe, Brazil, and Japan. The cost structure is as follows: US$4200 - US$4500 per vehicle with a flat monthly fee of US$35. The PC-Windows dispatch software sells for US$5000.

5.2.2. European Eutel-Tracs System

Figure 5-1 shows the Eutel-Tracs system concept. The primary and ranging satellites are used to take time difference measurements. The network management center calculates the position of the vehicle and sends the position to the vehicle.

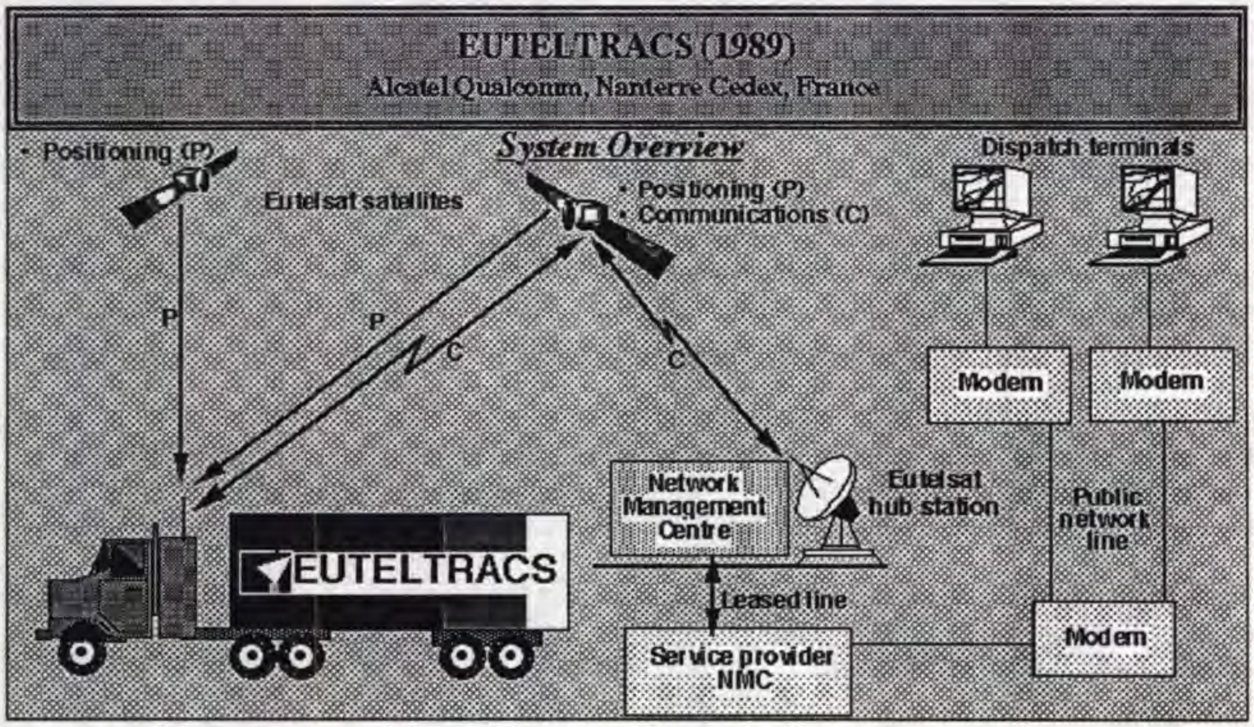

Figure 5-1: Eutel-Tracs System Concept

Alcatel, a major European telecommunications corporation, licenses the MT technology from QUALCOMM and sells the Eutel-Tracs system in Europe via national service providers: Telecom Systems Mobiles (France), Knud Hansen Kommunikation (Denmark), KH Mobicom (Benelux), Alcatel SEL (Germany and Austria), Telespazio (Italy), H-O Hilsson (Sweden) and Companhia Portuguesa Radio Marconi (CPRM - Portugal). Eutel-Tracs 's principal control centre (hub) in Europe is located in Rambouillet, France and can handle up to 45,000 vehicles. As of late 1995, 7000 terminals had been sold. HZ Transport of Holland has had 31 refrigerated units equipped with Eutel-Tracs. Other customers include Kombi Trafik and Samson Transport in Copenhagen, Denmark; Kadartrans and Hungocamion in Hungary; fast food suppliers in Sun Valley, England; and JSC Master in Russia. Turkey is another likely market - Satko believes that there will be a 3500 vehicle long distance trucking market.

Sales have been limited in Europe, and Eutel-Tracs may experience stiff competition from emerging LEO based communications networks in the next decade.

5.3. Geostationary Overlay - to enhance GPS service

In June 1995 Inmarsat launched the first of four satellites that will carry special transponders. These transponders will broadcast simulated GPS-like signals at the GPS L1 (1575.42 MHz) frequency. This simulated GPS broadcast, the Inmarsat Geostationary Overlay (IGO), can be received by GPS receivers with only slight software modifications. The IGO will provide an additional satellite signal that can be used for navigation, thereby improving the available GPS and GLONASS satellite coverage. Another major motivation for the IGO is the requirement expressed by the aviation community for a GPS Integrity Channel (GIC). The GIC integrity data will be broadcast through the IGO as a navigation message modulated on the simulated GPS signal.

5.4. Other Tracking Systems that use Geostationary Positioning

No other geostationary positioning systems exist except for the AMSC Sky-Cell, Reston, VA. AMSC launched their GEO in March of 1995 and the system is fully operational. The GEO positioning capability will not be realizable until TMI, Ottawa launches their MSAT in 1997. In the meantime both are using GPS for positioning.

TMI has set up a system in Canada in which they act as GEO infrastructure providers, while three main resellers - Bell Mobility, Montreal; Glentel, Vancouver; and InfoSat, Burnaby are the interface with system integrators who develop applications with end users. This is where the opportunity exists for Canadian firms to develop ITS navigation system related products.

5.5. Operational Geostationary Satellite Constellations

There are many Geostationary Satellite operators in the world. However most do not offer positioning service. If demand increases in the future, the satellite operators may be poised to offer a positioning service. The following list contains all of the operators of GEOs in the world.

- Alascom Inc.,Anchorage, AK USA
- American Mobile Satellite Corporation, Reston, VA USA
- APT Satellite Company Ltd., HONG KONG
- AT&T Skynet Satellite Services, Bedminster, NJ USA
- Comsat Corporation, Bethesda, MD USA
- Deutsche Bundespost Telecom, Bonn, GERMANY

- DirecTV Inc., El Segundo, CA USA
- Empresa Brasileira de Telecomunicacoes, Rio de Janeiro BRAZIL
- France Telecom, 6 Place d'Alleray, Paris FRANCE
- GE American Communications, Princeton, NJ USA
- Hispasat S. A., Madrid, SPAIN
- Hughes Communications Inc., Los Angeles, CA USA
- Indian Department of Space, Antariksh Bhavan, Bangalore INDIA
- Japan Satellite Systems Inc. (JSAT), Minato-ku, Tokyo JAPAN
- Norwegian Telecom, St. Olavs Plass, Oslo, NORWAY
- Ministry of Postal Services and Telecommunications, Moscow, RUSSIA
- Ministry of Posts and Telecommunications, Beijing, CHINA
- Optus Communications PTY. Ltd., Sydney, AUSTRALIA
- P.T. Satelit Palapa Indonesia, Jakarta, INDONESIA
- Shinawatra Satellite Public Company Ltd., Nonthaburi, THAILAND
- Space Communications Corporation (SCC), Chiyoda-ku, Tokyo, JAPAN
- Swedish Space Communications, SWEDEN
- TAO, Tokyo, JAPAN
- Telecomunicaciones De Mexico, Col. Navarte, MEXICO
- Telefusion De France (TDF), Montrouge, FRANCE
- Telesat Canada, Gloucester, ON, CANADA
- Telespazio, Rome, ITALY

5.6. Geostationary Satellite Constellations in the Planning Stages

The following list contains GEO constellations in the planning stages; most do not plan to make positioning and integral part of their service.

- Advanced Communication Corporation, Little Rock, AR USA
- CD Radio Inc., Washington, DC USA
- Comision Nacional De Telecominicaciones (CNT), Buenos Aires, ARGENTINA Directsat Corporation, Fremont, CA USA
- Dominion Video Satellite Inc. and Video Satellite Systems, Naples, FL USA
- Echostar Communications Corporation, Englewood, CO USA
- International Radio Satellite Corporation, Washington, DC USA
- Ministry of Communications, Chongro-gu Seoul KOREA

- Ministry of Postal Services and Telecommunications, Moscow RUSSIA
- Ministry of Post, Telegraph and Telephone, Riyadh, Saudi Arabia
- Nippon Telegraph and Telephone Corporation (NTT), Tokyo, JAPAN
- Norris Satellite Communications Inc., WGCB-TV 49, Red Lion, PA USA
- P.T. Mediacitra Indostar, Jakarta, INDONESIA
- Tempo Satellite Inc., Littleton, CO USA
- TMI Communications and Company Limited Partnership, Ottawa, ON CANADA
- Worldspace Inc., Washington, DC USA

5.7. Summary and Conclusions

The following are the chief summary and conclusion points vis-à-vis GEO communications and positioning technology:

- Presently, ITS continental communications and communications in remote areas is most economically achieved by GEOs.
- Canada is a key player in GEOs via TMI Communications, Ottawa who have a strong alliance with AMSC, Reston, VA. Each has their own mobile satellite (MSAT) to back one another up, but TMI has yet to launch their satellite. Thus, the positioning capability has yet to be implemented.
- QUALCOMM, San Diego has had a great deal of success employing both GEO communications and positioning. Their European alliance in Etel-Tracs has assisted in spreading this technology around the world.
- Through TMI (and resellers Bell Mobility, Glentel and InfoSat) and AMSC, Canadian firms have a ready made vehicle to form strategic alliances for building applications using GEO-based technology.

5.8. References

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6. LOW EARTH ORBIT (LEO) SATELLITE SYSTEMS: LITTLE LEO'S AND BIG LEO'S

6.1. INTRODUCTION

Although geostationary satellites offer solutions today, the spotlight has switched to a development of the future - the race to deploy full LEO constellations that will provide global, low powered, low cost, handheld communications. Unlike high-orbit geostationary satellites, LEOs orbit at distances of less than 2000 kilometers.

The only Little LEO-based AVLN systems ready for market is the Orbcomm system, which works in conjunction with its respective communications system. Many companies with AVLN systems claim to be compatible with future LEO networks. Orbcomm's plan calls for 34 satellites. Communications from satellite to subscriber is on a VHF channel at 137-138 MHz at 4,800 bps; from subscriber to satellite, communications are on VHF 148-150.5 MHz at 2,400 bps. Companies from 20 countries have signed up as service providers. Orbcomm's strategy is to convince its re-sellers to work with system integrators to develop end user systems.

6.2. GENERIC LEO BASED POSITIONING SYSTEMS

Many different types of positioning will emerge as LEO constellations become operational. However, the basic technique involves the combination of Doppler and ranging measurements (see Figure 6-1).

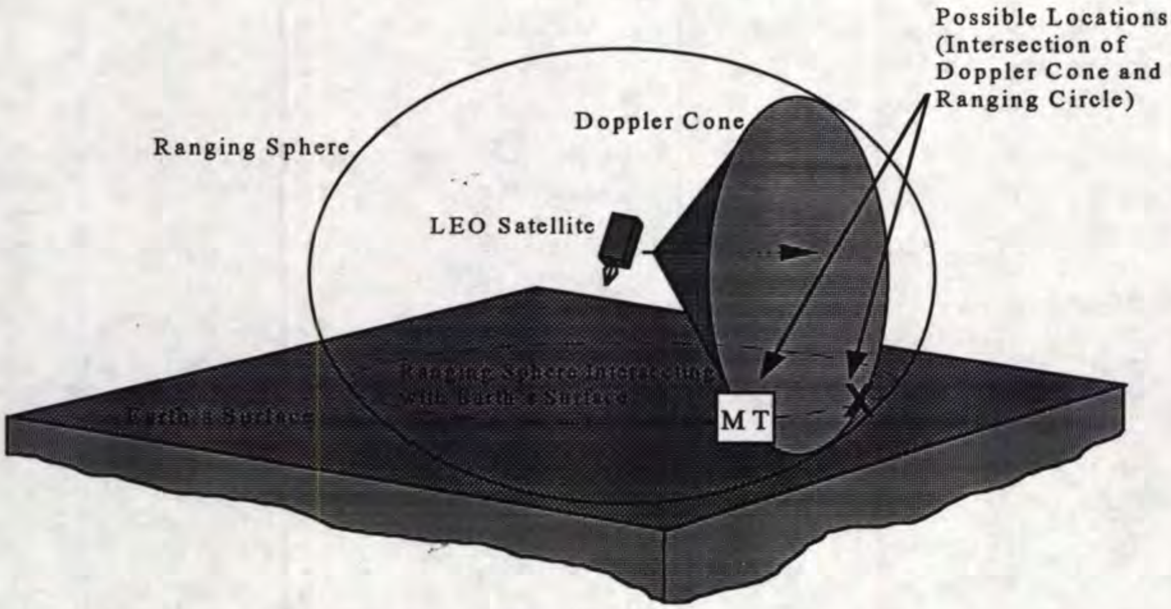

Figure 6-1: LEO Positioning Concept

It is assumed that the speed of the mobile terminal is negligible relative to the speed of the satellite. therefore the Doppler shift calculation is made at the satellite only. Ranging information is acquired from the round trip delay of the signal. Using one satellite, a solution to the mobile terminal's position is found. The solution is not unique, but it is also known what particular spot beam the communications link is on, which resolves the ambiguity. Furthermore, intelligent software and the MT's last known position are used to quickly resolve any ambiguities. Although many companies claim that their LEO technology will achieve position accuracies of 100 metres, a more reasonable figure is 1000 metres.

Typical mobile terminals are the size of a cellular phone and transmit brief coded digital messages at two to five watts. The devices may be battery operated. Communications costs run between US$ 0.35 and US$ 5 per minute.

6.3. Orbcomm Tracking System

Orbcomm is a Little LEO-based satellite data and tracking service. Two satellites were launched in April of 1995. Orbcomm was the first to offer commercial LEO communications on Feb. 1, 1996. By the end of 1997, 26 satellites will be available; 36 will be operational by 1999. Orbcomm is essentially a satellite communications company, however, resellers will develop applications in the fleet management, security, and SCADA sectors. The applications will include the option of LEO positioning.

The first U.S. resellers are Stevens Water Monitoring, IWL Communications, COREXCO, and ARINC. Stevens Water Monitoring will transmit data on water quality at a lake in Oregon. IWL is developing a cathodic protection terminal application, and COREXCO will provide pipeline monitoring services. ARINC is initiating service with an asset tracking application, providing location information for a company that services Virginia lottery machines.

Although the Orbcomm system is only commercially available in the U.S., eventually the entire globe will be serviced. In addition to offering LEO based positioning, Orbcomm claims that it will also be the "voice of GPS™" by transmitting DGPS corrections from a base station to a remote mobile terminal, and by transmitting the corrected GPS position coordinates from the remote mobile terminal to a dispatch center. Figure 6-2 shows the position of the two operating LEOs on Saturday, March 30 at 6:10 P.M. EST. Eventually the entire Globe will be covered with the cell-like footprints of Orbcomm LEOs.

The Orbcomm system is a result of close collaboration of companies who are providing financing, equipment and services. The parent companies Orbital Sciences Corporation, Dulles, VA and Teleglobe Inc., Montreal - and its partner Technology Resources Industries Berhad of Malaysia - recently announced the completion of financing to build the next 34 satellites needed to complete the Orbcomm global satellite network. These companies, which each own 50% of the venture, have committed a total of $160 million to the project.

Orbcomm Canada, Montreal has already begun SCADA applications using LEOs where several Canadian firms have begun building applications.

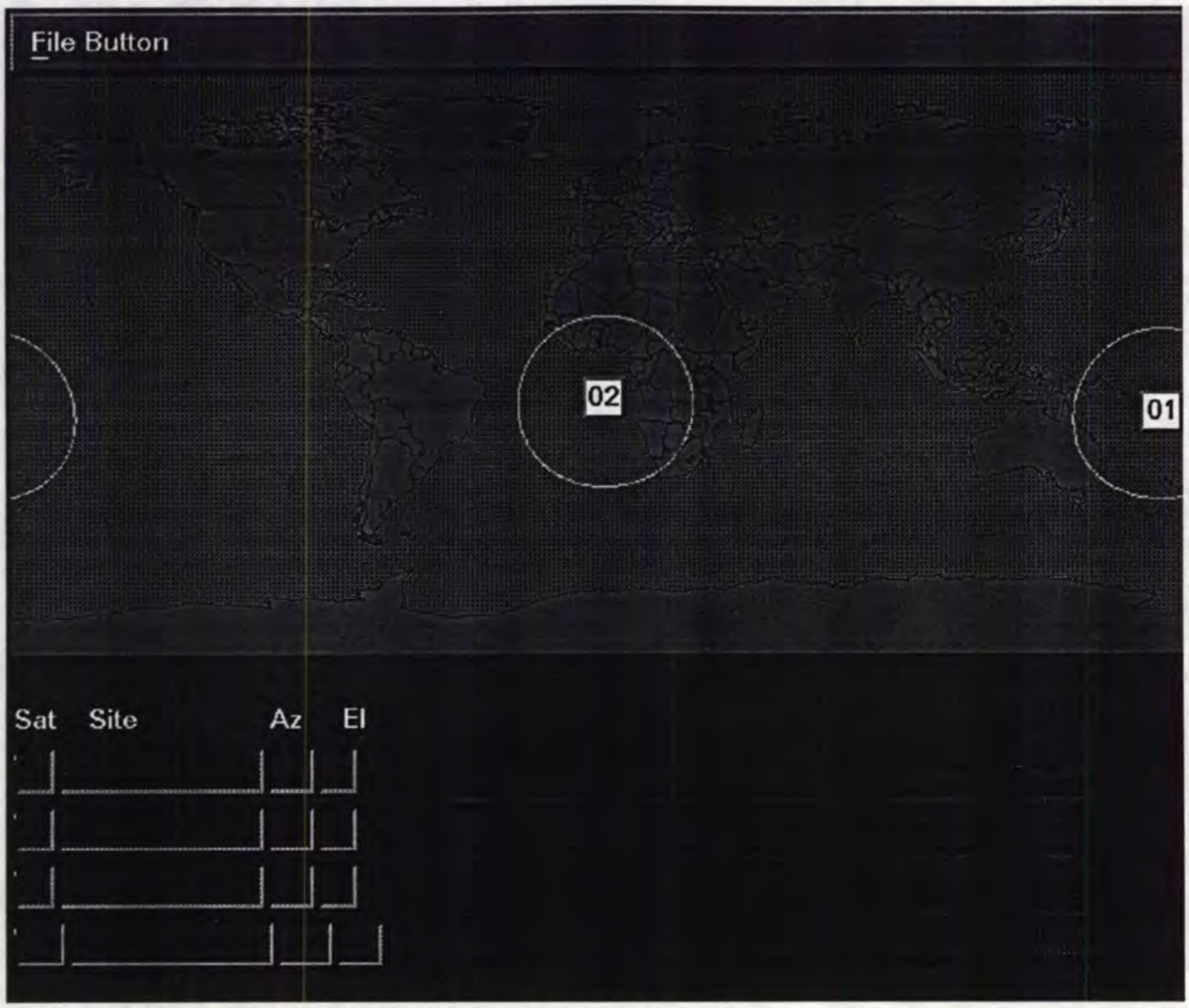

Figure 6-2: Position of Two Orbcomm LEO's on Saturday, March 30, at 6:10 P.M. EST

6.4. THE IRIDIUM BIG LEO POSITIONING TECHNOLOGY

Motorola's Iridium is an example of a big LEO satellite communications system. The Iridium constellation will consist of 66 satellites that orbit the earth at an altitude of 780 kilometers and in six inclined (near polar) orbit planes. Each satellite will project 48 beams and will cover a diameter of 4700 km. The earth will be covered by 2,150 active beams, with each one working as part of a cell-like infrastructure. The system is designed to crosslink between satellites. Gateway earth stations will provide satellite links to landlines where connections can be made appropriately. The subscriber units will be hand-held and battery powered, and the communications link will be digital and packet switched. Position data can be transmitted, and an external data interface will be available for connection to peripheral positioning devices, such as GPS or Loran units. In addition to global voice, data, and paging, the system will offer an inherent positioning service (RDSS) in the future. Their system is expected to be operational 1998.

The consortium includes Motorola, Sprint, Lockheed/Raytheon, Japan's Nippon Iridium, Saudi Arabia's Mawarid Corp., Canada's BCE Mobile, Venezuela's Muidiri Investments, Italy's STET, Korea's Hyundai Electronics, Thailand's United Communications, Russia's Krunichev Enterprises, China's China Great Wall Industry, Taiwan's Pacific Electric Wire & Cable CO., India's Infrastructure Leasing & Finance Services, Germany's Deutsche Aerospace, and UK's Vodafone Group.

6.5. Other LEO-based Positioning Technologies

Globalstar Ltd. Partnership, of San Jose, California is planning to offer position and location service to customers situated between 70 degrees north and south of the equator. Usage rates will be roughly US$ 0.45 per minute. Globalstar has received FCC approval and will be operational in 1998 with a constellation of 48 satellites using CDMA spread spectrum access techniques to provide full global services. Services will include voice, data, and global radio determination satellite positioning. Calls will be routed to customers through existing public and private telephone companies. Globalstar handsets can be used as mobile phones anywhere in the world using an individual subscriber number accessing either the local network, or the satellites directly. Globalstar is a company comprising of SS-Loral and QUALCOMM, both leaders in satellite technology. Loral is a US-based space contractor with international connections and QUALCOMM is a US company specializing in CDMA technology and spread spectrum techniques. Foreign partners include Italy's Alenia, France's Alcatel, Korea's Dacom Corporation, and the Hyundai Electronics, UK's Vodafone Group, Germany's Deutsche Aerospace AG.

Starsys Global Positioning Inc. of Maryland plans to begin launching the first of a 24 satellite constellation in 1997. Inherent positioning will be offered along with the GPS option. Some sources expect that Starsys positioning will locate the mobile terminal to within 100 to 1000 meters. The system is estimated to cost $200 million. Terminal costs are estimated to be between $75 and $250. Starsys claims that they will have 2 satellites functioning by the end of 1997; then 4 to 8 more in 1998. By the year 2000 they hope to have all 24 satellites operational.

Starsys is a reincarnated EOLE and GEOLE system that CNES (Centre Nationale d'Etude Spatial, France) built in the mid 70's. CNES has sold it to Centralized Location Service (CLS), Washington, D.C., who owns 90% of Starsys; Hughes STX owns about 5%, and Cancom, Toronto owns about 2%. Cancom is a Canadian company who also resells the OmniTRACS GEO tracking system. However the FCC has stated that Starysys is taking too long to get going, and there is pressure to acquire the financing that can make the project happen. It may be that GE is going to buy 80% of the company. Hughes and Cancom may get squeezed out, and CLS may get left with roughly 20% of Starsys.

Teledesic will link two of the USA's leading high tech companies Microsoft and McCaw Cellular in a newly proposed US$9 Billion global satellite system planned to start around 2000. By recently getting an international satellite service designation for the frequencies it will use, Teledesic has overcome a significant regulatory bottleneck. Yet skeptics remain. "The concept of deploying 900 satellites is more than the U.S., Russia, and Europe launch in one year," says Ray Peterson of Forecast International. "Teledesic is still pie in the sky. "Plans are for 840 "refrigerator-sized" satellites that will provide conventional voice channels, broad- band channels for video conferencing, and interactive multimedia. McCaw will be the initial manager of the project.

UoSat - The University of Surrey has been involved with small satellite construction for many years and worked closely with the USA's Volunteers in Technical Assistance (VITA) and others. Its first satellite was an experiment constructed and operated by the Surrey Satellite Technology Ltd. (an offshoot of the University of Surrey), and launched in January 1990. UoSat's as they are sometimes known, provide limited, but very important data in packages between small ground terminals in many countries.

Smalsat will eventually be a 36-satellite system in a low earth orbit at 1,300 to 1,500 kilometres. Prototypes were launched in July 1992 and have demonstrated store and foreward techniques at 2.4 Kbps between Russia, Australia and India. Later, data rates will increase to 9.4 Kbps.

EyeSat - EyeTel is a subsidiary of USA's Interferometrics. The first satellite was launched in 1993. EyeSats were developed from earlier prototypes. A Store and Forward system determines the position of users' assets (containers, trucks etc.). Small "tags" placed on the asset determine the position of the asset using GPS and Navstar satellites. The position of the asset is then transmitted to an EyeSat satellite and retransmitted down to a control center, analyzed, and forwarded to the customer.

6.6. SUMMARY AND CONCLUSIONS

The following are the key summary and conclusions items for LEOs:

- Economical satellite-based communications and positioning will be offered by the several LEO-based systems towards the end of the decade.
- Presently, Orbcomm Canada and Orbcomm USA are the only functioning LEO based systems with two satellites launched to serve static applications such as SCADA in remote areas and asset management.
- LEOs will have inherent communications and positioning coupled together, however, for higher accuracy GPS will be combined in a the same black box as the communications device.
- LEO systems are being launched as infrastructures with alliances made with solution providers - who will resell time and build applications for end users. Canadian firms have the possibility to be strategically positioned (via Teleglobe Canada and Orbcomm Canada) to be system integrators and solution providers of LEO-based positioning and navigation systems worldwide.

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7. MEDIUM EARTH ORBIT (MEO) SATELLITE SYSTEMS

7.1. INTRODUCTION

GEO satellites are at altitudes of 36,000 km, LEO's are at between 500 km and 2000 km. Mid Earth Orbit satellites are at altitudes of roughly 8000 km. No MEO satellites have yet been launched, but at least two are in the planning stages, and both will offer inherent position and tracking services.

Figure 7-1 shows the orbital altitudes of the MEO constellations Odyssey and Ellipso Concordia (the Ellipso network also consists of the Borealis constellation). Odyssey will be at 10,354 km while Ellipso Concordia will be an equatorial orbit at 8,040 km. Both will offer position and tracking service.

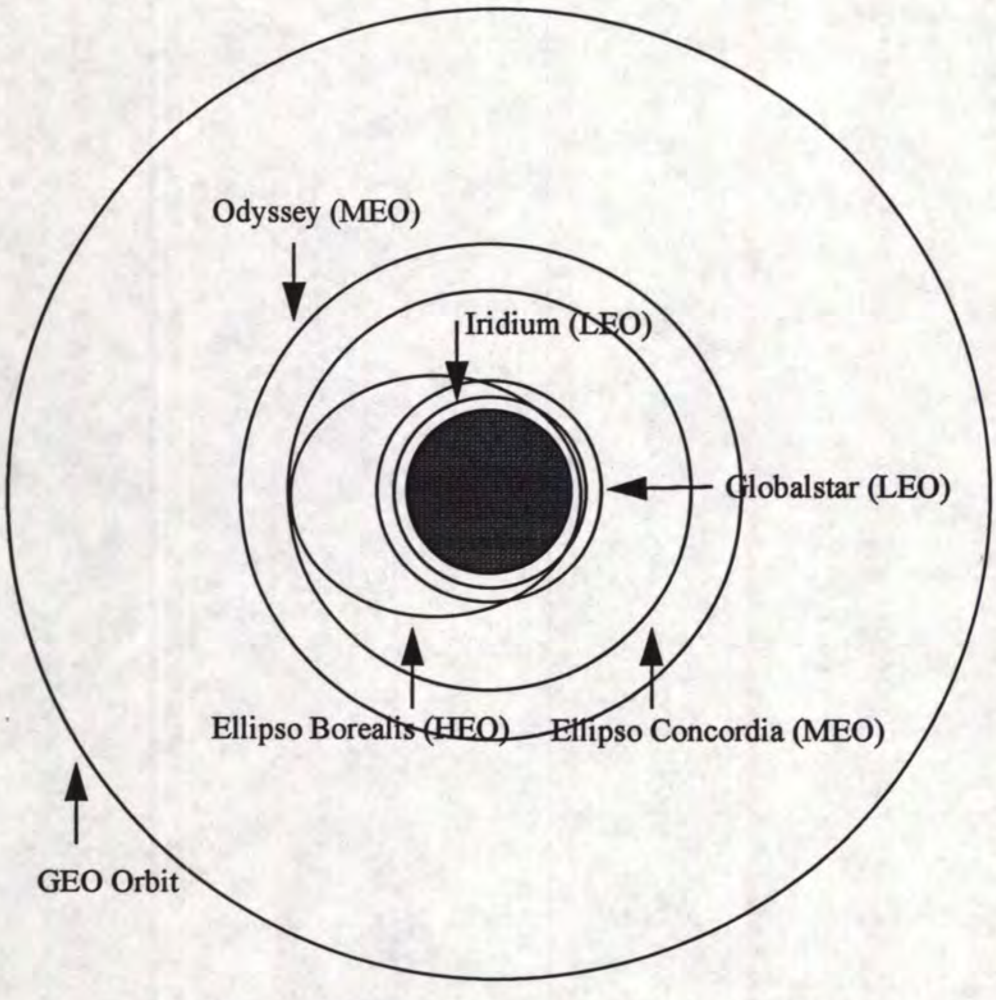

Figure 7-1: Odyssey and Ellipso Orbits Relative to LEO's and GEO's

A constellation of MEO's called Odyssey is in the design stage. Teleglobe and TRW are envisioning 12 satellites in space by the year 2000. Teleglobe claims that MEOs are the optimum constellation: lower power than geostationary; less satellites to provide global coverage than

LEOs; overall more economical. Another constellation by Ellipsat called Ellipso will incorporate MEO and Highly Elliptical Orbit (HEO) technology.

7.2. Generic MEO Based Positioning

There are no MEO satellite constellations in orbit and hence no operational positioning technology available. However, the generic method will be similar to that described for LEOs; ranging and Doppler calculations are combined to arrive at an ambiguous solution. The ambiguities are removed by knowing what particular spot beam the communication is on; furthermore, the mobile terminal's previously known position is used to remove any ambiguities. A conservative estimate as to the position accuracy is 1000 metres, although better algorithms will be developed to produce better results.

7.3. Odyssey

Odyssey is a planned global personal communications system using 12 low earth orbit satellites together with ground control stations as gateways to local networks for voice and data communications to hand-held terminals worldwide. Inherent positioning will be part of the services offered. Participants in the system design group include USA's Harris Corporation, Northern Telecom, France's Thomson-CSF, Canada's Aerospace Ltd., Germany's ANT Nachrichtentechnik GBH.

The system will be operational in the year 2000 and will cover the major land masses. CDMA digital communications will be used on 61 beams per satellite for a total of 732 beams. The mobile downlink frequency will 2483.5-2500 MHz (S-band) and the mobile uplink frequency range will be 1610-1626.6 MHz (L-band). The system will cost US$1.8 Billion, the mobile terminal cost will be roughly US$300, and the call rates will be close to US$ 0.65 per minute.

7.4. Ellipso: Concordia and Borealis

Ellipsat plans to have 24 Ellipso satellites operation by the end of 1998. Voice, data, fax, paging, messaging, and inherent positioning will be offered. Six experimental spacecraft have approval of the USA's Federal Communications Commission (FCC). Contracts exist with countries including Canada, Mexico, Israel, Australia.

FDMA (Frequency Division Multiple Access) and CDMA (Code Division Multiple Access) techniques will be used on 61 spot beams per satellite. Mobile downlink communications will be on the 2483.5-2500 MHz frequency band (S-band), while mobile uplink communications will be at 1610-1626.5 MHz (L-band). Coverage will be complete for areas north of 50 degrees south. Two constellations make up the network: Borealis (HEO); Concordia (MEO). Concordia will service the southern hemisphere (only north of 50 degrees south), while Borealis will service the northern hemisphere.

The system will cost US$750 Million, the mobile terminal will cost roughly US$1000, and usage rates will be close to US$.5 per minute.

7.5. SUMMARY AND CONCLUSIONS

The following summary and conclusion relates to MEOs:

- Odyssey will offer personal communications of voice and data in hand held units costing about $300 by the turn of the century. Connections to the Internet is also an important dimension of this futuristic technology.
- Canadian firms have an entry into this technology via Northern Telecom and Aerospace Ltd. who are participants in Odyssey.

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8. HIGHLY ELLIPTICAL ORBIT (HEO) SYSTEMS

8.1. INTRODUCTION

A constellation of HEOs, called ,Archimedes, has been designed by the European Space Agency. These satellites will have a 1,000 kilometers altitude at the perigee (near the earth) and 26,800 kilometers at the apogee (far from the earth). This design is supposed to provide higher vertical angles to the satellite, which is good in urban canyons. The European Space Agency claims that HEOs will provide satisfactory angles in cities and have large enough capacity for television to be beamed into cars, and provide personal communications. However, some experts doubt this claim.

The ARCHIMEDES satellite system consists of a constellation of four satellites in 12 hour Molnyia orbits. Each satellite hovers for six hours per day over Europe at an elevation angle of greater than 70 degrees. By spacing the satellites in orbit planes 90 degrees apart, full 24-hour coverage is provided. By using HEO orbits, a high elevation angle line-of-sight path between the mobile user and satellite can be maintained, even at northerly latitudes where signal fade and blockage will disrupt transmissions to and from a GEO satellite.

ESA plans for the first spacecraft to be launched in 1997. ESA will only commit to this plan if a commercial consortium can be formed to provide the remainder of the first generation system. Commercial partners, therefore, are required to sponsor the recurring development costs. Looking beyond the first generation system, subsequent generations could be expanded to cover other regions to build ARCHIMEDES into a global, mobile satellite system.

The system has the potential for mobile positioning service. However, it has not been decided whether or not the service will be offered.

8.2. GENERIC HEO BASED POSITIONING

There are no HEO satellite constellations in orbit and hence no operational positioning technology available. However, the generic method will be similar to that described for LEOs; ranging and Doppler calculations are combined to arrive at an ambiguous solution. The ambiguities are removed by knowing what particular spot beam the communication is on; furthermore, the mobile terminal's previously known position is used to remove any ambiguities. A conservative estimate as to the position accuracy is 1000 metres, although better algorithms will be developed to produce better results.

8.3. REFERENCES

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Part III: Terrestrial Radio Frequency (RF) Based Positioning Systems

9. LORAN-C COVERAGE AND ENHANCEMENTS

9.1. COVERAGE

This chapter is taken from Krakiwsky et al.[1990] and modified to reflect the completion of the mid-continent placement of four new transmitting stations.

The current Loran-C coverage in North America is shown in Figure 9-1 which is derived from RTAC [1987] with slight modification. The U.S. mid-continent expansion project was completed in 1992 (circa) has resulted in complete coverage of the U.S. and significant improvement new coverage in Western Canada. This coverage, determined by the U.S. Coast Guard, is shown in Figure 9-2.

Loran-C transmitter positions are referred to World Geodetic System 1972 (WGS72), a geocentric reference system whose relation with other systems such as WGS84 or the North American Datum 1983 (NAD83) is precisely known. A comparison of Figures 9.1 and 9.2 shows that uninterrupted coverage is available for trans-Canada road users. This coverage satisfies many road users provided proper calibration is carried out [Lachapelle & Townsend, 1990]. It should be noted that the new coverage still falls short of the RTAC desired coverage. The number and configuration of additional stations required to complete the desired coverage was studied by Transport Canada [1983] and RTAC [1987]; the findings of the RTAC sponsored study were also described by Hamilton & Polhemus [1986]. The number of new stations required varies from 7 to 12. The transmitting power requirements and related costs also vary significantly. The differences between the two studies, which are due to a number of factors such as different assumptions regarding conductivity and atmospheric noise, are currently being analyzed.

9.2. EQUIPMENT AND ACCURACY

Loran-C user equipment has matured steadily during the past 20 years. Competitiveness among manufacturers specializing in land vehicle user products appears to be healthy and their equipment already satisfies most requirements in terms of cost, reliability, ruggedness, size and power consumption. Nowadays, reliable and accurate low power Loran-C receivers packaged on a 6 in. x 6 in. board can be procured for well below $1,000 in large quantities. The availability of such user equipment may well be the strongest point in favour of Loran-C today for land navigation users.

The accuracy performance of Loran-C can be improved by proper calibration which can take different forms. In some cases, detailed conductivity measurements can be performed to estimate more effectively the secondary phase lag in the coverage areas of interest. Long term averaged or on-line weather data can be used to decrease the effects of seasonal and other weather related variations. In mountainous area, topographic models can be used together with conductivity measurements to estimate the secondary phase lag on the ground. Direct en route calibration with an accurate positioning system is becoming realistic with the advent of GPS; an accuracy of 50 to 100m may be achievable even in mountainous areas, depending how weather effects are taken into account.

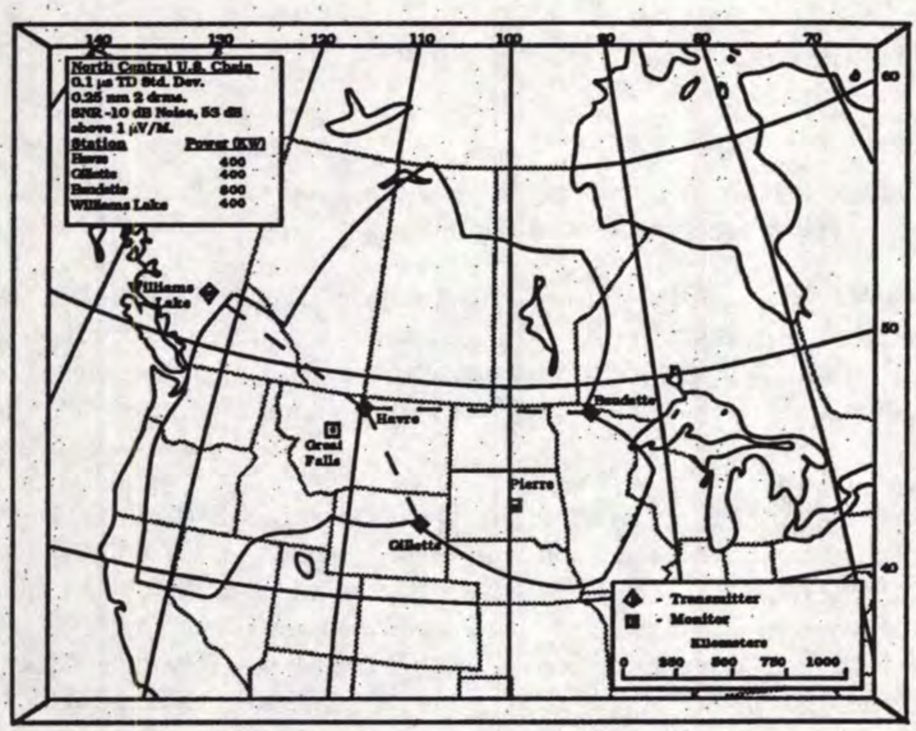

Figure 9-1: Coverage in North America [1989] (before expansion)

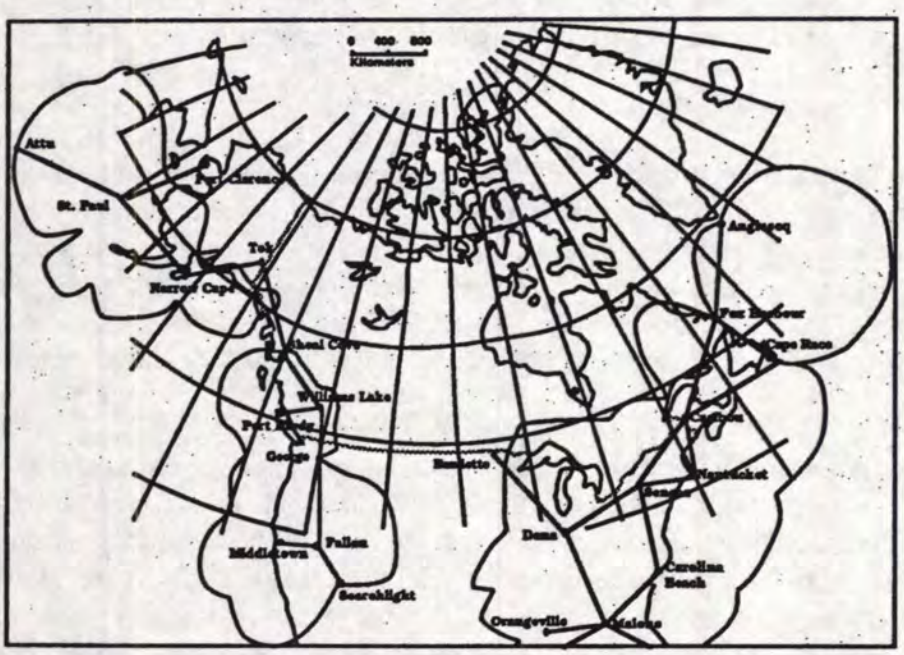

Figure 9-2:Loran-C Coverage in Western Canada After Expansion (After Heyes [1988])

The use of the differential Loran-C (DLC) mode, where a monitor station installed at a known location in the area of interest broadcasts differential TD corrections, can improve the performance of Loran-C dramatically in areas where the conductivity is fairly constant and the topography relatively flat. The most suitable environment for DLC is evidently the marine one. Accuracy's of 8 to 20 m have been confirmed by the U.S. Coast Guard [Viehweg et al., 1988]. DLC for land navigation cannot however deliver the above performance except in areas relatively close to the monitor due to ground conductivity variations and spatial weather variation effects [e.g., Lilley and Edwards, 1986]. The use of some of the above combinations would likely result in a level of accuracy of the order of 50 - 100 m, which would fulfill many of the requirements discussed in the previous Section.

9.3. LORAN-C INTERNATIONALLY

Important developments related to Loran-C occurring outside Canada may have an impact inside Canada. The U.S.A., through the Federal Aviation Administration, has implemented Loran-C as a supplemental navaid for en route navigation, terminal and non-precision approaches in the U.S. National Airspace System [Sherman, 1987; Kern, 1989]. Loran-C has already been approved for some 12 airport sites. Some 200 monitor stations are being deployed at VOR stations to monitor the integrity of Loran-C. The U.S. mid-continent expansion project referred to earlier is primarily aimed at that project. An estimated 70,000 aircrafts in the U.S.A. are equipped with Loran-C receivers.

Two different types of receivers have been approved by the FAA up to now. In Europe, many new chains are under consideration for the North Sea, parts of the North Atlantic and the Mediterranean [Stratton, 1995]. The International Association of Lighthouse Authorities (IALA) is strongly supporting the expansion of Loran-C for maritime use in many parts of the world for increased safety of navigation [Matthews, 1989].

The above developments related to Loran-C point to an increased use of the system during the next 10 to 25 years for multi-modal applications. The infrastructure required to support some of the above programs is complex and costly and will very likely result in the system being used extensively in the foreseeable future. Use of the system has not yet peaked; this is likely to occur between 1995 and 2000. With the success of GPS and similar satellite-based systems, one would assume that sometime between 2000 and 2015, the gradual phasing out of Loran-C would naturally begin. For two decades, both Loran-C and satellite-based systems will coexist to provide additional reliability and integrity in a world increasingly concerned about safety and protection of the environment.

9.4. SUMMARY AND CONCLUSIONS

The following are the main summary and conclusion points related to Loran-C:

- Loran-C coverage is now complete in most of North America except for the northern part of the continent. Its advocates believe that it can be used as an independent system to add redundancy to integrated navigation systems - mainly for marine and air navigation systems.

- Loran-C is a sunset technology with limited growth, thus Canadian firms have very limited opportunities in this domain.

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10. PAGING BASED SYSTEMS

10.1. OVERVIEW

Paging based systems are being considered more and more in the urban areas as an economical and efficient way of providing fleet management and mobile data communications for multiple groups of end users. The reasons for its popularity are the low cost of two way paging and the convenience of having both positioning and data communications. Below, several systems are given as examples of the way in which this technology is being implemented.

10.2. AIRTOUCH TELETRAC SYSTEMS INC.

- Airtouch Teletrac Systems Inc. of Garden Grove, California previously PacTel Teletrac Systems Inc. has developed a fleet management and safety-security system based on paging as its method of communications as shown in Figure 10-1.

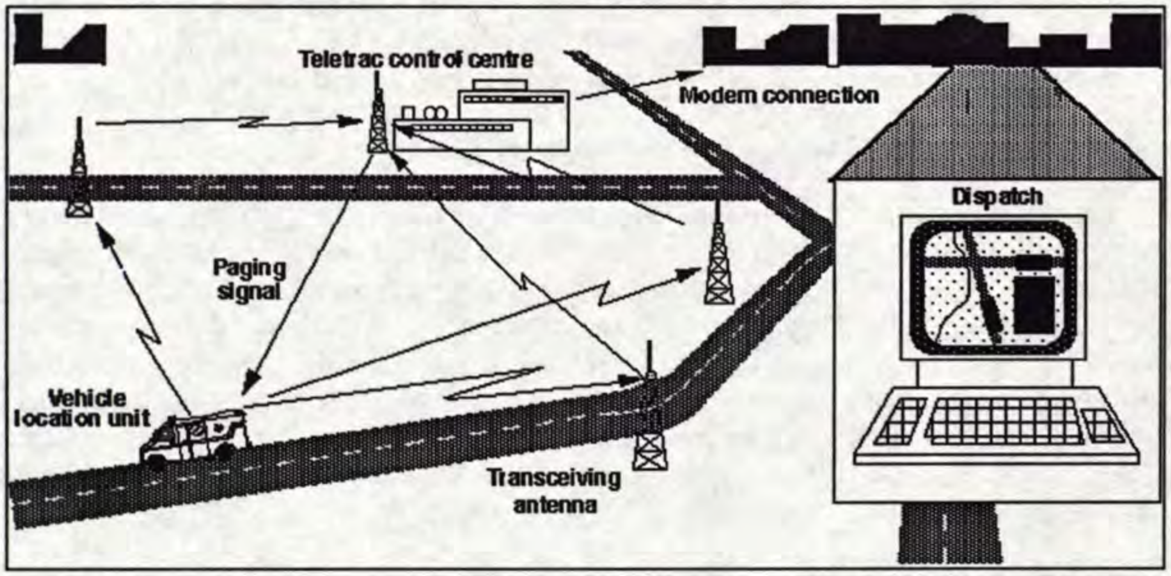

Figure 10-1: Airtouch Teletrac System Overview

The system was first introduced in 1992 and they are now marketing a second generation model. Strategic alliances include:

- International Teletrac Systems (ITS), Inglewood, California, USA.
- Mitsubishi International Corp., Japan. (transceiver)
- Matsushita Electric Works Ltd., Japan.
- Samsung Electronics, Seoul, Korea.
- Kenwood Corp., USA.
- Etak Inc., Menlo Park, California, USA.
- Tadiran, Ltd (Israel) on transceiver

Audiovox.Airtouch is currently marketing both an OEM and a retrofit version of its hardware which target commercial and government fleets as well as private consumers. The system is called the Fleet Director. They claim to be the largest provider of metropolitan based fleet location and information services in the world including cities like Los Angeles, Detroit, Chicago, Dallas, Houston and Miami with over 35000 users in these cities and over 5 million vehicles and messages per month. The company has FCC licenses to operate in 140 of the largest US metropolitan areas.

10.2.1. System Configuration

A paging system is used for both positioning and communications functions. The on board vehicle system consists of a single Vehicle Location Unit (VLU) which were engineered and built by Mitsubishi, Samsung, Kenwood and Audiovox. The VLU can be equipped with route guidance and navigation, scheduling, 2-way communication and location, Mobile yellow pages (under development), Traffic Information and development (under development), Emergency Roadside Assistance and Stolen Vehicle Recovery, Remote Door Locks, Vehicle Location using touch tone phones, and a panic button which allows the operator to call for help. The systems can also be outfitted with a message display terminal for both message and status display.

10.2.2. Communication and Location Determination

The system requires the dispatch to have a computer with modem to connect into the Teletrac network. When the dispatch requests a location, the Teletrac network would send a paging signal to the VDU in the vehicle. The VDU responds with a time tagged signal at 900 MHz. The signal is received by at least 3 transceivers towers and the location is determined by hyperbolic determination of the time difference between the reception of the signals. The location is then sent to the dispatchers workstation displaying the location of the vehicle on an Etak based map usually within 3 to 5 seconds. The system allows for the simultaneous tracking of multiple vehicles and is accurate to about 30 m. Speed, position and direction of travel are computed and displayed for each vehicle.

Recent investment by Toronto Dominion Bank and related investors have given a Canadian connection to the system. To date, there have been no installations in Canadian cities; therefore there exists an opportunity for Canadian firms implement the system in the larger cities in Canada.

10.3. Pinpoint Communications Inc.

Pinpoint Communications has developed a fleet management system which they are marketing under the name ARRAY - see Figure 10-2. This system was first introduced in 1992. Their only known current strategic alliance is with Westinghouse, USA. Pinpoint has been issued licenses by the FCC to operate in Atlanta, Baltimore, Boston, Dallas, Detroit, Fort Lauderdale, Houston, Miami, Minneapolis, Oakland, Philadelphia, Phoenix, San Diego, San Francisco, San Jose, St. Louis and Washington DC. Fort Worth, St. Paul and Los Angeles are expected to be added soon.

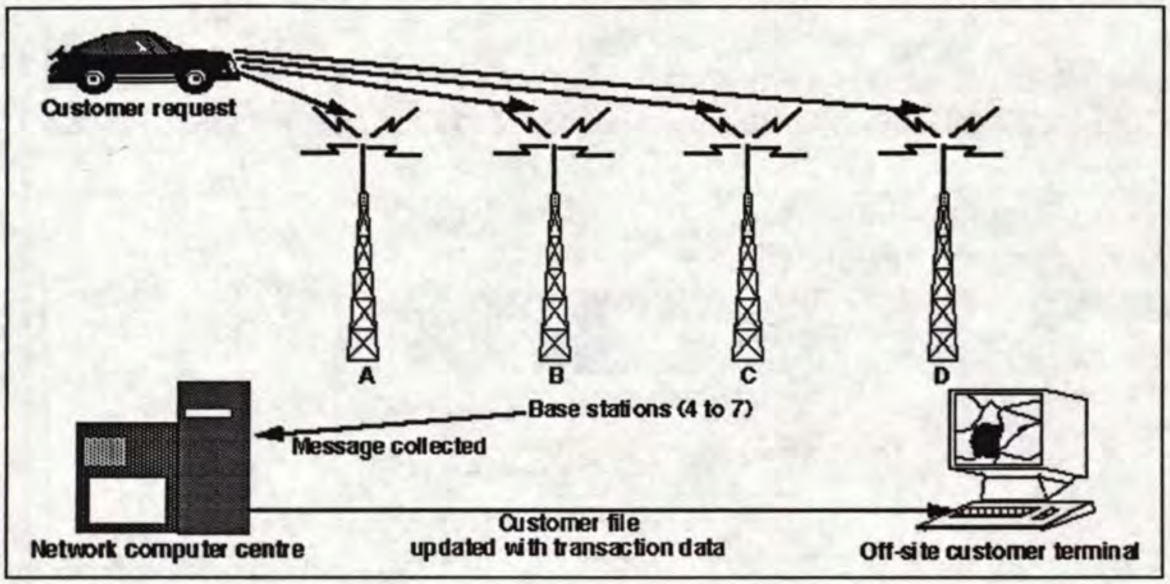

Figure 10-2: ARRAY Network Transaction

10.3.1. System Configuration

The Array system is PC based. Both the Vehicle and Dispatch can be run from any PC which has the strength to run the software and handle the proprietary modems (named the "TransModem") data transmission rate of 38.4Kbps. The TransModem can operate as a data radio receiver, data modem and locating transponder.

10.3.2. Communication and Location Determination

The Pinpoint Array's mobile unit transmits a time marked data packet which must be received by a minimum of three towers. This information is transmitted to a central processing center and the vehicles position is determined through time difference of arrival hyperbolic multi-laterations. The system operates in the 902-928 MHz range and has an individual transceiver rate of 38.4 Kbps and a network rate of 380Kbps. It is operated as a Intelligent Mobile Data Network (IMDN) and has the capacity to transmit 5 million data packets per hour and service more than 1 million users concurrently at a very low per packet cost.

10.4. ADVANCED SYSTEMS RESEARCH PARTY LTD.

Advanced Systems Research Party LTD. with Lend Lease Corporation LTD of Australia has developed a paging system based fleet management system. Advanced Systems Research Party is a division of British Aerospace Australia Ltd. The system is marketed under the name Quicktrak and was first announced in 1987 - see Figure 10-3. They are currently marketing a first generation system. The Quicktrak system was intended originally for fleet management but has spread into personal and home security in which alarms cannot be disabled by cutting phone lines, to monitor and report meter readings, or low inventory and faults in dispensing machines.

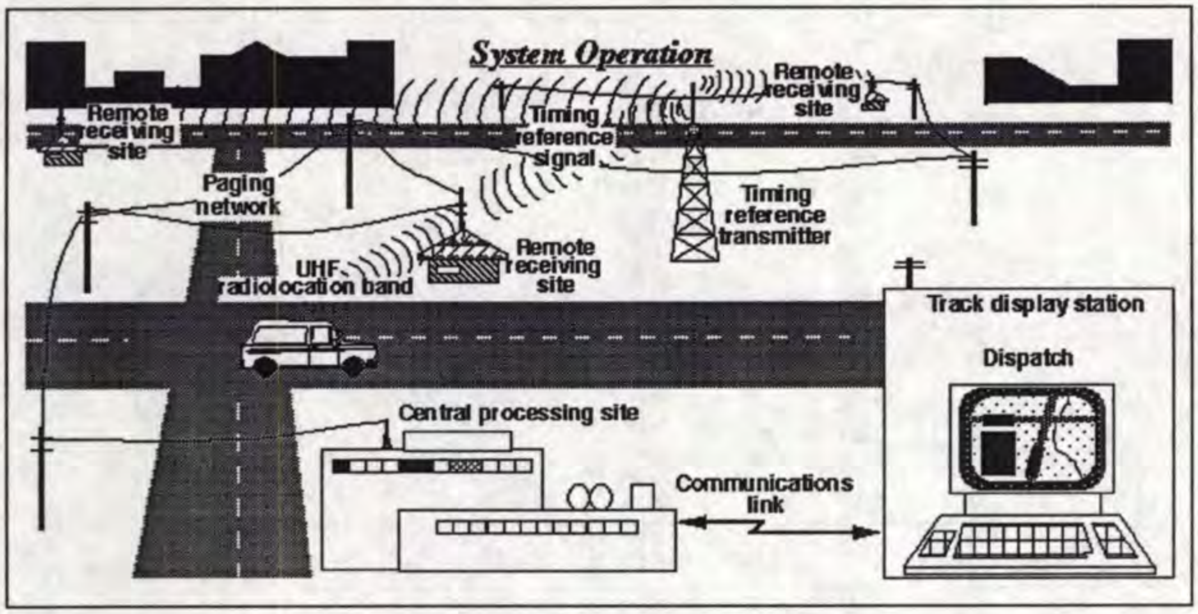

Figure 10-3: Quicktrak by Advanced Systems Research Party LTD.

10.4.1. System Configuration

The in vehicle unit consists only of a transponder consisting of a specialized paging receiver and a low power spread spectrum transmitter which is capable of transmitting only preprogrammed messages. The central processing site runs on a MicroVAX 3500 but user dispatch service is provided on a IBM PS/ 2 486. The system operates on a 2400 baud modem and uses color raster maps as it is basically a position reporting system.

10.4.2. Communication and Location Determination

The system utilizes a paging network operating in the UHF land mobile band for two way paging. Quicktrak employs code division multiple access and can accommodate 10 channels defined by carrier offsets allowing the system to track 30,000 locations per hour. The central processing site continually broadcasts a 511 bit pseudo noise code at 1Mbit per second as a reference signal. Each vehicle broadcasts the same signal either when polled or automatically. The time of arrival at a minimum of three receivers is transmitted back to the central processing site and the time difference of arrival is used to calculate the position of the vehicle using a hyperbolic navigation technique. A spread spectrum multi-lateration technique is used in severe multi-path environments. Quicktrak is able to schedule up to 10 simultaneous transponder activities while maintaining a mutual interference to signal margin of at least 60 dB.

10.5. GALAXY AVL

Galaxy Microsystems has developed an AVL system based on pager type technology shown in Figure 10-4. They were intending to run a pilot test program in Austin Texas with the assistance of Mark IV Eagle Signal, Austin Metro Group, the University of Texas Transportation Department and the Texas Department of Transportation.

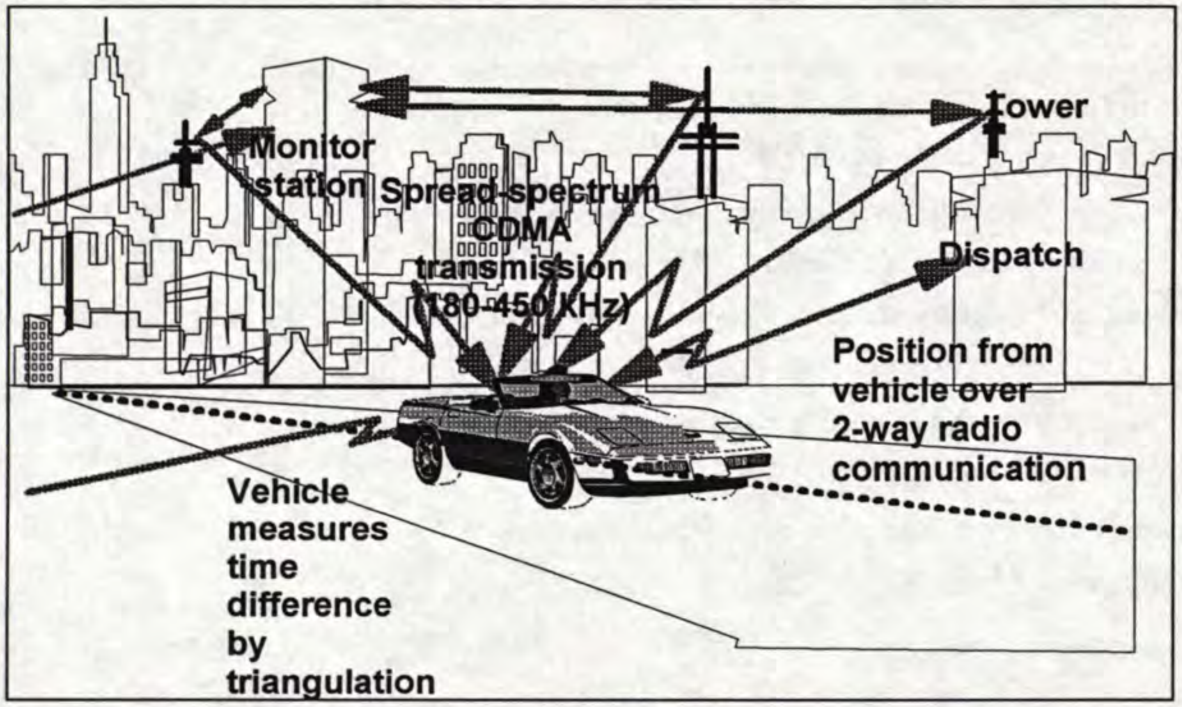

Figure 10-4: Galaxy AVL System Overview

10.5.1. System Configuration

The Galaxy AVL system uses four transmission towers placed on the perimeter of the metropolitan area. This is estimated to cost roughly $200,000 to set up. The in vehicle unit is a single circuit board which will sell for approximately $500. Galaxy is hoping to get this to a single chip set which could be installed in a cellular phone or two way radio and would sell for as little as $25.00.

10.5.2. Communication and Location Determination

The Galaxy AVL system is different than most others in that the calculation and determination of position is handled by the in vehicle unit and not a central dispatch. The four transmission towers each broadcast a spread spectrum Code Division Multiple Access modulated signal in the LF band (180-450 kHz) at approximately 30W. The systems is monitored by a central controller. This controller maintains the alignment of the signals from the four towers. Three of these are used to calculate by Time Difference of Arrival the position of the vehicle using the fourth as a reference. The composite signal is separated, their corresponding tracking loop and stamped data is converted to digital format with an analog circuit. The control, processing, clock, and user interface operate digitally. They estimate their system to have an accuracy of better than 10M. The method of informing the central office of vehicle location has not yet been determined but will be some form of two way radio.

10.6. Other System Developers

There are several other companies with either production models in the market or working on new systems whose communications are pager based. They include:

1. Bell Corporation of San Diego, CA.
2. Columbus Electronic Navigation Systems of the UK.
3. Ford Motor Company of the UK.
4. International Road Dynamics of Saskatoon, Saskatchewan.
5. NUKEM CmbH. Nutronic Division of Germany.
6. Pulsearch Navigation Systems Inc. of Calgary, Alberta.
7. Sumitomo Electric Industries of Japan.
8. Terrapin Position & Navigation Systems of Garden Grove, CA.
9. Trafficmaster of the UK.

10.7. Summary and Conclusions

The following are summary and conclusions related to paging-based communications and positioning systems:

- Terrestrial paging-based communications and positioning systems are numerous and present a huge opportunity for Canadian firms, however, the competition is high.
- There are no Canadian, paging based positioning systems, but the Toronto Dominion Bank investment in the Air Touch Teletrac system may be an opportunity worth exploring and supporting.
- The use of paging for communications in ITS navigation systems is growing and is a technology worth considering because of its low cost.

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11. CELLULAR BASED LOCATION SYSTEMS

11.1. Introduction

There are more than 24 million analogue cellular phone users in the United States alone. Therefore, Cellular based location systems must be considered. Most emergency response agencies are capable of determining the location of 911 call made by a telephone on a land-line network. However, there are no established systems that are capable of determining the location of a mobile caller from a wireless phone. It is expected that by the summer of 1996 the Federal Communications Commission (FCC) in the U.S. will require that all cellular phone providers know the position of a caller to within a quarter of a mile. If the FCC proceeds with this regulation, it is expected that Canada will follow. The emergency 911 market is driving the emergence of cellular positioning technology.

Because of its wide acceptance and coverage (for example, over 90 percent of the entire U.S. population and 60 percent of the geography), cellular technology has attracted significant interest in the AVLN marketplace as a convenient way to transmit data over the air. According to an Owner-Operator Magazine reader survey (Jan/Feb 95) of 3319 drivers throughout North America, in the trucking industry over 53% of owner-operators utilize a cellular phone for business purposes in their truck. Of those who do not own a phone, 85% are planning a purchase in 1995-6. Complete two-way voice (67%) is the highest rated single feature that owner operators want in mobile communication and information system. Most drivers (62%) expect to pay between $50 and $200 a month for a mobile communications system with complete voice and data capabilities.

The current standard cellular air interface specification in North America is named AMPS (Advanced Mobile Phone Service). Designed for analogue voice cellular, AMPS is required on all phones in North America. To provide a common medium for nationwide roaming, it also is required as the second mode on all next-generation phone designs (including digital cellular). Various techniques and ideas for broadcasting data using cellular technology exist. On analogue voice networks, off-the-shelf modems can be purchased that will modulate data over cellular. Voice cannot be used, however, until the modem is disconnected.

Several clever filtering and multiplexing schemes are in development to mix voice and data simultaneously over current analogue cellular networks. In the future, the carriers will directly provide digital services, such as CDPD (cellular digital packet data) and digital cellular. CDPD, also known as Celluplan II, is a data strategy that utilizes idle channel space on analogue cellular networks. CDPD seems to be gaining acceptance in North America, but it may be superseded by digital cellular, which has already arrived in other parts of the world: Europe's Global System for Mobile Communications (GSM) is one example.

11.2. Generic Cellular Positioning

Two types of position calculations are used in cellular network technology: Time Difference Of Arrival (TDOA); and Direction Finding. The former uses time measurements from at least four receiving towers to define the intersection of three curves, which is the position of the caller. The second method uses at lease two (but usually more) towers equipped with direction sensitive antennas which point in the direction of the incoming call. The intersection of two directions defines the position of the caller. For TDOA measurements it is very important to use narrow correlator technology to determine when the signal has actually arrived; because the signal is a distorted analogue signal, it is difficult to determine when the same part of a signal has arrived at different receiving towers. For both types of position determination, sophisticated filtering is used to distinguish between multi-path components of the signal.

11.3. KSI, INC.

An example of the Direction Finding type of cellular system is the Direction Finding Localization System (DFLS) by KSI, Annandale, Virginia, USA. The system, shown in Figure 11-1, is designed to calculate the location, speed and heading of a wireless phone caller to a 911 service. Direction sensitive receivers are located at the cellular (or wireless) network towers, direction data from the receivers is relayed to a central station where the data is processed, and location is determined. DFLS can provide a caller's phone number and location to the area emergency services agency.

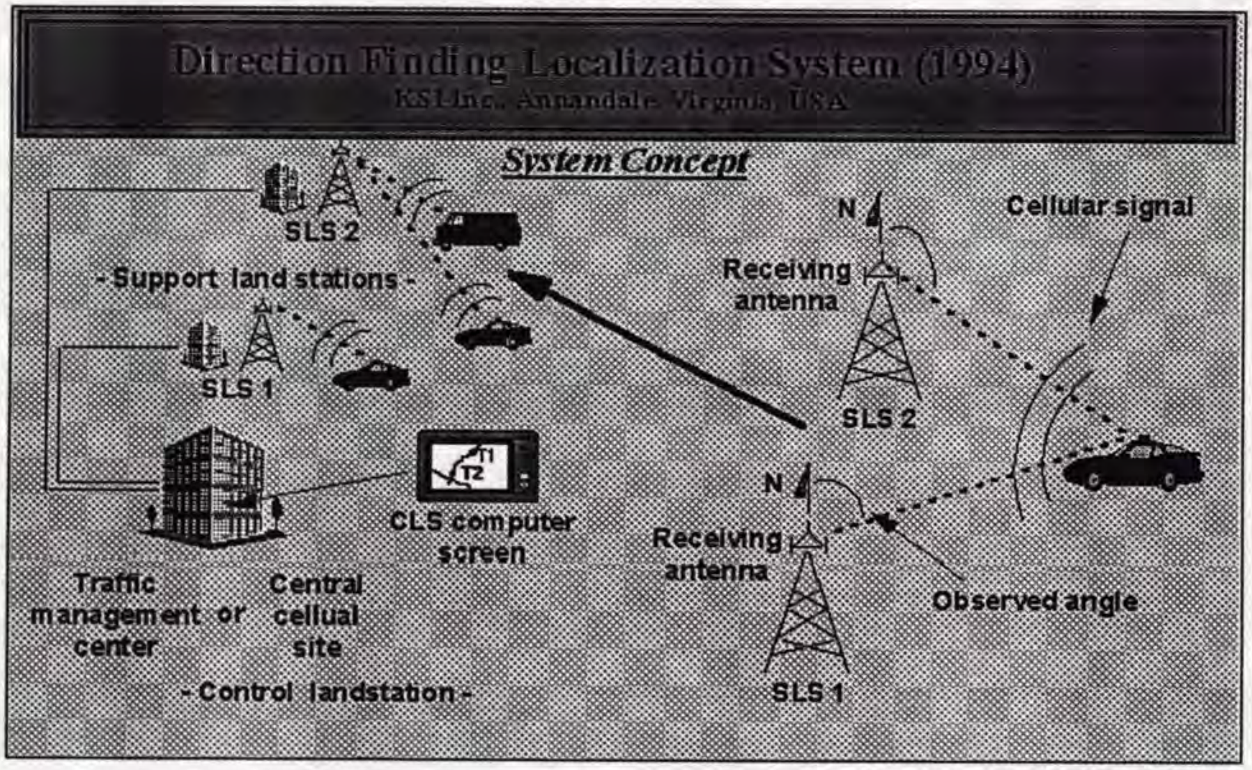

Figure 11-1: KSI Direction Finding Concept

The system achieves an average accuracy of 50 metres with two direction finding receivers, but higher accuracies can be achieved with more than two receivers. In dense urban areas, it is necessary to use more than two receivers because of multi-path effects.

KSI intends to target the emergency notification, roadside assistance, routing, and fleet management markets. A demonstration DFLS system consisting of two direction finding receivers and one control central has been operational in Virginia since 1991. KSI requires funding to make the system commercially viable. KSI estimates that a major metropolitan area can be equipped for $3-5 million. KSI has stated that they are actively looking for partners, venture capital, research funding, and operational test opportunities.

11.4. CELL-LOC SYSTEM

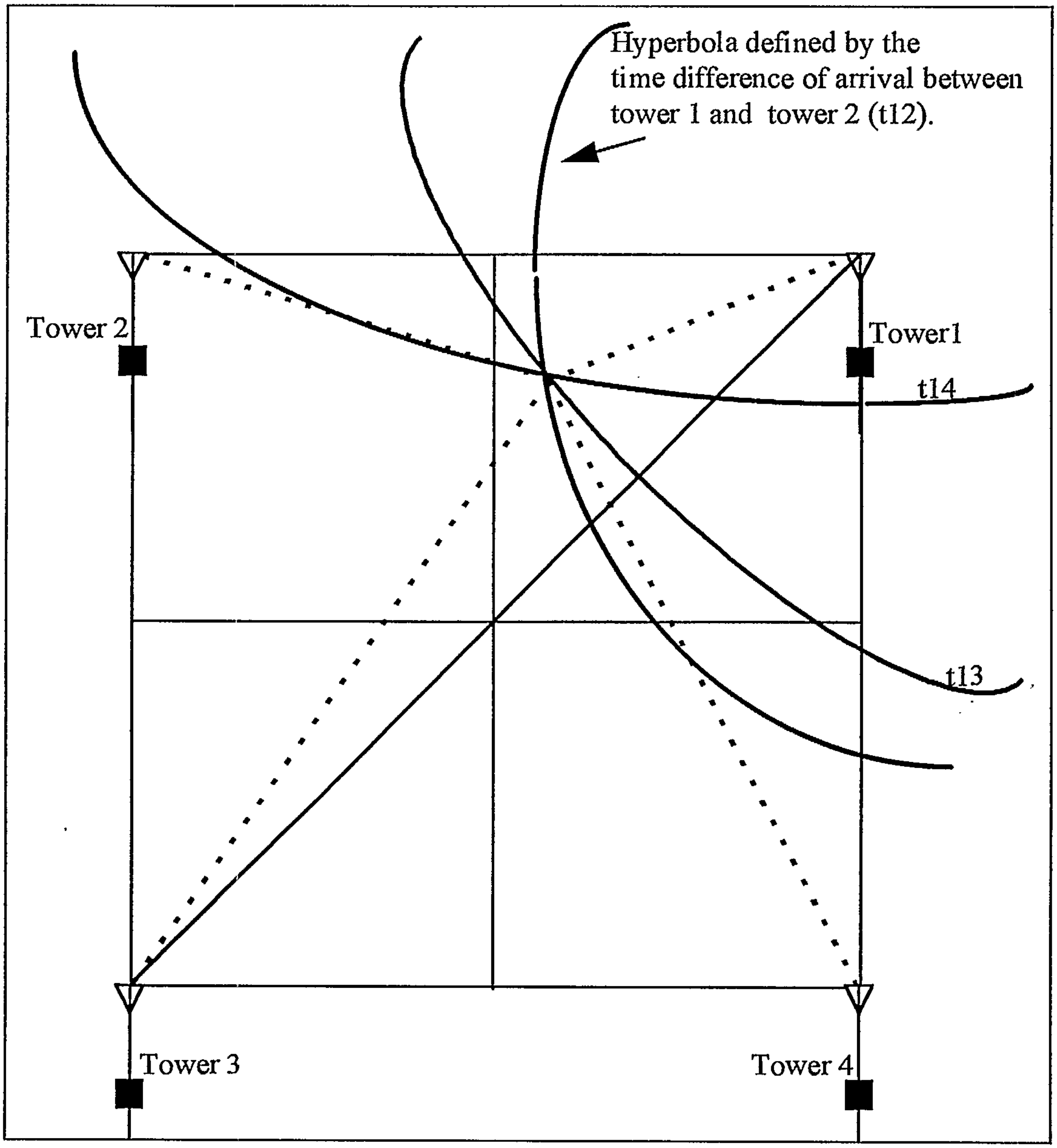

Figure 11-2: TDOA Positioning Concept

The Cell-Loc System by Cell-Loc, Inc. from Calgary Alberta, is a Time Difference Of Arrival (TDOA) system capable of achieving accuracies of under 120 metres. The hallmark of the Cell-Loc system is the super resolution technique used to combine multi-path elements of a signal and determine the precise time of arrival of the main element of the signal. For position determination, at least four different receiving towers are required, where four time of arrival measurements are made. These four time measurements define three hyperbolas as shown in Figure 11-2.

The intersection of the three hyperbolas defines a position. For a position accuracy of 100 meters, the time measurements must be made to within microseconds accuracy. Cell-Loc uses GPS receivers for timing at each cellular tower.

Cell-Loc, Inc. has performed a test of the system specifically for AGT in the spring of 1996. No specific details of the test have been released. However, Cell-Loc is pursuing a business relationship with AGT who is negotiating with the Bell family for a roll out throughout Canada. Cell-Loc claims that the market for their technology is US$90 MM in Canada and US$90 B in the U.S. Cell-Loc states that there are 2,000 cellular base stations in Canada and 20,000 base stations in the U.S., and that a base station installation can be performed for US$45 K.

11.5. OTHER CELLULAR POSITIONING DEVELOPERS

1. Associated Communications Corp
2. Engineering Research Associates (E-Systems)
3. TrackMobile, Inc.
4. US West New Vector Group
5. US WEST Technologies, Inc.
6. Lockheed Sanders, Inc.
7. Lattice Communications System Cartesia Corp Systems

11.6. SUMMARY AND CONCLUSIONS

The following summary and conclusion items related to cellular positioning:

- Canada has a promising development of cellular positioning in Cell-Loc, Calgary.
- There are seven other developers (all USA) which will be competing for the market.
- Canadian firms should study how innovative applications could be built around this technology for there is a large market with a growth potential.
- Given the soon to be available digital maps in Canada, this new positioning technology has all the necessary components for a successful product - positioning, communications (uses a standard cellular phone) and maps.

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12. AM AND FM BASED SYSTEMS

12.1. OVERVIEW

There was a great interest in this area of positioning technology in the late 1980s as alternative infrastructures such as cellular and GPS were not available. Modifications required to implement these systems is cost effective. There is a renewed interest in AM and FM broadcasting for the one way communications of transmit traffic, parking information and differential GPS corrections to vehicles. In this chapter we focus on using these signals for positioning; the hallmark of AM-FM based systems is that they are capable positioning inside buildings.

12.2. TERRAPIN POSITION AND NAVIGATION SYSTEMS

Terrapin has developed and patented a chip set called PINS (Position, Information, and Navigation System) which can in incorporated in other communications products such as cellular phones - see Figure 12-1. They have no currently marketed product and are looking to get their positioning product incorporated into someone else's product. Terrapin is promoting its chipset as ideal for use in a wide variety of applications such as Mobile 911, vehicle navigation, stolen vehicle recovery and fleet management. The chipset is very inexpensive and is expected to be found in many applications in the near future.

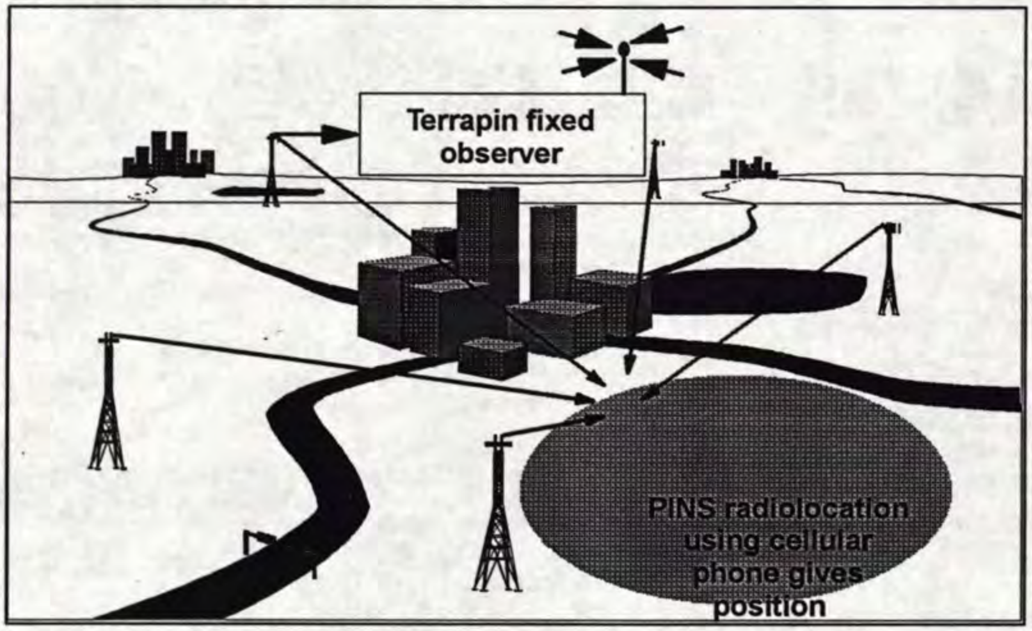

Figure 12-1: Terrapin PINS Overview

12.2.1. System Configuration

The PINS systems relies on existing FM Radio stations carrier signal at 19KHz. The other operating requirement is a Terrapin Fixed Observer Station from which the frequency drift can be measured and transmitted via a FM sub carrier signal to the in-vehicle unit. The in-vehicle unit consists of a chipset incorporated into another electronic device such as a cellular phone or even a laptop computer.

12.2.2. Communication and Location Determination

The PINS chipset follows FM Radio carrier signals at the 19KHz range as well as the subcarrier from the Observer Station. A minimum of three signals is required but the system can follow up to ten in order to improve accuracy. This information is used to calculate the position of the vehicle. Terrapin estimates the accuracy of the position determination to be within 20m. The position information can be transmitted through the equipment containing the PINS chipset (i.e. cellular phone). The sub-carrier used to transmit correction information to the receiver can also be used to transmit other information such as traffic or parking information.

12.3. Cambridge Research and Innovation Ltd.

Cambridge Research, in partnership with Lynxvale of the UK, has developed a system using terrestrial bases AM/FM radio signals. They are marketing this product in the UK under the name CURSOR (Figure 12-2). They are targeting fleet and container management, position monitoring of emergency vehicles and personnel, in-vehicle navigation and vehicle security as their primary markets. They did beta testing of the latest model in August of 1995.

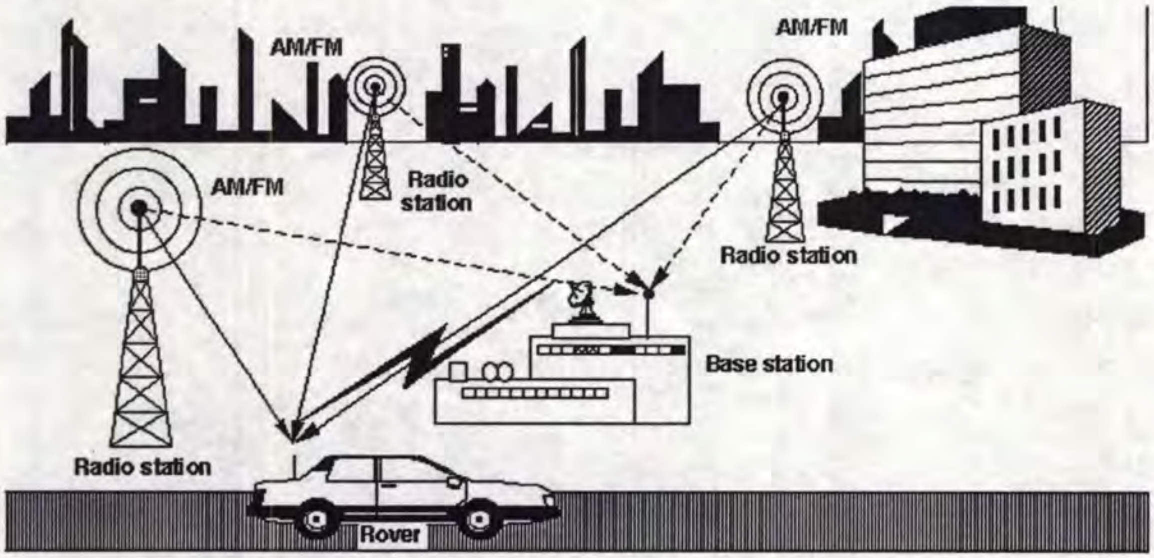

Figure 12-2: Cambridge Research's CURSOR Overview

12.3.1. System Configuration

The CURSOR system requires a minimum of three stationary AM or FM radio signals. These can be of any origin; proprietary or commercial. Two receivers, one in the vehicle whose position is to be determined and one of fixed, known location (base station), are required. This system requires integration into an existing 2-way communications system.

12.3.2. Communication and Location Determination

Both the base station and the in-vehicle receiver pick up the radio signals. A minimum of three independent signals is required. The information from one is then transmitted to the other in a representative form. The direction of the information transfer is dependent upon which requires the position information. Either the Base Station or the Vehicle can calculate the position. The link used to transmit the information is a narrow band such as a 2-way radio or cellular signal and can be shared by many units. The position is then determined by time of phase difference between the signals received at both positions. The best accuracy expected from this system is 5m. The CURSOR system is a positioning system only and requires an existing external 2-way communications system to complete the communications component.

12.4. AM Based Systems

There are two historical systems based on the use of AM radio for the determination of position. In 1975, James C. Fletcher, through the North American Aeronautics and Space Administration, patented a system originally invented by George R. Hansen and improved upon it and then renamed it as the Fletcher AM system. The patent describes a positioning algorithm that uses hyperbolic isophase gridlines created from the carrier signal of commercial AM radio broadcasts. The other example of this type of system is a patent from E-Systems Inc. for a unit called the Dalabakis AM which was filed in 1977. This system uses the feedback circuit and a reference oscillation to determine the radial distance from the transmitter. Neither of these systems are known to have gone beyond the concept phase but operate on similar principles (see Figure 12-3).

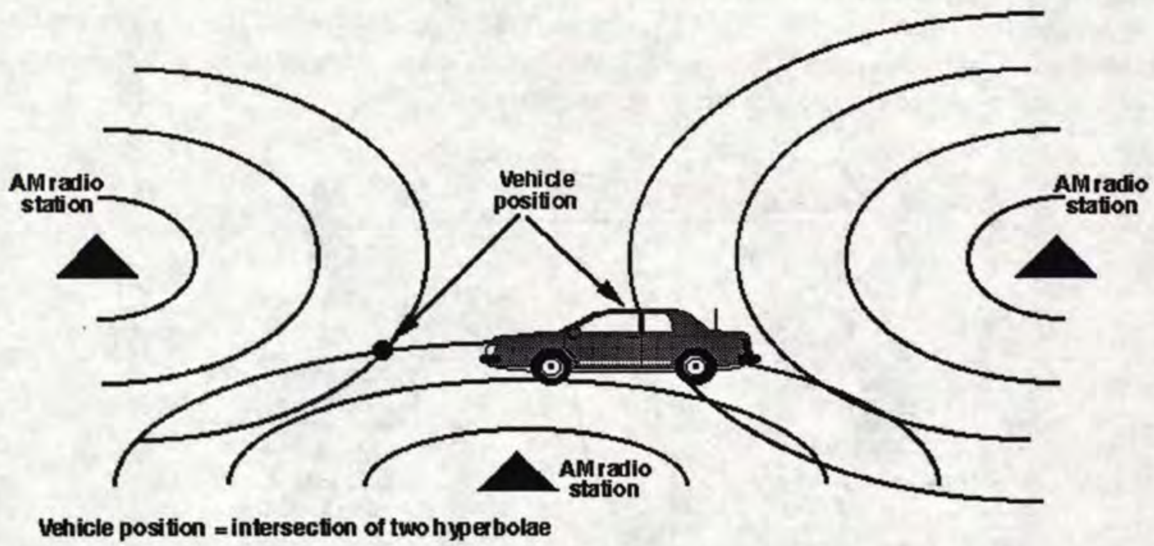

Figure 12-3: AM based Systems Overview

12.4.1. AM-Based System Configuration

Both systems discussed use similar equipment. The each require a minimum of three AM radio signals. These signals are from Commercial AM radio stations. The signal is received by a unit in the vehicle which is capable of monitoring three channels. In the Fletcher system, a modified car radio receiver and a standard aerial is used. The Dalabakis describes proprietary Radio Navigation Equipment. Both systems also require a base station which would perform the correction and position calculations. This means that a 2-way communications system must be combined with this module to effectuate data transmission between the mobile unit and the base station.

12.4.2. Communication and Location Determination

In the Fletcher system, the three AM carrier signals are used to form hyperbolic isophase gridlines. A counter in the vehicle is used to determine the number of lines crossed and this information is transmitted to a central station where the signal is corrected for drift in transmission with respect to a stationary reference receiver. The transmissions from the in-vehicle receiver are established by a volunteer polling method where transmission frequency is proportional to speed. The Dalabakis uses a similar method where each channel has a feed back loop to keep a constant phase relation between a replica of the carrier signal and a reference oscillation. A constant phase relationship means that pulses get added or subtracted from a counter as the vehicle moves toward or away from a fixed transmitter. The accumulated count is converted to a radial distance and the information is transmitted to a central station where it is corrected for frequency drift in the commercial signal and the vehicle's reference oscillator. This information is then be used to calculate position. Both systems require integration into a 2-way communications system.

12.5. VOLKSWAGEN AG.

The Volkswagen Company of Germany developed a FM based locator system in 1989 called the Volkswagen FM shown in Figure 12-4. The company has been involved in the development of several other types of positioning and navigation systems, one being the Autoscout by Siemens. This system was developed for use as a personal navigation unit.

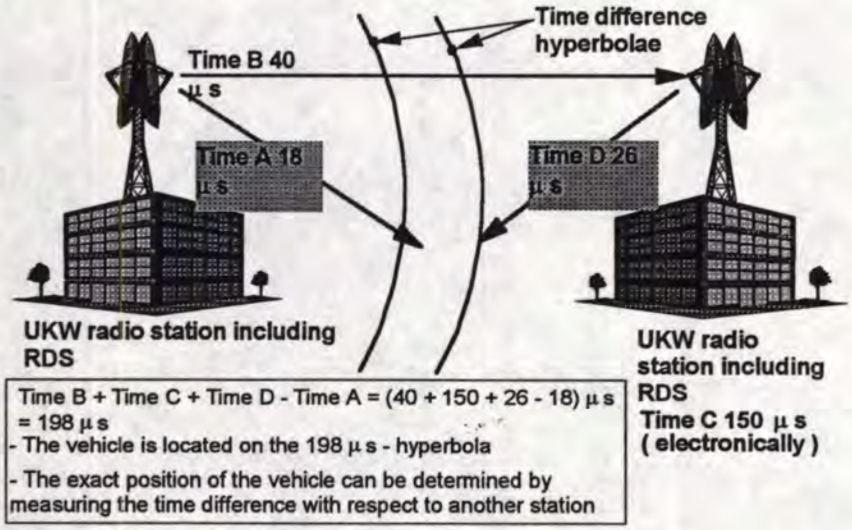

Figure 12-4: Volkswagen FM Overview

12.5.1. System Configuration

There is only an in-vehicle unit. It consists of a receiver unit which can monitor the VHF (150 MHz) FM carrier from commercial broadcasts upon which a Radio Data Systems (RDS) signal is imposed. There is also a LCD panel which is used to show the computed coordinates.

12.5.2. Communication and Location Determination

The position of the vehicle is determined by synchronizing the RDS digital signal data stream of three independent transmitters and measuring the signal time delay. This is converted to position information by a proprietary signal synchronization method based on time difference of arrival. The results are displayed on the LCD panel. The system can also accept other RDS information which allows it to identify and use map and traffic information as a function of position. There is no other communication device required with this system.

12.6. SUMMARY AND CONCLUSIONS

Summary and conclusions related to the use of AM and FM radio signals for positioning vehicles and persons are listed below:

- AM and FM positioning is a novel idea with several patents in place but there is little commercial activity and no Canadian involvement.
- Only limited testing has taken place meaning that the technology is low on the R&D curve.
- The positioning off these signals must be combined with two way communications for fleet management applications.
- A very interesting application is in the area of personal positioning inside buildings and the imbedding of these types of positioning modules into palm and laptop computers.

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Part IV: Digital Map Databases in Support of Tracking and Navigation

13. MAP RELATED FUNCTIONS

13.1. 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 coordinate 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 coordinates, 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 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 Chapter are the major data formats/suppliers being used in vehicle navigation systems, and the navigation functions that they support.

The development of vehicle navigation systems is occurring throughout the world, with most of the activity being centered 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.

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 Harris et al.[1988], Lee [1988], and White [1987].

13.2. 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 (coordinates), however, users operate in the location domain (real-world objects). Most people know the address of their destination rather than the coordinates, so to navigate to an address, the address must be converted to coordinates.

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 coordinate system that can be related to the coordinates output from positioning systems, such as ellipsoidal or UTM mapping plane coordinates. Given a latitude and longitude then, the nearest road in the digital road map is found using a shortest distance 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 modeling 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.

13.3. Map Matching

The assumption behind map matching is that the vehicle is on a road. When a positioning system gives coordinates 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 traveled are used to determine the shape of the route traveled; 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 traveled 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 coordinates 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 traveled 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 traveled 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.

13.4. 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 path-finding. The Dijkstra [1957] and A star (Nilsson [1980]) 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 criterion is to determine the shortest route according to time or distance traveled. 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 criterion 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.

13.5. 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.

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 maneuver approaches, the algorithm must alert the driver, with audible or visual signals, and then indicate when the maneuver is to be performed. If all goes well, the vehicle will continue along the planned route. If the driver misses a turn or maneuver, 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 path-finding 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, path-finding, and digital road maps.

13.6. Mapping Needs by Types of Navigation Systems

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. Inventory systems do not have extensive navigation systems for the driver, so they will not be discussed in the context of this report. 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.

13.6.1. 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 on board maps, 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.

13.6.2. 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.

13.6.3. 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, path finding, 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.

13.7. SUMMARY AND CONCLUSIONS

The following summary and conclusion points are made regarding map related functions:

- Locations relative to physical features are given by maps and thus are an indispensable component of ITS navigation systems along with the coordinates from positioning sensors.
- There are several map related functions that are needed in ITS navigation systems and they are: address matching, map matching, best route calculation and route guidance.
- Digital maps for ITS navigation systems have varying requirements depending upon what type of system, namely: fleet management, autonomous, advisory, inventory and portable.
- Digital maps for ITS navigation systems must be seamless, digital in form for intelligent queries, follow international standards and work in real-time.

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14. MAP DATABASES IN JAPAN

14.1. INTRODUCTION

As in the United States and Europe, the development of automobile navigation systems in Japan has been spurred by their role in ITS. However, commercial development and marketing of automobile navigation systems has been pursued far more vigorously in Japan even though ITS communication links are not yet in place (like in the United States and Europe) for providing real-time traffic information to in-vehicle units. Nevertheless, over one million autonomous type navigation systems have already been sold in Japan. Initially they were priced at $10K US, while presently they are being sold for about $1.5K US.

Most of these systems were sold as factory-installed equipment in top model automobiles, and many are integrated with entertainment features such as AM/FM, tape cassette, CD, and color TV. Virtually all of the systems use dead reckoning with map matching, and the majority of the new models incorporate GPS satellite receivers as well. Superimposition of present car location and destination on a map display is the most common format for presenting navigation information to the driver. However, a few of the most recent systems also offer route guidance features and voice activation of selected functions.

Outlined below are the goals of government programs for ITS infrastructure support and other important factors that have contributed to this burgeoning private-sector business activity in Japan. In particular we focus on the development of digital map databases in support of vehicle navigation - an initiative which Japan planned and supported for more than a decade.

Toyota's introduction of the Electro-Multivision navigation system on September 1, 1987 initiated the era of navigation computers, color map displays and CD-ROM database storage as factory-installed equipment. Although there is some slowing with the current recession, the number of automobile navigation systems sold in Japan has grown by an average of approximately 50 percent annually since 1987.

All major Japanese motor companies now offer navigation systems (e.g., Honda, Nissan, Mazda, Mitsubishi, Toyota, and Suzuki). Most major electronic companies are also in the automobile navigation systems business, either as OEM or after market suppliers (e.g., Sumitomo Electric, Matsushita Electric, Toshiba, NEC, Panasonic, Sanyo, Sony Yazaki, etc.).

Virtually all of the present generation Japanese navigation systems use CD-ROM for digital road map storage and use map matching in combination with dead reckoning as the basic navigation platform. Most of those sold in the last two years also include GPS satellite receivers which are fast becoming a standard feature. All have color CRT or LCD displays which show road network, current location, location of the destination, etc.

Many of the navigation systems include "digital yellow page" directories, and most OEM versions are integrated with entertainment and convenience features such as AM-FM radio, cassette and CD players, color TV, climate controls, etc. GPS is part of every new system being launched.

14.2. ITS Influence

How did Japanese industry manage to come so far in only five or six years after sophisticated automobile navigation systems were introduced on the market? Part of the answer lies in ITS initiatives that have been underway in Japan continuously since the 1970s - the mains ones of which are described immediately below. Specifically, we focus on the events that led to the development of their sophisticated digital map database of the entire road network.

14.2.1. CACS

Starting in 1973, the Ministry of International Trade and Industry (MITI) sponsored CACS (Comprehensive Automobile Traffic Control), a seven-billion yen, six-year route guidance research project. Much like the earlier ERGS (Electronic route guidance System) research in the United States, CACS used inductive loop antennas buried in the roadway as a digital communication link between the equipped vehicles and the infrastructure.

However, unlike ERGS (which was tested only at the subsystem level), CACS infrastructure was established in a 28 square kilometer area in southwestern Tokyo and used for trials involving a fleet of 330 test vehicles equipped with route guidance and driver information displays.

14.2.2. JSK

The CACS operational trial, along with related computer modeling, confirmed the efficacy of dynamic route guidance and led to MITI's establishment in 1979 of JSK (Association of Electronic technology for Automobile Traffic and Driving). JSK is a non-profit membership foundation whose initial objective was to popularize CACS results and expedite the introduction of in-vehicle route guidance and information systems.

Subsequent JSK activities included investigations of social needs, technical trends, and means for introducing such systems. JSK also performed extensive technically-oriented research towards developing specifications and protocols for digital communications between vehicles and ITS infrastructure. Present JSK activities focus on advanced ITS technologies such as those of the SSVS (Super Smart Vehicle System) project.

14.2.3. RACS and AMTICS

From the mid-1980s until 1990, parallel and somewhat competitive field tests involving data communication links between navigation-equipped vehicles and ITS infrastructure were carried out by the Ministry of Construction (MC) and the National Police Agency (NPA). The RACS (Road Automobile Communication System) project of the MC and the AMTICS (Advanced Mobile Traffic Information Communications System) project of the NPA differed mainly in the types of communication links tested and in the jurisdictions of the sponsors (the MC manages expressway traffic whereas the NPA manages surface street traffic). Both AMTICS and RACS offered communications infrastructure for field testing of open-architecture navigation systems with standardized communications interfaces. Following earlier experiments with inductive radio, RACS settled on two-way microwave beacons whereas AMTICS initially focused on teleterminals, a cellular-like mobile data communications system.

14.2.4. Industry Participation

Navigation systems from approximately 12 different automobile manufacturers and electronic firms were entered in both RACS and AMTICS field tests. Participation required paid membership in associations attached to the sponsoring agencies: the MC's Highway Industry Development Organization (HIDO) in the case of RACS and the NPA's Japan Traffic Management Technology Association (JTMTA) for AMTICS.

Many of the navigation systems entered in the RACS and AMTICS tests included features such as color CRT map displays and CD-ROM digital map storage. Some were prototypes or adaptations of systems marketed for autonomous operation.

14.3. JDRMA MAP DATABASE

The Japan Digital Road Map Association (JDRMA) is a consortium of Japanese companies involved in vehicle navigation. Member companies, 82 in all, include Toyota Motor Corporation, Sumitomo 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 kilometers 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 path-finding to their navigation systems had to modify the DRM database. Often these companies would add the turn restriction data as well as traveler 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.

The MC provided a special digital road map database for use with the RACS trials and, in 1988, established the Japan Digital Road Map Association (JDRMA) of about 80 members to standardize map formats and share the efforts and costs in quickly digitizing the major roads and highways of Japan. JDRMA has since digitized road maps at a scale of 1/25,000 or 1/50,000 for all of Japan which are available to its members for a fee. Individual developers enhance and supplement the JDRMA map database in a variety of ways (e.g., with larger scale maps for local streets) for use in current navigation systems. To date, over one million kilometers of roads are contained in the database with about 20 000 km of new roads being added each year.

14.3.1. The Navigation System Research Group of Japan

The Navigation System Research Group of Japan is a group of approximately 40 companies which has developed a hardware and software standard for car navigation and entertainment centers. The standard is called Naviken and its logo appears on all compatible hardware and software developed by member companies. The list of member companies producing hardware includes Alpine, Casio, Kenwood, Sanyo, Xanavi, Sharp, Sony, Chuo Jidosha, NEC, Toshiba, JVC, Fujitsu Ten Maspro, Panasonic, and Mitsubishi. Another major member is Zenrin who concentrates on software. Their Navisoft Digital CD maps and software are designed to work in all systems produced under the Naviken standard, and an example of which is given below (Panasonic).

14.3.2. Zenrin Navisoft

Zenrin Navisoft is a major CD map and software producer. Their software is made under the Naviken standard and can be used in all systems displaying the Naviken logo. Their CD maps and software are broken up into four categories - the first being the ALL JAPAN Drivemap. This map includes a list of the phone numbers for all JAF(Japan's equivalent of the AAA)offices , NTT(Telephone Information) Operators, Tourist Information Centers, Local Weather Centers and Local Highway Patrol Offices in Japan. It also includes a list of all major tourist destinations such as golf courses, airports, hotels, ski areas, and Shinkansen train stations. The software has the ability to call up a map by either the start of the phone number or from a list major communities organized in Japanese phonetic order (Japanese Alphabetical Order).

Their second set of maps divides Japan into six regions. Each of these regions is on a separate CD and has a few more features than the ALLJAPAN map. These features include complete yellow pages and service guide.

The third set of maps is aimed at specific activities - skiing, golf and sightseeing are the major focus. The software includes views of the ski area or golf course including runs or individual hole statistics. Others are focused at dinning and dancing or hot springs and beaches.

Last, Zenrin has developed several entertainment software packages. There are three Quiz Game CD's - one is aimed at children, one at families and one for adults. They have also started to publish novels on CD to be displayed and heard on hardware shared with that being used by the navigation system.

14.4. JAPANESE NAVIGATION SYSTEMS AND MAP RELATED FUNCTIONS

14.4.1. Map Related Functions

The map related functions tabulated are map matching (MM), best route (BR) and route guidance (RG). Best route calculation refers to the capability of a navigation system to determine a route to the destination. route guidance (RG) is the ability of the unit to give the driver turn by turn instructions to their destination. Figure 14-1 shows the use of these three map related functions by navigation systems in Japan.

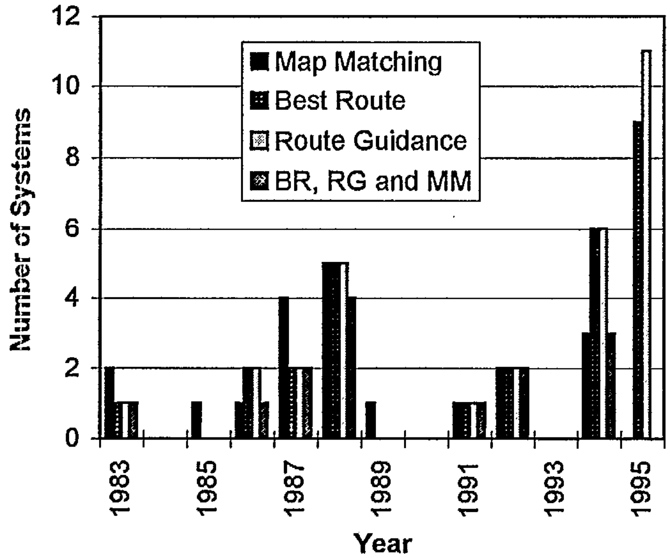

Figure 14-1: Number of Japanese Systems Using Map-Related Functions by Year

Japanese development refers specifically to the development of systems for use in the Japanese market and not to all systems developed by Japanese companies and sold in other regions of the world. The Japanese market has had four distinct developmental periods in which systems have been introduced to the market. The first is in 1983. These systems relied on dead reckoning, map matching or a combination of the two. From 1985 to 1989 several new systems entered the market. The majority of these still used dead reckoning and map matching but many also included GPS positioning. Between 1991 and 1993 only a few systems were introduced but their dependence upon GPS increased. In the last two years, over 30 new systems have entered the market. The majority of these rely upon GPS and only a few use either dead reckoning or map matching. One interesting development is the development of a system which uses GPS and map matching without dead reckoning. Best route calculation and route guidance have been included in the majority of these systems from the start.

14.5. Selected New Navigation Systems Utilizing Japanese Databases

14.5.1. Panasonic KX-GA3LTV

The Panasonic KX-GA3LTV is one of the latest units on the market. The system is one of the first units to have map matching capabilities relying on only GPS for its positioning. The system also integrates a television tuner and CD player into its design. The system also allows the monitor to be used to play video games or view a video through an RCA adapter on the side and to put the output to a TV monitor through an 8 pin micro channel adapter. The whole unit is only 163mm × 211mm × 76mm and weighs only 1.3 kg making the unit highly portable. The manufacturer has developed three power systems for this system. A car lighter adapter for in car use, a rechargeable battery unit for outdoor use and an AC power adapter for indoor use.

Like many new systems, this system uses the Zenrin Navisoft Map and associated software. This software is available for all of Japan in a single volume, for individual areas of Japan and for specific interests(e.g., skiing, golf, dinning). The unit also includes a remote control that can be used for both the TV and Navigator. Although the system is operated on a 32 bit processor, it does not have best route calculation but it allows the manual setting of up to five routes and, once the routes are set, the system does provide voice guidance instructions to the destination. It also is able to find destinations from either addresses or from phone numbers as the Zenrin Navisoft does contain a fairly extensive yellow page directory. For safety, many new systems do not allow certain functions to be used while the vehicle is in motion. This unit is no exception. It requires that the park brake be set before the system can be programmed. This is accomplished through the integration of the GPS antenna lead and the in car power supply with a park brake sensor.

14.5.2. Nippondenso Mercedes Benz

Mercedes Benz is introducing a manufacturer installed Car navigation System in the 1996, 600 series. This unit, made by Nippondenso, is only being offered in Japan and will add approximately $6,000US to the price of the vehicle. The unit is designed to replace the equipment and controls currently found on the center dash. The unit will provide AM and FM radio, TV, CD audio, Car navigation and will control the environmental control system (air conditioning, heating, etc.).The enhanced model also includes a back-up video monitor to assist the driver in parking the vehicle. The unit is equipped with ATIS communications (requires a cellular phone). The cellular phone can also be built in to the equipment. The navigation system relies on both GPS and dead reckoning for the determination of position.

14.5.3. Kenwood GPR-03 Advanced navigation System

The Kenwood system is one of the most advanced systems on the market. It has GPS and dead reckoning sensors (including a gyro for heading change). The system is capable of best route calculations and route guidance. The best route calculation system allows the user to choose whether the route is calculated for the shortest distance or for the least time required. It also allows the user to specify whether or not to use freeways. The route guidance system automatically adjusts to the type of road being used. While in urban areas, the system informs the driver 700m and 300m prior to the intersection using a voice synthesis unit. The system lengthens these to 2 km and 500 m in rural areas and on freeways to allow for higher speeds.

The unit contains the configuration and graphic representations of over 200,000 different intersections. The unit automatically switches to a view of the intersection with the second voice warning. This representation shows all the roads converging at that location and indicating the one the car will enter on and the one which the drive should leave on. The makers have focused on intersections that have more than the standard two roads crossing. The voice synthesizer incorporates an auto-volume control which adjusts the level of the voice output so that it is always at a constant level above the background noise level. The menu is both button (Touch Screen) and voice driven having the ability to recognize and respond to 64 different phrases which allows for ease of use while driving. It is capable of isolating these phrases even while there are multiple voices present (the air circulation due to an open window does exceed its tolerance). The system uses Kenwood proprietary CD-ROM maps but can also operate on the Zenrin Navisoft Map CD's though not all functions will be available. The total system retails for ¥295800.

14.5.4. Pioneer Carrozzeria

Carrozzeria is product line name for all car navigation models introduced by Pioneer. Each of these models include the same basic features and can be upgraded easily with the addition of new software and hardware parts. The software for these systems is a proprietary CD which includes the maps. Each year a new CD can be purchased which will allow the system to take advantage of new technologies. Their proprietary CD titles include regional maps, golf, leisure, games and Karaoke discs. Hardware upgrade kits can be purchased in a like manner. The software upgrade for 1995 include the ability to do best route calculations, close ups of intersections, a highway mode, map matching, GPS and dead reckoning (with a hardware upgrade kit). The gyro sensor unit has also been released in 1995. In 1996, they expect to release a hardware upgrade which will implement VICS communications and the software to drive it.

14.6. ANALYSIS

Automobile navigation evolved rapidly and has already been commercialized in Japan because of, among other reasons, promises of ITS traffic data communications infrastructure which have been dangled by the public sector off and on since the 1970s. Other factors include the promotional and research efforts of the JSK Foundation under the auspices of the Ministry of International Trade and Industry (MITI) and the availability of a standardized nation-wide digital map database developed by the Japan Digital Road Map Association (JDMRA) under the auspices of the Ministry of Construction (MC).

Yet another factor may be the coordination and focus provided by industry membership in the government-sponsored associations related to each new ITS initiative. These include HIDO, JTMTA, JDRMA, VICS Promotion Association, UMTS Japan, etc.

The early public-sector pursuit of ITS was a response to the serious state of traffic congestion in Japan. However, as a result of jurisdictional issues among the various government agencies involved, the movement towards establishing an ITS infrastructure has not been seamless.

Nonetheless, Japan's existing traffic management systems are highly advanced, and almost all elements are already in place for supporting in-vehicle navigation and information systems with traffic data. One of the principle missing elements is consensus on an organizational body for accumulating, fusing and distributing traffic data. Another critical element which is still missing is the final selection and implementation of one or more ITS communication links.

It is also recognized that one major objective of industry's strategy of aggressively seeking early market penetration for autonomous navigation systems has been to help encourage the government to take decisive actions to establish the institutional arrangements and the ITS communications infrastructure required for supplying traffic and other dynamic information for the next generation of navigation systems - those of the advisory and guidance type. At the very least, the present generation of navigation systems is acclimating domestic users and preparing the Japanese market for future versions which will receive real-time information support. In the process, Japanese industry is also gaining a significant head start in the practical aspects automobile navigation design and manufacturing that will facilitate entry in the international ITS market as automobile navigation and supporting ITS infrastructure are deployed in other countries. Sony, Panasonic, Toshiba , Nippondenso and Zexel are examples of Japanese based companies who are presently introducing navigation systems into the North American market.

The number of Japanese navigation systems has shown a steady increase over the years reaching a total of 65, and thus matching the numbers in Europe, and those in the USA prior to circa 1991-2. After 1992, however, the number of systems in the USA has dramatically increased and have surpassed both Europe and Japan; this phenomena is linked to both former President Bush's allocation in circa 1990 of $600US million to ITS activities and the secondly the coming of a fully operational GPS system in 1994-5.

14.7. SUMMARY AND CONCLUSIONS

The following are summary and conclusion items as they apply to the Japanese digital map database issue:

- Japan has led the world in removing digital map databases of road networks as an impediment to the development of ITS navigation systems by forming an association to foster the development of a map database for all of Japan (one million km or roads with 20K km of new roads being added per year).
- The map database was made available to all members to develop applications and systems; this lead to an explosion in applications and products.
- The experience gained through this effort has positioned Japanese firms to enter the European and North American markets;

- This movement is planned for 1997 and one already sees movement in this direction through the purchase of Etak by Sony, the setting up in Los Angeles of Nippondenso, Sony products already operating in California, to mention just a few.
- Japan has totally integrated the navigation functions and displays into the electronics of modern vehicles; maps are on CDs and read with the same hardware as the audio system, and then shown on the same CRT as the car TV.
- Traffic information is being broadcast to vehicles and correlated with map information for route selection.
- In short, Japan has taken a holistic-integrated approach to ITS navigation systems.
- Forming alliances with Japanese firms should be a top priority for Canadian agencies and companies.

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15. MAP DATABASES IN THE UNITED STATES AND EUROPE

15.1. INTRODUCTION

There are five mapping suppliers that are predominant in vehicle navigation systems: JDRMA in Japan; Etak and NavTech in the United States; and EGT and the European Data Pool in Europe. The latter four data suppliers, their origins, and their database formats are discussed in this chapter.

The reason for combining the USA and Europe in the same chapter will become abundantly clear. At this juncture, it is suffice to say that the two titans-Etak of Menlo Park, CA and NavTech of Sunnyvale, CA have gone head-to-head in the USA and this fierce competition has spread into a once united Europe with Bosch and Phillips originally working together, but now one is aligned with Etak and the other with NavTech. In so far as Canada is concerned, this same duality is occurring. In 1996, Canadian companies and government agencies began to form strategic alliances with one or the other silicon valley based company. To bring in a further international dimension, it was announced during the completion of this report that Sony has purchase Etak.

15.2. ETAK IN THE USA

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. 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. 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. With their Version 4 product, Etak has officially entered the race to build navigable databases-a vision adopted by NavTech right from the outset.

Etak estimates that to build a fully navigable database for the entire USA, an investment of $700 million is required, while $300 million is needed annually to maintain it in a proper fashion. This fact explains why there are only these two major players in North America.

15.3. NavTech in the USA

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. 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. 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 Traveler Information System (ATIS). Nippondenso has demonstrated their system (normally based on DRM) with NavTech maps.

15.4. Other Map Suppliers and Users in the USA

Out of the 300 navigation systems in the IVHS Navigation Systems Database™, there are about 100 that have in-vehicle mapping functions. The map suppliers discussed above account for about 50 of these systems. This means that their are many smaller players in the mapping game. 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 to mention just a few.

There are about 170 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.

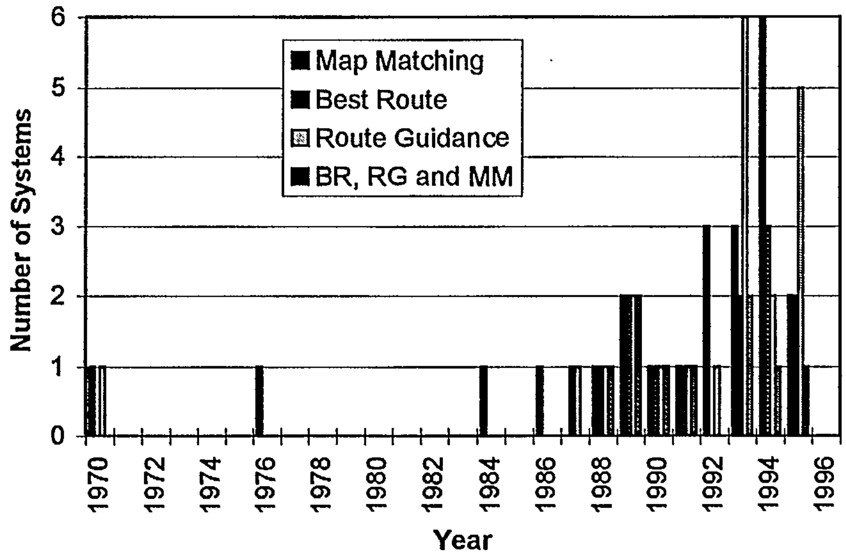

Figure 15-1: North American Systems Using Map-Related Functions by Year

Shown in the figure are the new navigation systems developed each year in North America; Canada accounts for about ten percent of these for a total of about 20 systems relative to about 170 US systems.

15.5. GDF, EGT, AND THE EUROPEAN DATA POOL

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

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, DaimlerBenz 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 cooperative agreement to create a pool of digital road map data for all of Europe; this project is known as the European data pool. EGT has declined to join the data pool, opting to map all of Europe on their own. 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 1997, 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 Bosch Travelpilot navigation system and the other systems that used GDF also use the EDP data.

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 (i.e., their maps are of the navigable variety).

Shown in the figure are new European navigation by year and the way they employ map related functions.

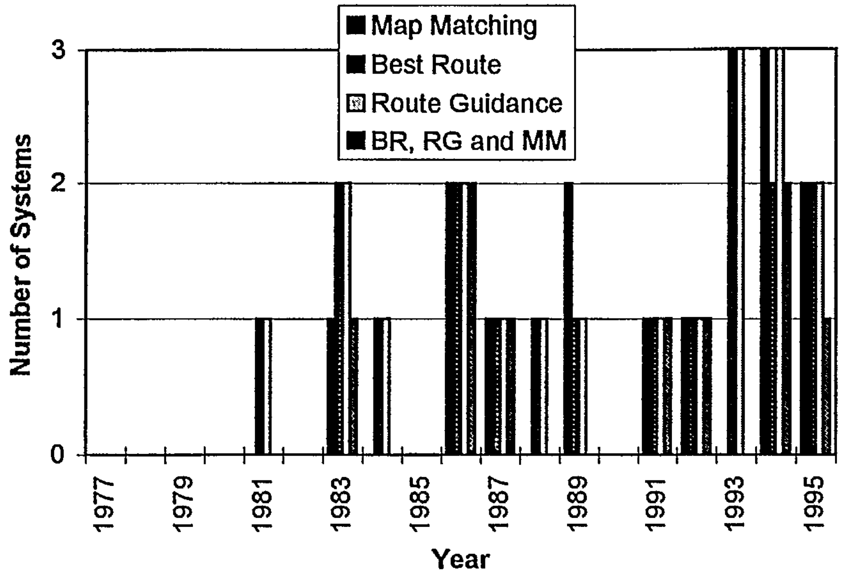

Figure 15-2: Number of European Systems Using Map Related Functions by Year

15.6. ANALYSIS OF MAP SUPPLIERS AND FUNCTIONS SUPPORTED

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.

Table 15-1: Map-Related Functions Supported by Major Digital Road Maps

Use**	DRM	Etak	Etak V4	NavTech	EDRA	EGT
AM	Yes	Yes	Yes	Yes	Yes	Yes
MM	Yes	Yes	Yes	Yes	Yes	Yes
BRC	No*	No	Yes	Yes	Yes	Yes
RG	No*	No	Yes	Yes	Yes	Yes

* 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.

**AM = address matching, MM = map matching, BRC = best route calculation, RG = route guidance

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 path-finding and route guidance, it is said to be navigable.

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 raster maps are used as the backdrop for vehicle tracking.

Most autonomous and advisory type systems developed to date require fully navigable maps, however, there is a trend developing that in an attempt to reduce costs, no maps are carried on board, thus route determination is performed centrally and sent by paging devices to drivers; phones are used in some systems but this increases the cost.

15.7. 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 and 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, i.e., by the end of 1997. As navigable digital road maps are completed for the U.S. and Europe, the market for path-finding vehicle navigation systems should flourish. As more vehicles are equipped with path-finding 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 JDRM 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.

15.8. Summary and Conclusions

The following summary and conclusions relate to the United States mapping situation:

- NavTech and Etak are the main digital road network map suppliers in the United States and compete head to head.
- NavTech is multiple owners including AAA and Phillips; it licenses its technology form SEI, Chicago.
- Etak is now owned by Sony.
- NavTech has focused on producing navigable maps which contain most turn restriction data; and plan to have most of the major cities complete in 1997.
- Etak has focused on coverage (non-navigable maps) and has maps for most of the major cities in the USA. They, however, also have embarked upon producing navigable maps for selected areas.

The following summary and conclusions relate to the European mapping situation:

- Bosch and Phillips lead the development of digital map standards with the issuing of the GDF (Geographical Digital File) back in about 1988; others involved were DaimlerBenz and Renault.
- Both Bosch and Phillips have developed ITS navigation systems of their own: Berlin system by Bosch and the CARIN system by Phillips.
- Bosch has joined the European Data Pool whose members include Tele-Atlas, Intergraph and Etak, with Etak servicing only the UK.
- Phillips has joined a competing group which includes EGT (European Geographic Technologies) which it partly owns with NavTech.
- EGT was originally to join the EDP but has gone on its own with Phillips.
- The NavTech - Etak division in Europe mirrors the same competition set up in the USA.
- With NavTech and Etak each setting up shop in Toronto in 1996, the same split will be present in Canada; Canadian firms will have to pick their sides with the understanding that Sony now owns Etak.

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16. ROAD NETWORK DATABASE DEVELOPMENT IN CANADA

16.1. INTRODUCTION

It is often stated that "Canada is one of the best mapped countries in the world". The reason for this belief is that the federal government, provinces and municipalities all have had strong surveying and mapping programs for the past four decades or so. The data is relatively recent and the technology used in creating these maps is regarded as high tech, digital in form, and thus the information is of high quality. The chief products of this are the digital topographic map series of scales 1:250 000, 1:50 000, 1:20 000 and 1:5 000 of the three levels of government - federal, provincial and municipal.

In addition to these topographic series, Statistics Canada has produced maps of the street networks for the purpose of census gathering. A relatively new player, Canada Post has been building databases of postal codes and street networks to facilitate efficient postal delivery. In addition the provinces and municipalities have been building GIS infrastructures of the street networks under their jurisdiction. Some even have all the roads in the entire province named, with full address ranges, and other attributes defined in their databases.

To date, the focus has been on local-region, large GIS systems with an emphasis on digital topographic and resource data. Static systems were envisioned by the creators of these databases while kinematic (real-time) systems for tracking and navigation were somewhat ignored. Only a few groups have begun to focus on the theme of the road network being the backbone upon which to build a national transportation oriented utility to support a multitude of intelligent transportation related activities.

This changed a few years ago when a nationwide program was instituted by Natural Resources Canada in Sherbrooke. Others have also embarked on provincial and municipal oriented projects where the focus has been on the establishment of single line road network databases. In this Chapter we briefly describe some of these initiatives with the aim to, first, identify the essential elements needed for ITS in Canada and secondly, to define the necessary environment that would foster the development ITS tracking and navigation related products for operation in Canada. The aim is to supply to Canadian and international based companies road network data at prices that would spurn the development of ITS products.

16.2. NATURAL RESOURCES CANADA

Natural Resources Canada at their Center for Geomatics in Sherbrooke have an aggressive program to map the entire country using the federal National Topographic Data Base (NTDB) of scales 1:250 000 and 1:50 000. Their product is called the Canadian Road Network (CRN). It is a digital vector dataset comprising roads and other related entities such as highway exits, obstacles, dead ends, ferry routes, as well as, inter-provincial and international boundary limits. The geometry of the road networks are defined in terms of NAD'83 (near geocentric geodetic datum) based coordinates.

CRN is a relationally structured data set in which mathematical closure, segmentation and connectivity between entities has been maintained. Version 1.0 transfer formats are CCOGIF (Canadian Council on Geomatics Interchange Format), DXF (AutoCAD) and several others such as MapInfo, CARIS, Arc/Info, Intergraph (DGN) and Spans.

CRN has three levels of positional accuracy, namely:

1. 5 m in urban areas where stereo digital data has been used;
2. 50 m rural areas where electro-optically scanned data was used (scale of 1:50 000); and
3. 250 m in rural and hinterland areas where electro-optically scanned data was used (scale of 1:250 000).

Individual data sets are available for each of the provinces, the territories, selected regions and for the whole of Canada. The price ranges from about $1,000 for the smaller provinces to less than $10,000 for the larger provinces, and under $40,000 for the whole of Canada. Royalty arrangements or profit sharing can be negotiated with Natural Resources Canada. Many believe that the cost of this data doesn't foster the development of ITS related products by Canadian industry.

Geomatics Canada is in the process of designing an enhanced product (CRN Version 2.0) to meet specific needs such as: address locating; vehicle monitoring (map matching); best route calculation and route guidance. In other words, they have embarked on making fully navigable map databases. In 1995, they estimated the release of Version 2.0 to be some time in 1996.

Geomatics Canada has developed data sets that contain a wealth of information on the Canadian road network geometry in both the absolute and relative positional sense. This framework is the first prerequisite to building ITS tracking and navigation systems. Other road related data needs to be added to this geometric based data as explained immediately below.

16.3. STATISTICS CANADA

Statistics Canada has been building and maintaining Area Master Files (AMF) of the street addresses in the urban and rural cities and towns of Canada; rural and hinterland areas are not covered in the AMF. This census and demographic related data has been used to produce information for elections, population statistics and the like.

The AMF reference streets, address ranges, block faces and centroid coordinates, and geographical features such as rivers, railroad tracks, municipal boundaries, hydro lines.

The accuracy of the AMF is estimated to be about 10 m relative to ground truth, but large inaccuracies have been found in their data sets.

Pulsearch [1992] has investigated this source of road network data and have identified its strengths and weaknesses. Briefly stated, it used to be the most comprehensive list of street names and addresses in Canada until the arrival of Canada Post, while its main weakness is low geometrical and positional accuracy. Also, it will not support navigation related functions in a real-time environment, thus their data is of limited value.

Etak has a license to the Statistics Canada AMF, but have done little with it to date. Statistics Canada's policy vis-à-vis the dissemination of the AMF is believed by many to be rigid thus few other significant deals have been made. As a result, the AMF data has not made its way into ITS related products. Etak has recently moved to Toronto to begin developing map databases of the Canadian road network. An interesting development has occurred at the time of finalizing this report - Etak, a California based company has been purchased by Sony, Japan which has developed several ITS navigation systems. This has added an international dimension to the development of Canadian map databases.

16.4. CANADA POST CORPORATION

In the course of improving efficiency and profitability, Canada Post has developed 275 individual street network databases across Canada. These databases cover the territory where mail is delivered and consist of coordinates for all intersections; no coordinates are available for shape points such as would be needed to describe curves in the road or cloverleaves. Also included are street names, address ranges and postal codes.

Canada Post works closely with Geomatics Canada for the geometry component of their database. Canada Post then adds postal related information to this geometric base, as well as information on the navigability of the streets. One ways, speed limits and two level crossings, turn restriction information are added so that best routing computations can be performed for delivery purposes. Giro of Montreal has worked with Canada Post in the development of the optimization portion of the system.

Canada Post doesn't sell their present product because the database contains some data from Statistics Canada which has third party restrictions. Canada Post is however looking at creating a future product which will be seamless and cover all of Canada, and which will be available to third parties. The vision is that Geomatics Canada will supply the geometry, Statistics Canada the demography, Canada Post postal codes and delivery route data, while other road related data such the digital yellow pages will be overlaid by say the telecommunications companies, e.g., Bell Mobility or even system integrators.

At time of completing this study, Canada Post began a series of interest groups to determine the level and kind of interest in their road data.

16.5. PROVINCIAL GOVERNMENTS

The Saskatchewan government through a crown corporation is mapping the entire road network in the province. It is using its digital map data of scale 1:20 000 to supplement the federal Geomatics Canada data to improve the latter's accuracy. This kind of federal-provincial alliance is being formed on a bilateral basis. It is hoped that more such alliances will be developed so that the basic data will become available for the entire country at a cost that will spawn the development of ITS navigation related products. To date, the lack of availability of such data at reasonable cost has been the chief impediment to Canadian industry.

Ontario has been working on the Ontario Standard Labeled Road Network (OSLRN) since 1989. This project was instigated and chaired by the Ontario Ministry of Health, Emergency Health Services Branch and Geographic Information Services Branch. Its main function was to establish standards for a single road network. It was envisioned that these standards would be adopted by Canadian Standards Board for use by the entire country. Concurrent with this movement, there has been developments by the Toronto Ambulance Service to implement a full dispatch service in which tracking and road network databases would be key technologies. Various private sector and government groups within the province have been driving the roads of Ontario with specially equipped vehicles using differential GPS (DGPS) of accuracy of 1 to 2 m to define the centerline of the roads. The standards work along with this high level of geometric accuracy bodes well for establishing a quality road network database in Ontario.

British Columbia is the only province where every road - urban, rural and hinterland- has a name and an address range assigned to it by the BC Highway Dept. This data along with the geometric data being produced by Surveys and Mapping of the Geographical Unit puts BC in an excellent position of being a leader in furnishing the necessary data towards establishing a seamless Canadian Road Network Database.

16.6. MUNICIPAL GOVERNMENTS

Several cities in Canada have gone and built comprehensive single line road network databases that support navigation related activities, namely those of Calgary, Edmonton, Toronto, Ottawa and Montreal. Others are now following suit. For example, Calgary has built a product called Roadnet. Roadnet is a structured relational database built around the Bosch and Phillips European based standard called GDF (Geographic Data File). About 40 000 nodes (intersections and shape points) are contained in the database. They were generalized from an Intergraph file of the double line road network made from highly accurate subdivision plans. The centerline was graphically interpolated using Intergraph workstations. Street names and address ranges were added. No, turn restrictions have been added at this time. Calgary has had several ITS projects take place that have used this database. Notably, several police vehicles have been tracked by the NavTrax system of Pulsearch Navigation Systems in 911 dispatch scenarios. Also, the database has been used in the City of Calgary's HACS helicopter system where the helicopter's position is plotted on Roadnet which is carried on-board in laptop computer. These positions are then related, along with the suspect's position to the police on the ground for the purpose of closing in on the suspect.

The City of Edmonton has also built a base of the road network but from a completely different set of data, namely from aerial photographs of the curb lines of the road. The accuracy of the centerlines of the roads thus produced are somewhat more accurate than those of Calgary in that in the latter interpolation was made between the property lines and not curb lines. Calgary supplemented their property data with engineering drawings in the case of cloverleaves and interchanges. Other cities in Canada has comprehensive databases of their road networks, notably the Intergraph files of Ottawa, Toronto and Lethbridge. The AMF for Winnipeg and Lethbridge have also been embellished for use in GIS and ITS applications.

16.7. THE PRIVATE SECTOR

Giro, Montreal are probably the first in Canada to do extensive work on navigable databases. Their optimization software performs allocation of vehicles to pickup and delivery. Once the assignments are made, the best route to each pickup and delivery is computed. Canada Post has implemented this software in their mail delivery system and School Boards in several cities in Canada use this software for determining optimum bus routing. Before the Giro software can be used, it is necessary add navigable attributes such as turn restrictions and one ways to standard road network databases, hence the reason for stating that Giro have been leaders in Canada on building navigable road network databases.

In 1990, Pulsearch Navigation Systems of Calgary built the first database in Canada (City of Calgary) to an international road network standard. They introduced the Bosch and Phillips 1989 GDF standard. It is one of the most comprehensive standards in existence then and even today. It is still used in Europe and a great part of it has found its way into other standards around the world. Pulsearch, under contract to the City of Calgary, assisted in the development of the product called Roadnet.

Another important player in the development of road network databases is QC Data in Calgary. Over the past few years they have had relationship with NavTech of Sunnyvale, CA and have carried projects in Europe and in Canada. In Calgary, they converted Roadnet into a navigable database which allowed the operation of Zexel's NAVMATE full route guidance system in the streets of Calgary. Parenthetically, the operation of the NAVMATE system in Calgary was one of the first times it has operated outside of the USA. In the USA, NAVMATE has found its way into the following ITS installations:

1. Zexel's direct license to GM in the 88 Oldsmobile;
2. Zexel's direct license to Avis;
3. Licensed by Rockwell for use by Hertz; and
4. Licensed by Siemens for use by National in the USA and by Peugeot in France.

The important point to be made in this context is that Canadian road networks are not read for use in such systems, hence, explaining why the deployment of more Canadian ITS navigation systems have not been made to date. Finally, QC Data has had large road network database development for Europe out of their office in Ireland via strategic alliance with NavTech, CA. They are poised to be a significant player in Canada. NavTech has recently established an office in Toronto with the aim of producing navigable road network databases for Canada.

Etak was one of the first foreign companies to come to Canada for the express purpose of doing business in ITS databases. Several years ago Etak obtained the rights to the Statistics Canada AMF. More recently (circa 4Q95), Etak has teamed up with Compusearch of Toronto to build single line road network databases for the country. Given that Ford uses Etak maps for the

Lincoln Continental RESCU system in the USA (at the Westinghouse Monitoring Center in Dallas) the Etak-Compusearch alliance would have a ready made opportunity with Ford in Canada. Presently, Ford's RESCU system, which employs a GPS receiver and cellular phone combination, cannot operate in Canada because they have not been able to acquire a seamless road network database for the country. Besides Ford, GM wants both Canada and Mexico map databases as soon as possible. It was once thought that the lack of affordable communications systems was the chief impediment to the implementation of ITS systems; as it turns out GPS is performing wonders while map database development is lagging. Etak has been recently purchased by Sony Corp. thereby bring Japanese connections to Canada.

NavTech has pioneered the development of building navigable databases, first in the USA and then in Europe. They also have partners in Japan and are now looking for other Canadian partners to supplement the QC Data alliance and their Canadian operations out of Toronto.

16.8. SUMMARY AND CONCLUSIONS

The following are summary and conclusion items of importance to digital maps for ITS navigation systems:

- The development of a seamless database of the Canadian road network is about to take shape as several governmental organizations and firms are poised to take advantage of the opportunity.
- The main federal agencies are Geomatics Canada, Canada Post and Statistics Canada.
- The provinces which have shown leadership are Ontario, British Columbia, Alberta and Saskatchewan.
- Canadian firms who have developed applications using road network databases are Giro, Pulsearch, QC Data, Compusearch, Premier, AVeLTEC Systems, International Road Dynamics, and DataTrax.
- Mapping firms poised to supply seamless Canadian roadnetwork databases are Etåk (owned by Sony) and NavTech (partially owned by AAA and Phillips)- both have established offices in Toronto in 1996.

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Part V: Sensors for Relative Position Determination

Relative Position Determination Overview

The positioning and navigation capabilities of GPS was described in Chapter 3. GPS systems provide positions and heading which are absolute, i.e. it does not require an initial position or heading to commence navigating. However, as previously noted GPS requires a clear line of sight to three or more satellites to determine a position solution. Often in urban applications this is not possible due to obstructions such as tall buildings and trees. During these outages, additional sensors are needed to provide continuous positions.

To continue navigation either velocity components or speed and heading are required. Velocity components are available from inertial systems and will be described further in Chapter 20. Sensors providing speed include odometers and Doppler radar. Absolute heading can be determined from a compass while relative heading can be accumulated from rate gyros which give change in heading information. North seeking gyros are not considered practical or economical for automotive applications. Table V-1 lists various sensors with their direct output along with the desired output.

Table V-1: Sensors and Their Output

Sensor	Direct Output	Derived Output
Three Odometers	Pulse count left wheel. Pulse count right wheel.	Relative change in azimuth. Forward or reverse motion distance travelled (centre line of vehicle).
Single Odometer	Pulse count from transmission.	Forward or reverse motion. Distance travelled (centre line of vehicle).
Fluxgate Compass	x and y voltages (0-4 volts).	Absolute geodetic azimuth.
Rate Gyro	Rate of change about axis (0-5 volts).	Rate of change in geodetic azimuth.
Inclinometer	Pitch and roll of vehicle.	Tilt with respect to horizontal.

A driving force with the automotive manufacturing industry to reduce the cost of these sensors to make them economically acceptable for mass production. This includes a reduction in size, cost, weight, and power consumption.

There are also efforts to obtain output from sensors already on-board the vehicles. These include output from the anti-lock braking and anti-collision systems for speed. Common screens could be used for vehicle information and navigation and guidance instructions. A number of companies are focusing on connecting sensors and processing systems to a standardized bus that is installed in vehicles. The concept is that there is a defined standard for interface of these sensors and their output, somewhat similar to the NMEA 183 in the marine industry. An agriculture interface standard is currently under development that will eventually allow automatic steering from a navigation system.

Heading Determination

Gyroscopes are angular sensors that output either angular rate or attitude, depending whether they are rate sensing or rate integrating. A low cost rate gyro, that is typically used for land navigation applications outputs a voltage proportional to the rate of angular displacement. The rate gyro has only recently been considered as a heading sensor. In the past, most systems have relied only upon compass based systems, however, they have proved unsatisfactory for most urban applications where there are an abundance of external forces.

In terms of navigation errors, the heading has proven to be the most problematic to solve. Figure V-1 shows the position error that can accumulate given various heading errors that act as a bias rather than a random error. The typical accuracy from a low cost, well calibrated rate gyro and compass are depicted. As shown, a 5 degree error in heading causes a 1 km error in position, if left uncorrected after driving a 10 km distance.

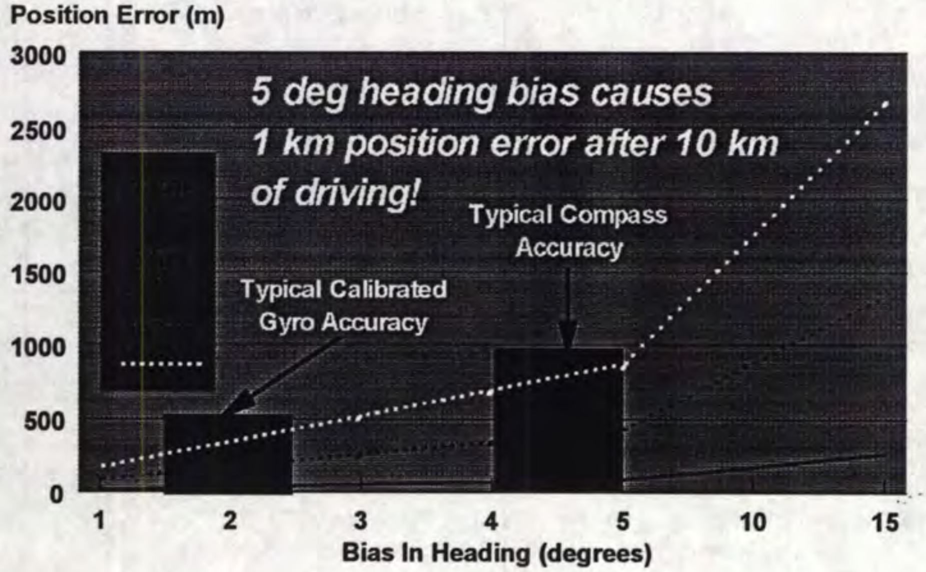

Figure V-1: Position Error Due to Heading Error

Odometers consistently provide sufficient accuracy for distance traveled, hence gyro research and development has received considerable efforts. In evaluating inertial system performance, the gyro has often been the limiting factor [Krakiwsky et al., 1990] and is also one of the most costly items. Table V-2 contains a list of absolute and relative heading sensors.

Table V-2: Heading Sensors

Types	Sensors	Accuracy	Advantages	Disadvantages
Rate Gyro Type	Vibratory	0.1° sec^{-1}	Small size. Long life. Low cost.	Vibration and temperature sensitive.
	Spinning	0.03° sec^{-1}	High accuracy.	Short life.
	Gas	0.15° sec^{-1}	Vibration proof.	Long startup time
	Fibre optical	0.001° sec^{-1}	Very high accuracy.	Very expensive.
Absolute Course	Flux gate compass	2 - 4°	Absolute course Small size. Low cost.	Course offset. Sensitive to external objects.
	Gyro compass	2 - 4°	Absolute course Not sensitive to external objects.	Large size. Long startup time Expensive.

Some companies [McLellan, 1992] have developed systems that combine several heading sensors into a heading filter. These filters are used to provide a consistent continuous heading. The filter also solves for gyro bias and other parameters to a specific sensor. Systems have also been developed using a combination of two, three or four GPS receivers to provide either heading or attitude.

The compass and rate gyro have been combined into a heading filter in several systems. This technique exploits the absolute heading determination, though noisy, with the relative yaw rate of the rate gyro which drifts over time. The filter is periodically updated using the GPS derived heading and from map matching when available.

The next chapters will describe these sensors in detail. Their current status will be given along with some projections for the future.

17. ODOMETERS

17.1. Types of Odometers

Odometers are basically used to determine distance traveled over a period of time. The difference in distance traveled by a pair of wheel odometers over a period of time can be used to determine a change in heading.

Taxis have been the largest users of precise vehicle odometers in the past, as their fares are often based on distance traveled. In this case a precise odometer had to be retrofitted to the vehicle as an aftermarket product. Many of the new vehicles with anti-lock barking systems provide an output directly with no additional sensors required. Thus in the automotive market the odometers sensors come standard with the vehicle which means the sensor is manufactured as part of the automobile production.

Table 17-1 - Distance Sensors(after McLellan, [1992])

Types	Sensors	Accuracy (% distance)	Advantages	Disadvantages
Wheel Revolution Type	Hall effect	0.3 - 2 %	High sensitivity at high and low speeds.	None.
	Light shield	0.3 - 2 %	None.	Limitation of sensor position.
	Generator	0.3 - 2 %	Simple.	Low sensitivity at low speed.
Speed Type	Doppler radar	1 %	Remote sensor.	Errors caused by road surface irregularity and vehicle motion.
	Space filter	3 %	Remote sensor.	

Table 17-1 lists various types of distance sensors available for vehicle applications. A number of off road equipment such as tractors use Doppler radar as the slippage is too great. The output is used to control velocity rather than measure distance traveled.

17.2. Odometer Technology

17.2.1. Differential Odometry

Three odometers are mounted on two wheels of the non-driven wheel pair providing distance traveled, heading change (i.e. change in azimuth) by differential odometry, and forward-reverse motion detection.

Distances are computed by observing the number of pulses detected from targets affixed to, and equally spaced around each wheel, and, by multiplying these pulse counts by a calibration value representing pulse counts per distance traveled. A pulse is generated each time a magnet passes the magnetometer. Changes in the magnet spacing changes the quantization values. An example of this type of sensor is shown in Figure 17-1.

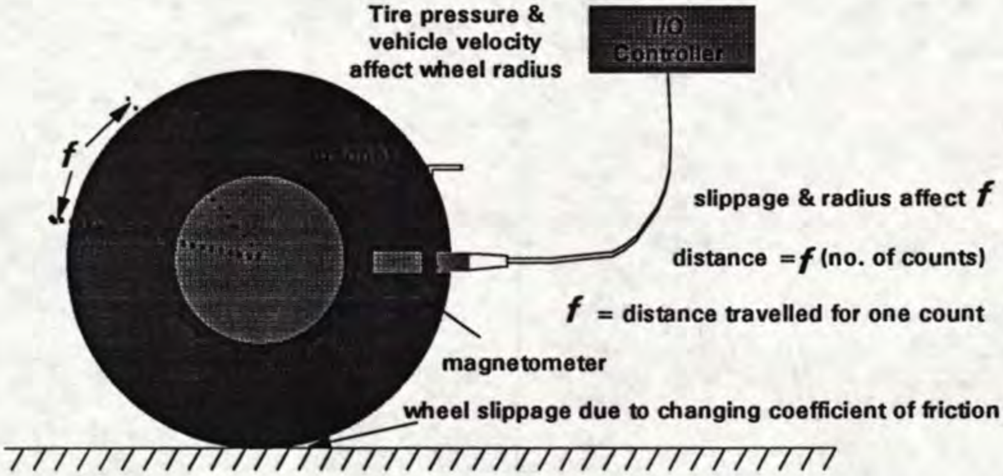

Figure 17-1: Odometry Sensor

Etak wheel sensors are similar in nature except rather than magnetic clips, there is a magnetic strip with holes approximately every 3 cm. This magnetic strip is installed where the bead of the tire meets the rim. Quantization error is significantly less with the Etak strip as compared to the sensor shown in. It is also constant except at the point where the ends of the strip join together.

Heading change from differential odometers is observed by differencing the two odometer distance measurements across the TRACK [Harris, 1989]. The concept is made clear by realizing that through the act of turning, while in motion, an automobile's outer wheel travels a further distance than its inner wheel - see Figure 17-2. This difference can be represented as a function of the change in azimuth corresponding directly to the turn itself). When the odometers are mounted on the rear wheels, the TRACK remains constant, however, it changes on the front wheels as a function of the steering angle.

The notation in Figure 17-2 is defined as follows:

- t_k is the time of epoch k (sec),
- t_{k-1} is the time of epoch k-1 (sec),
- *TRACK* is the distance between the treads of a wheel pair in rest on the road surface (m),
- az is the geodetic azimuth (rad),
- $\Delta az_{k,k-1}$ is the change of azimuth (rad sec^{-1}),
- R^R is the radius of right wheel path (m),
- L^L is the radius of left wheel path (m),

- $\Delta^{R}_{k-1,k}$ is the distance traveled by the right wheel (m), and
- $\Delta^{L}_{k-1,k}$ is the distance traveled by the left wheel (m).

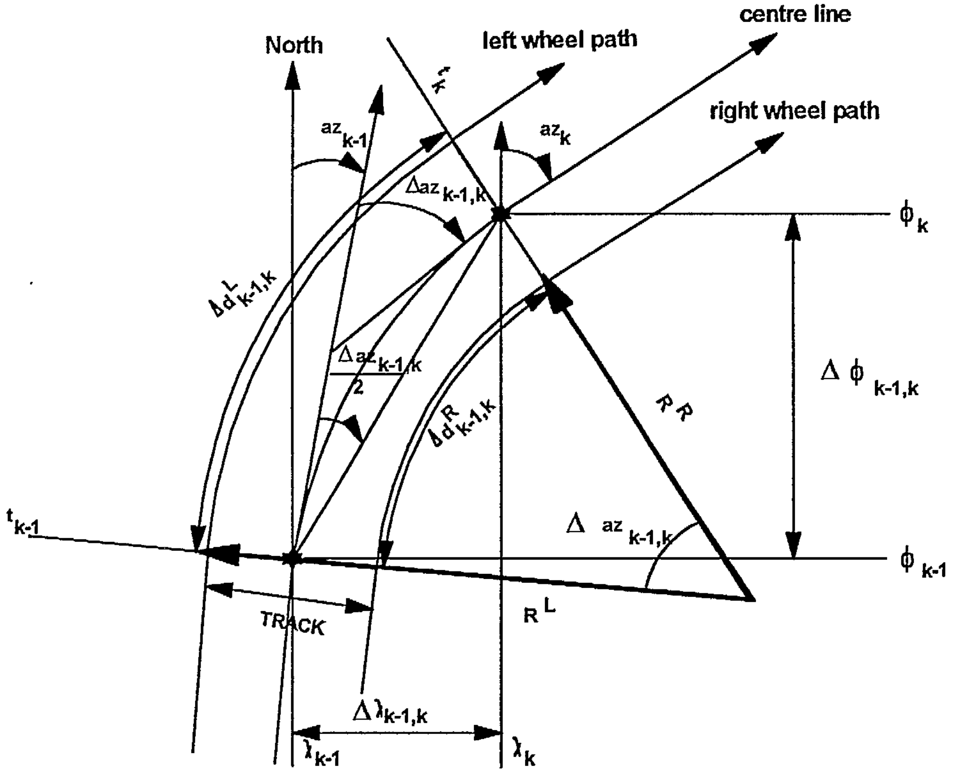

Figure 17-2: Differential Odometer Geometry (after Harris [1989])

There is reluctance to mount the wheel based sensors due to time required for installation and the required maintenance.

17.2.2. Single Odometer

Single odometers are typically of the transmission type and mount where the speed odometer cable connects to the transmission. Reverse motion is detected externally by connection to a back-up light switch.

Distances are computed by observing the pulse count detected from speed odometer transmission output, and, by multiplying these pulse counts by a calibration value representing pulse counts per distance traveled. Odometers are typically rated as producing a certain number of pulses per distance traveled..

The scale factor tends to change quite slowly varying with velocity, tire pressure and the coefficient of friction of the tire to the road.

The White odometer outputs 4000 pulses per kilometer traveled. The odometer is connected to the transmission. When the vehicle rolls ahead or backwards, the odometer outputs pulses proportional to the distance traveled. Many new vehicles have an output available from the anti-lock braking system which will give a direct pulse count.

The scale factor for converting pulse counts to distance traveled is dependent upon the effective radius of the wheel. This radius can vary as a function of tire pressure and speed. It is also affected by the tread wear of the tires and the type of tires used.

17.2.3. Odometer Errors: Pressure and Velocity

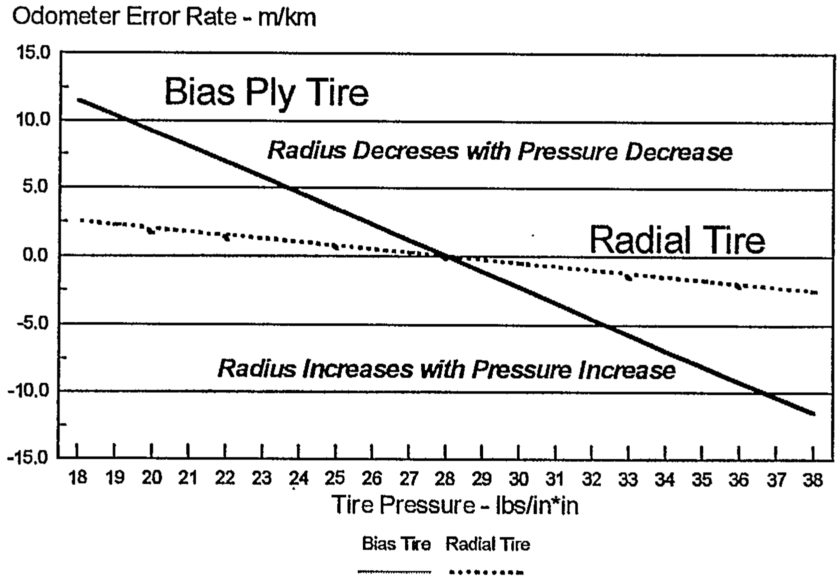

Figure 17-3: Distance Error Growth Due To Tire Pressure Variations

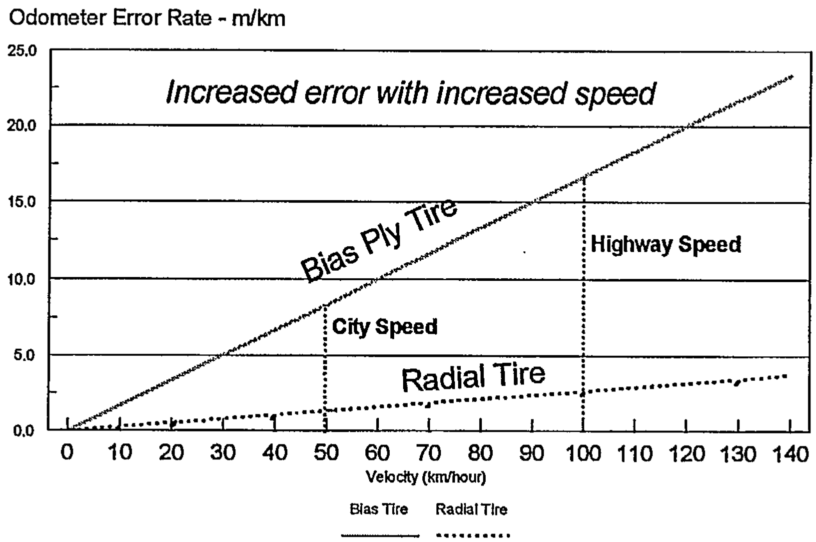

Figure 17-4: Distance Error Growth Due To Increased Speed

Shown in Figure 17-3 and Figure 17-4 are changes due to variations in tire pressure and velocity. It can be seen that bias ply tires are much more sensitive than radial tires. The type of tires should be taken into account when choosing the filter state parameters. Clearly, the odometer scale is much more sensitive to tire pressure variations in bias ply tires than in radial tires.

17.3. SUMMARY AND CONCLUSIONS

The following are issues related to odometry:

- Differential wheel mounted odometers allow for change in azimuth determination as well as distance traveled and in modern vehicles (circa 1990s) the ant-lock breaking system outputs the necessary data.
- Maintenance is especially difficult in vehicles that are often in off road conditions.
- Transmission odometers are concealed and installed in the transmission where the speed odometer cable is connected.
- Errors sources are primarily due to wheel slippage and changes in wheel circumference due to tire pressure and velocity changes.
- Many new vehicles with anti-lock braking systems installed provide a direct pulse output that may be connected to directly.
- Some companies have built a special gear tooth which they have connected to each wheel with anti-lock braking to provide differential odometry.
- GPS velocity measures can be used to calibrate the odometers continuously.

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18. COMPASS

18.1. INTRODUCTION

Compasses have been used for decades for providing an absolute heading for marine and airborne applications. These applications typically operate in areas that are free from external magnetic disturbances. Once the system has been installed and calibrated it then can be used with in-frequent calibration updates and adjustments.

Compasses where installed in early vehicle navigation systems by a number of companies. Great efforts were made to continuously calibrate these sensors to account for the often rapidly changing external effects. The sensors were satisfactory for rough navigation but proved unsatisfactory for mass market AVL applications.

An electronic compass, which measures the direction of the vehicle in relation to the earth's magnetic field (Figure 18-1), gives information about the heading. An electronic fluxgate compass contains transducers that convert a magnetic flux into voltage. The compass heading can be used when other sources of heading are unavailable or unreliable. GPS derived heading is interrupted or degraded by tall buildings or poor satellite coverage.

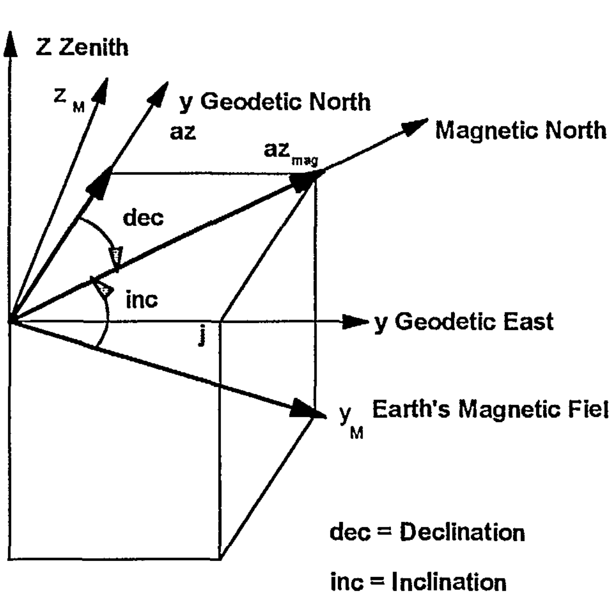

Figure 18-1 - Earth's Magnetic Field

The magnetic compass observes angles in reference to the Earth's magnetic field. Thus the angles are measured relative to the Earth's magnetic pole and not to the Earth's spin axis which is the reference required for reduction to geodetic north. A magnet takes up a position parallel within the lines of force of the earth. In a horizontal projection, the lines define the magnetic meridians. In elevation, the lines are inclined downward toward the north in the northern hemisphere, and downward toward the south in the southern hemisphere. The angle between the horizontal and the inclined line is called the angle of inclination. The inclination varies from 0° at or near the equator to 90° at the magnetic poles. The angle between the true meridian and the magnetic meridian is called the magnetic declination or variation. If the magnetic heading is east of true north, the declination is said to be east. Magnetic declination is a non-linear function of both position and time.

Isogonic charts displaying magnetic declination plots over geographic regions are often used to obtain magnetic declination parameters but exist in paper format only. Typically, values are stored in a look-up table (e.g., 1° *x* 1° grid) or mathematical expression (e.g. spherical harmonic series) is used. In Canada, maps of declination and inclination are available from the Department of Energy, Mines and Resources, Ottawa. The declination and inclination in Calgary (ϕ = 51° N; λ = 114° W) are approximately 21° and 74.3°, respectively.

The electronic compass may contain three transducers for the magnetic field. They measure the components of , the strength of the terrestrial magnetic field, in three orthogonal directions. The Etak compass contains only the two horizontal axes. Ideally, the outputs would correspond to the sine and cosine of the angle between the compass and the field but the axes are not orthogonal. To relate the compass derived heading to vehicle heading, it is necessary to know the pitch and roll of the axes, the amount of non-orthogonality between the axes, and the effect of the magnetic field inclination angle.

Often in a local area, the inclination is treated as a constant and becomes part of the scale factor. If the compass is constantly calibrated, the inclination will be computed as part of the scale factor rather than extracting it from look-up tables.

18.2. MODEL

The output of the compass varies with the component of the Earth's magnetic field in the sensitive axes of the sensor. The output is affected by the pitch, roll and heading of the vehicle and also by the inclination angle of the magnetic field. The relationship is depicted in Figure 18-2.

The observations from the flux gate sensor are of the magnetic field in the sensor frame. The inclination and declination may treated as known values from a look-up table or solved for as part of the continuous calibration. The requirement is thus to relate the sensor observations in the compass frame to the required local geodetic frame to obtain the required geodetic azimuth. The compass observations in an x, y plane tend to lie in an ellipse with an offset as shown in Figure 18-3 where:

- a is the semi-major axis of the ellipse,
- b is the semi-minor axis of the ellipse,
- Y_C is the y axis of the compass in the forward direction of the vehicle, and
- X_C is the x axis of the compass.

A best fitting ellipse usually has its axes rotated with respect to the sensor axis. The axes of the ellipse are also non-orthogonal. The shape of the ellipse is dependent upon the magnetic field of the vehicle and external magnetic sources.

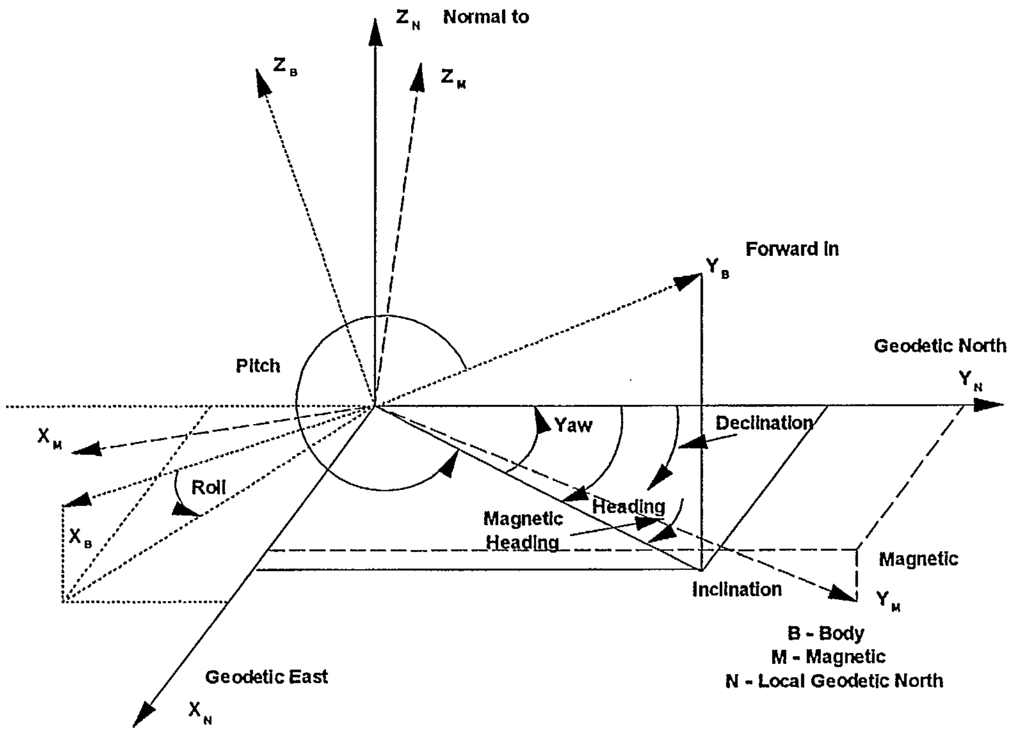

Figure 18-2 - Fluxgate Compass Coordinate Frames

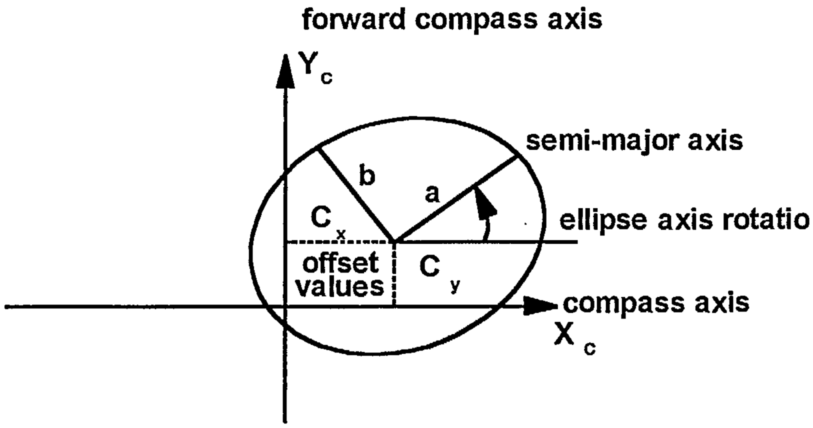

Figure 18-3 - Compass Observations Modeled as an Ellipse

In typical vehicle installations the compass is positioned so that the x and y ranges are very close to being equal. In this situation, the observations tend to lie more closely on a circle. The solution for the ellipse becomes very unstable as the two axes become close to being equal. Hence, the observations are often modeled as lying in a circle as shown in Figure 18-3.

External updates can be done via two sources, namely; Constant heading from GPS filter; and Heading rate change of zero when odometer is stopped. It is well known that compass-derived headings are adversely affected by a variety of unmodeled external magnetic forces, such as driving over a steel girder bridge or other vehicles passing by. In some cases these magnetic disturbances can cause almost instantaneous heading deflections of greater than 90 and at times even 180. In order to learn about these effects on the compass, raw compass data was gathered under a variety of conditions.

The compass derived headings are extremely sensitive to unmodeled external forces. It seems that concentrations of metal in nearby objects (bridges, other vehicles) cause large instantaneous heading deflections. If the compass is to be used for dead reckoning in a land vehicle, algorithms must be employed to filter out these effects and other blunders.

The vehicle takes on its own magnetic field. The field can be changed instantaneously by events such as hitting a pot hole, slamming a door or putting metal material in the vehicle. It was also found that the number of people in the vehicle changes readings, since the increased weight changes the pitch and roll of the vehicle.

A number of companies are producing compass engines that are being integrated into navigation systems mainly used in aircraft and boats. The sensors used in aircraft are usually compensated for tilts up to a maximum of about 50°. Most new models also perform their own internal calibration. Output is usually through a serial port. In some aircraft that are using GPS for navigation, a compass is still used to determine the crab angle needed for such things as aerial photography.

18.3. SUMMARY AND CONCLUSIONS

The following is a list of issues important to compasses:

- They are very sensitive to external magnetic field disturbances such as bridges, railway tracks, overpasses.
- Spurious readings as large as 180° are often encountered. Tests have shown the presence of large errors due to the operation of power windows and air conditioning.
- Inclination of the sensor has a large effect on the heading determination (e.g.., 1° tilt causes 2° heading error).
- Empirical testing has led to using a standard error of about 5° for this sensor.
- Most companies have abandoned the use of a compass in AVL applications.
- New low cost compass engines are being used in aircraft and in marine applications. In both these applications the external effects are minimal.
- New compasses can handle tilts up to 50° assuming that the vehicle is not undergoing accelerations.
- Compass engines are being frequently installed in aircraft and marine applications to determine the crab angle to be used in aerial photography.
- Compasses are being manufactured by US and Japanese companies. Canadian companies are using compasses in various applications but are not manufacturing compasses.
- Opportunities for Canadian firms are very limited in this domain.

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19. RATE GYRO

19.1. INTRODUCTION

Most companies supplying dead reckoning solutions in today's AVL market have either switched to rate gyros or are planning on it in the future. The basic requirements for a rate gyro for automotive applications are: mass production, low cost, resistance against environmental influences (such as temperature, vibrations, EMI), stability of all characteristics over time, high reliability and designed-in safety. The majority of the development in rate gyros is being done in the US, Europe and Japan today. The US manufacturers have typically been involved with large military or aviation contracts where accuracy, size and weight have been the prime factors. As military developments have declined in the past several years, these companies are now focusing their efforts on the civilian markets. The demands on accuracy are orders of magnitude less, however the demands on cost are also orders of magnitude less as well.

The Japanese manufacturers have been focused on high volume and low cost for a long time. They have often worked with North American companies who have done the original research and development. This technology has then been further refined to become incorporated into mass production and low cost manufacturing.

Due to the limited military contracts and funding available in Canada, research in the inertial and gyro hardware development has been very limited. What was previously called Geodetic Survey of Canada worked with large expensive inertial systems in the 1980's. This hardware was however purchased from the US. Shell Canada also done extensive development using hardware from Scotland. Both these groups have since ceased to be involved actively with inertial. Companies such as Nowsco are using small, though still expensive inertial systems for determining the location and condition (curvatures) of pipelines.

Consumer demand for increased automotive safety features has sparked interest in vehicle chassis control systems. These systems which perform active control of braking, steering or suspension, require real-time chassis dynamics .data. Yaw, pitch, and roll rates as well as linear accelerations in three axes are required for complete knowledge of chassis dynamics. Several automotive manufacturers are using or have announced intentions to use yaw rate sensors to implement vehicle yaw control [Johnson et al., 1995].

Yaw raw, or angular velocity about a vehicle's vertical axis, is critical piece of information to a chassis control system. This control system might also using steering wheel angle, wheel speeds and tire normal force information as part of the control algorithm. The same information can be used for heading in the navigation solution.

The scale factor stability and bias define the accuracy of a gyro. The scale factor stability is the capability of the gyro to accurately sense angular velocities at various rates. Designers strive for output values which are linear over their dynamic range. The vehicle dynamics play a major part in the attainable heading accuracy. For instance, an aircraft undergoing high dynamics would require a much larger dynamic range than vehicles which are traveling generally on paved roads with a reasonably low rate of heading change. Any errors in scale translate into affects on the rotation rate, which when integrated over time affects the heading.

The capability of the gyro to reference all rate measurements to the nominal zero point is characterized by the gyro bias. The bias model varies according to the various sensor designs.

Gyros are basically designed following three principles and are listed in Table 19-1 [Krakiwsky et al., 1990].

Table 19-1 - Rate Gyro Principles and Designs

Type	Principle	Design	Degrees of Freedom	Example
Rotor	Constancy of Angular Momentum	Rigid Rotors. Dry Tuned. Nuclear Resonant.	1 and 2 2 1	Etak
Optical	Sagnac Effect	Ring Laser. Fibre Optic.	1 1	Hitachi Andrews
Vibration	Preservation of Plane Vibration	Hemispherical Resonant	1	Murada Delco Draper Bosch

For land vehicles traveling in a horizontal plane, only the angular velocity produced during vehicle turning is of interest. For a constant sampling rate, the angular speeds are in proportion to the relative headings. Therefore, gyroscopes can be used in a similar manner to differential odometers to measure the relative headings of the vehicle. Unlike differential odometers, the performance of the gyroscopes is not subject to factors such as a change in effective tire size [Kao, 1991].

The single axis gyros used in land navigation applications are mounted with their z axis approximating the local level z axis as shown in Figure 19-1.

The output from the low cost rate gyros is offset by a voltage that varies with the power supply. The GPS heading is used to determine the constant of proportionality and offset for the rate gyro so that a heading based on the gyro output can be calculated when no GPS heading is available.

19.2. THREE TYPES OF GYROS

The following sections will examine the three types of gyros listed in Table 19-1.

19.2.1. Etak Turn Sensor

The Etak turn sensor incorporates two subsystems; a two axis gyroscopic turn-rate sensor, and two-axis fluid inclinometer. The gyroscope is used to measure yaw rate and the inclinometer is used to measure pitch and roll.

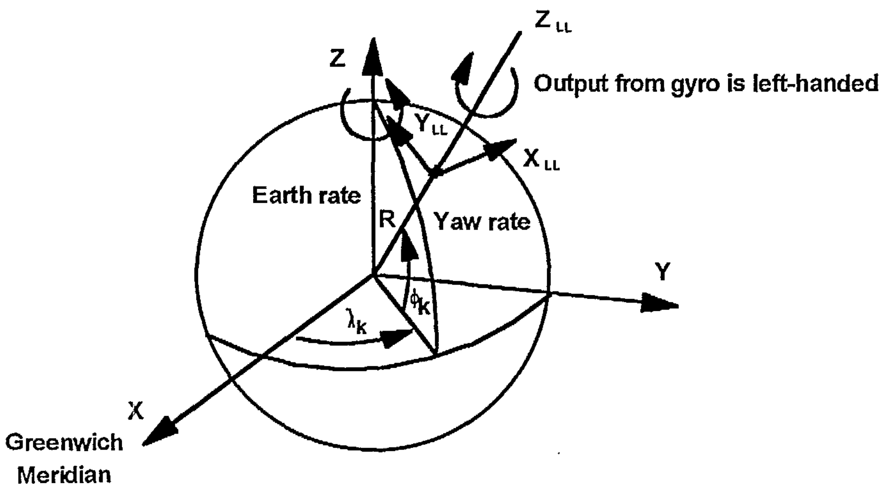

Figure 19-1 - Heading Rate Determination

The gyro uses a rotating flexible disc. Precessive flex in the disc is measured capacitively. The primary output is a digital pulse train. With the gyro stationary, the pulse train has a quiescent frequency; the deviation from the quiescent is proportional to the yaw rate. Typically the pulse train is time integrated in a counter, the quiescent counts subtracted, and the remainder is yaw. The secondary gyro axis is an analog output voltage.

The inclinometer uses a bottle filled with a dielectric fluid. Capacitive plates sense the position of the fluid. The inclinometer outputs are analog. With the sensor upright, the outputs are nominally half of the supply voltage. Deviations from the quiescent are proportional to the tilt.

The linearity of the yaw rate is +/- 1% over a +/- 60 sec.

This type of gyro was the most common type in early gyro development. It size, cost and manufacturing complexity has precluded it from use in mass production.

19.2.2. Vibratory Gyros

Vibratory gyros have a long history with very few obtaining marketable performance. Exceptions include the Quartz Resonator Gyro (QRS) by Systron Donner (size is 7 to 11mm- used for tactical grade applications), and the Hemispherical Resonator Gyro (HGR) by Delco (size is larger than 50 mm - used for inertial navigation). The HGR has not been competitive with Ring Laser Gyros (RGL). The HGR is limited by its production costs.

For the automotive industry there has been a quest for low cost mass fabrication rather than high performance gyros. There has been a considerable investment in Micro Electro-Mechanical Sensors (MEMS), usually on the order of a millimeter and less. All MEMS are vibratory gyros.

The current trend in vibratory gyros is to develop both macro and micro scale gyros for automotive applications, with much reduced performance requirements compared to inertial or tactical requirements. The total emphasis is on low cost, rather than performance. They are striving for a high volume solution with a component cost in the order of a few dollars.

Many companies in specializing in the area of mass production have formed alliances with companies specializing in high end inertial systems. One example in the US is Draper Labs in an alliance with Rockwell International Corporation. They are currently developing an integrated Micromechanical Inertial Sensor Assembly (MMISA) and GPS receiver configuration. Projections of size, weight and power once it is completed to the ASIC level is 2 x 2 x 0.5 cm, 5 gm, and less than 1 W. Rockwell's main thrust is manufacturing for automotive applications.

Draper builds its micromechanical instruments using a dissolved silicon wafer process that results in crystal silicon structures anodically bonded on a Pyrex (glass) substrate that contains the electrodes [Connelly et al, 1995].

The vibration gyroscope employs a mechanical phenomenon in which the coriolis force develops in the direction perpendicular to the vibration when an angular velocity is applied to a vibrating body [Nakamura, 1990].

In practical terms, a free-free-bar or a tuning fork vibrator and a piezoelectric ceramic are pasted together and the vibrator is driven (x axis). When rotational angular velocity is applied to the central axis (z axis) of the vibrator, the coriolis force develops (y axis) in the direction perpendicular to the vibration direction (x axis) and the rotational angular velocity is detected from the piezoelectric ceramics glued in the y axis direction. The basic principle is shown in Figure 19-2.

The vibration gyroscopes require high sensitivity to rotational angular velocity; at the same time, the detection voltage at the time of no rotation must be zero or null voltage. Using the conventional square gyro shown in Figure 19-2 the null voltage is not exactly zero due to the manufacturing inaccuracy of vibrators and the variability of the gluing position.

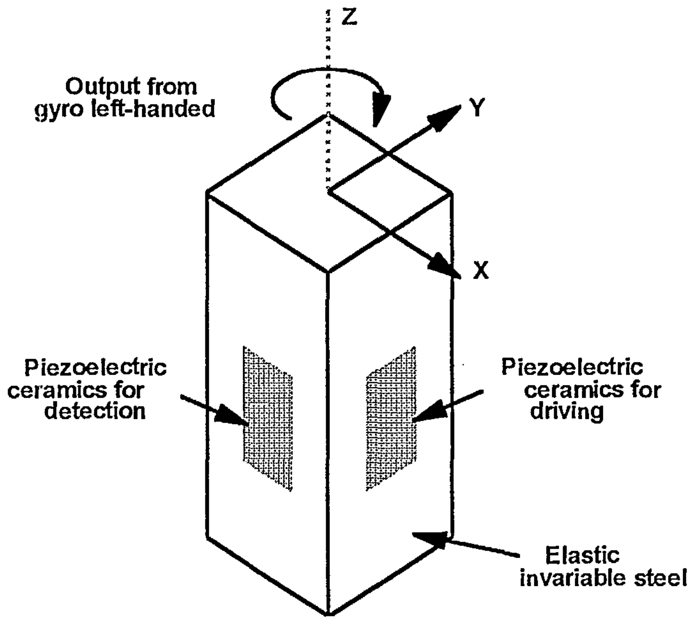

Figure 19-2 - Outline of a Piezoelectric Vibratory Gyroscope Using a Square Bar (after Nakamura, [1990])

19.2.3. Murata GYROSTAR

The GYROSTAR™ rate gyro is in the shape of an equilateral triangle and shown in Figure 19-3. The equilateral triangle prism vibrating unit allows the left and right piezoelectric ceramics to be arranged in the direction of the compound vibration mode. This means that the same ceramics can be used for both excitation and detection, enabling a simple structure and simplified circuit [Nakamura, 1990].

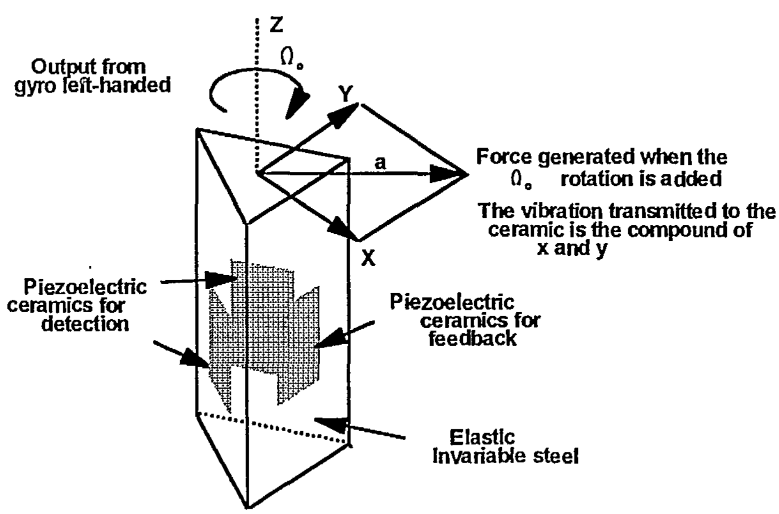

Figure 19-3 - Outline of a Piezoelectric Vibratory Gyroscope Using a Triangle Bar (after Nakamura, [1990])

The GYROSTAR™ detects the angular velocity by subtracting the left and right outputs from each other. When there is no rotation (i.e. driving in a straight line), the unwanted vibrations entering due to vertical movement and backward-forward motion are subtracted, so the noise components are reduced, minimizing their effect on the angular detection.

When rotating, the left and right detection values are subtracted from each other Figure 19-4. In equation form, the detection voltage is $2a = (A + a) - (A - a)$ which yields a relatively large detection output.

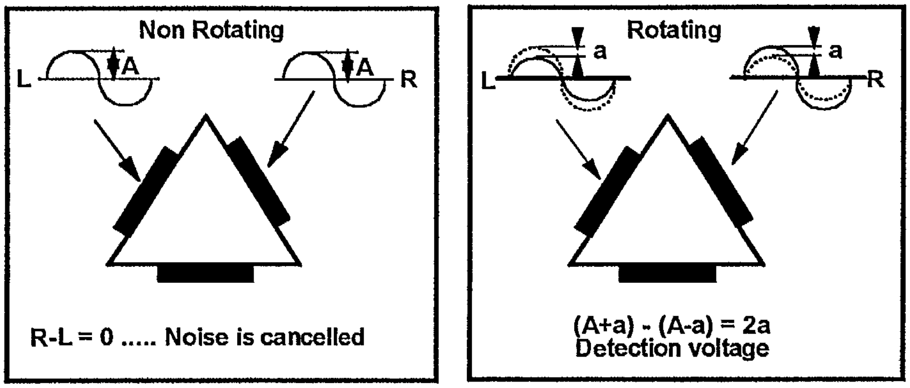

Figure 19-4 - GYROSTAR Rate GyroOutput Detection [after Nakamura, 1990]

The maximum angular velocity is +/- 90 sec-1. The scale factor is 22 mV per degree per sec. The reference voltage is 2.5 volts, which represents zero velocity. The linearity is less than 0.1% at maximum angular velocity. The drift rate is less than 0.2% of the maximum angular velocity per hour.

This gyro was one of the earliest to be introduced to the market that was priced at a level that could be considered for the automotive market. Initial testing showed instability with changing temperatures as well as changes due to shock and vibration. Frequent or continuous calibration could minimize these shortcomings.

19.2.4. Fiber Optic Gyro

Fiber optic gyros (FOGs) may become a key sensor over the next decade, because they are potentially compact and maintenance free, have a long operating life and are becoming lower in cost. They also start quickly, need little power and resist vibration.

The operating principle of the FOG is based on the Sagnac effect, which describes the relative difference in path length traveled by counter-propagating beams of light in a rotating reference frame (Figure 19-5). In a fiber optic gyro two counter-rotating laser beams are routed in opposite directions through a hair-thin optical fiber tightly wound around a cylindrical spool. The interference fringe patterns are created at a rate that is directly proportional to the rotation rate of the parent craft.

When the fiber coil is not rotating, the two beams of light travel exactly the same path before being recombined. When the coil is rotating, the two beams arrive at the beam splitter at different times since they have traveled different distances through the coil. The path length difference , ΔL, is given by:

$$\Delta L = \frac{RL}{c}\Omega$$

where:

- R is the radius of the coil,
- L is the length of fiber in the coil,
- c is the speed of light in a vacuum, and
- Ω is the rotation rate.

Note that the pathlength difference is directly proportional to the rotation rate.

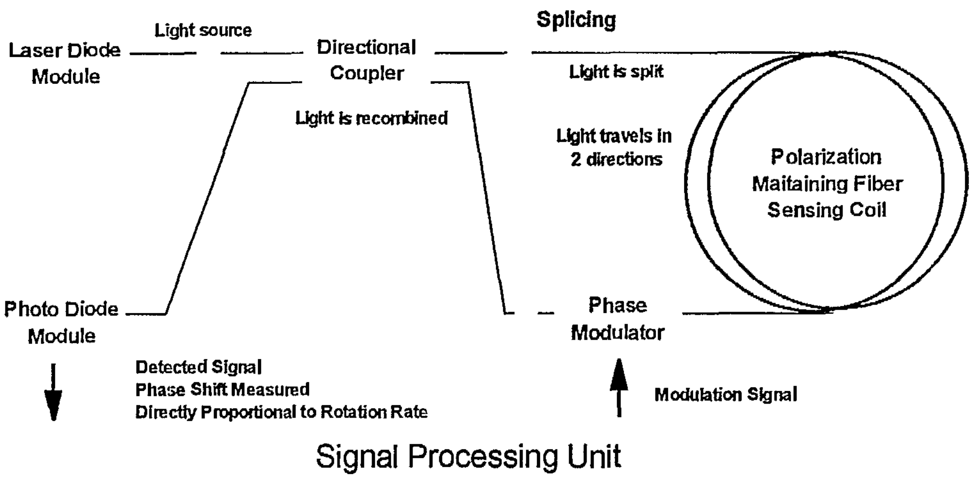

Figure 19-5 - Fiber Optic Rate Gyro

FOG technology is being used for a wide performance range of rotation sensors. The performance range is achieved by adjusting one of several variables, including the length of fiber and radius of the fiber coil, the operating wavelength and type of light source, and the signal processing scheme.

The Andrews gyro has recently been modified to accept odometer input and combine it with the yaw data over a serial port. This current cost of this gyro has limited to dead reckoning systems on the high end.

19.3. SUMMARY AND CONCLUSIONS

- Gyroscopes are angular sensors: angular rate = rate integrating, and attitude = rate sensing.

- Rate gyros require an initial reference heading.
- Vibration gyros are sensitive to temperature fluctuations and vibrations.
- Typically errors of 1°- 2° are encountered, though this may increase significantly, if un-calibrated. The drift is generally linear.
- Outputs a voltage proportional to the rate of angular displacement.
- Scale factor stability and bias define the accuracy.
- Capability of the gyro to reference all rate measurements to the nominal zero point is characterized by the gyro bias.
- FOGs, with a decrease in cost, offer the greatest potential for future heading sensors. Vibratory gyros are currently the lowest in cost and are being used in a number of automobile makes and models.
- Low cost sensors will most likely be manufactured in Japan due to their high level of electronic manufacturing capabilities. Delco and Rockwell are manufacturing gyros aimed at the automotive industry in the US. Bosch and British Aerospace and producing low cost gyros in Europe.
- Most land dead reckoning systems now use a rate gyro as a change in heading sensor.
- Some gyro manufacturers are now able to accept input from other sensors such as odometer and backup light switch. This information is then passed though one interface to central processor.
- Japanese technology is apt to dominate lost cost AVL systems in the future. They have had a much wider acceptance in Japan and they are much further ahead in terms of commercialization.
- Canadian companies will likely not be involved with the manufacturing of gyros, but may incorporate them into custom navigation systems.

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20. INERTIAL NAVIGATION UNITS

20.1. INTRODUCTION

An inertial navigation system is a simple, self-contained position-fixing device that continuously measures three mutually orthogonal acceleration components, numerically integrates those accelerations to obtain the instantaneous velocity, and then integrates the resulting velocity to determine the vehicle's current position.

The major attraction of inertial systems is their capability for autonomous navigation in any environment. They operate without reference to an external signal and are therefore not affected by atmospheric conditions, line of sight obstructions or underwater or underground operation[Krakiwsky et al, 1990]. This characteristic has been the major driving force for their incorporation into many military systems.

Inertial systems are used in three different modes, namely:

1. Dead-reckoning device - used as sole means of navigation;
2. Interpolator - used to interpolate positions between fixes with other sensors such as a GPS system; and
3. Attitude reference system - used is required and relied upon heavily for aircraft navigation systems. Current development and research is underway using multiple GPS antennae to also provide heading. It has been very difficult to match the high frequency output available from inertial systems. Companies such as NovAtel and Pulsearch have developed GPS attitude systems in Canada, but cost has precluded their ready acceptance. US companies such as Adroit, Trimble and Ashtech have also built systems for aerial photography and marine applications.

Most companies supplying dead reckoning solutions in today's AVL market have either switched to rate gyros or are planning on it in the future. Accelerometers have been incorporated somewhat through anti-lock braking systems. The basic requirements for an inertial system for automotive applications are: mass production, low cost, resistance against environmental influences (such as temperature, vibrations, EMI), stability of all characteristics over time, high reliability and designed-in safety. The majority of the development in inertial systems is being done in the US, Europe and Japan today. The US manufacturers have typically been involved with large military or aviation contracts where accuracy, size and weight have been the prime factors. As military developments have declined in the past several years, these companies are now focusing their efforts on the civilian markets. The demands on accuracy are orders of magnitude less, however the demands on cost are also orders of magnitude less as well.

Due to the limited military contracts and funding available in Canada, research in inertial development has been very limited. What was previously called Geodetic Survey of Canada worked with large expensive inertial systems in the 1980's. This hardware was however purchased from the US. Shell Canada also done extensive development using hardware from Scotland. Both these groups have since ceased to be involved actively with inertial. Companies such as Nowsco are using small, though still expensive inertial systems for the location and condition of pipelines. Bombardier through its Canadair division was manufacturing custom inertial systems for its airborne unmanned surveillance systems, but has recently scaled down development and operations in this area due to decreased US and Canadian military contracts.

As stated in a previous chapter, consumer demand for increased automotive safety features has sparked interest in vehicle chassis control systems. Yaw raw, or angular velocity about a vehicle's vertical axis, is critical piece of information to a chassis control system. This control system might also use steering wheel angle, wheel speeds and tire normal force information as part of the control algorithm. The same information can be used for heading in the navigation solution.

The two major types of inertial systems currently on the market are gimbaled or stable platform systems and strapdown systems. Initially gimbaled systems were the most popular, but strapdown systems have become predominant in recent years due to major increases in computer processing power coupled with decreases in size and cost.

Traditionally, inertial units have been considered too expensive for incorporation into vehicle navigation systems. There are major development efforts in the following areas which may make them economically feasible in the future. These efforts include:

- Interferometric Fiber Optic Gyros (IFOG)
  - improved performance, lower cost
  - leveraging off communications industry
- Silicon Gyros and Accelerometers
  - performance improvement
  - batch production
- Strategic Mechanical Systems
  - supportability and reliability
  - IFOG and ring laser gyro (RLG) initiatives

There are three different types of angular rate sensing devices shown in Table 20-1 and there are two different types of acceleration sensing devices as shown in Table 20-2.

The current gyro applications are shown in Figure 20-1. As can be seen most of the current applications are either with the military or high end aircraft applications. In the past inertial systems were expected to navigate from takeoff to landing with no external updates. As such they are often classified in terms of drift over time (usually nautical miles per hour). Typical navigation grade systems are rated as 1 NM/h, while a high performance system could reach the level of 0.1 NM/h. Many commercial airliners will use up to three independent inertial systems to verify navigation information.

Table 20-1: Angular Rate Sensors

Gyros		
Spinning Mass **(angular momentum)**	**Vibratory/Resonator** **(corollas)**	**Optical** **(Sagnac)**
• single degree of freedom • rate • integrating floated • two degree of freedom • ESG • Gas Bearing • DTG	• vibrating shell • HRG, START • tuning fork • QRS, TFG • vibrating beam	• active RLG • passive IFOG • passive RFOG

As differential GPS systems are more widely adapted into aircraft applications, they will be used to continuously update and calibrate the inertial sensors. This may also allow for the inclusion of lower cost inertial systems.

Table 20-2 - Acceleration Sensors

Accelerometers	
Pendulous Mass **(displacement/rebalance)**	**Resonant Element** **(frequency)**
• electrical restraint • PIP, Bell XI, Qflex, A4 • rotational restraint • PIGA, DRAG CUP-VM • elastic restraint • FMA/MRA, acoustic, optical	• vibrating beam • VBA • double-ended tuning fork • VQA, QRA, RBA, superflex

The future gyro technology developments are shown in Figure 20-2. As can be seen mechanical systems will still excel in the areas of high precision and stability. These types of systems will still be required for underground and underwater applications.

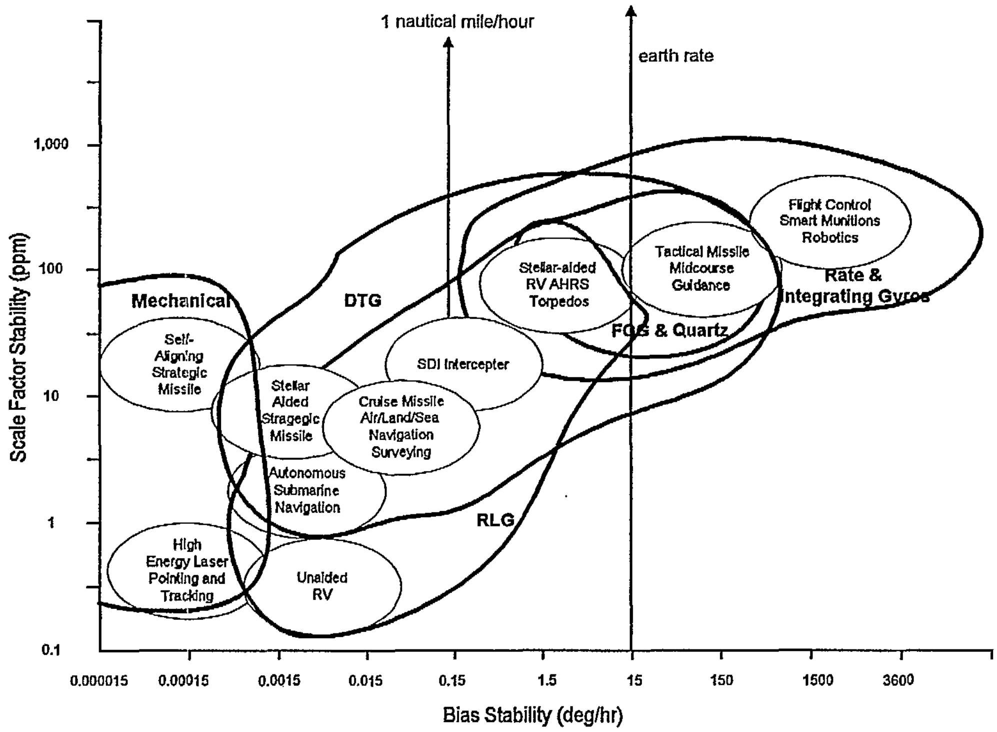

Figure 20-1 - Current Gyro Technology Applications

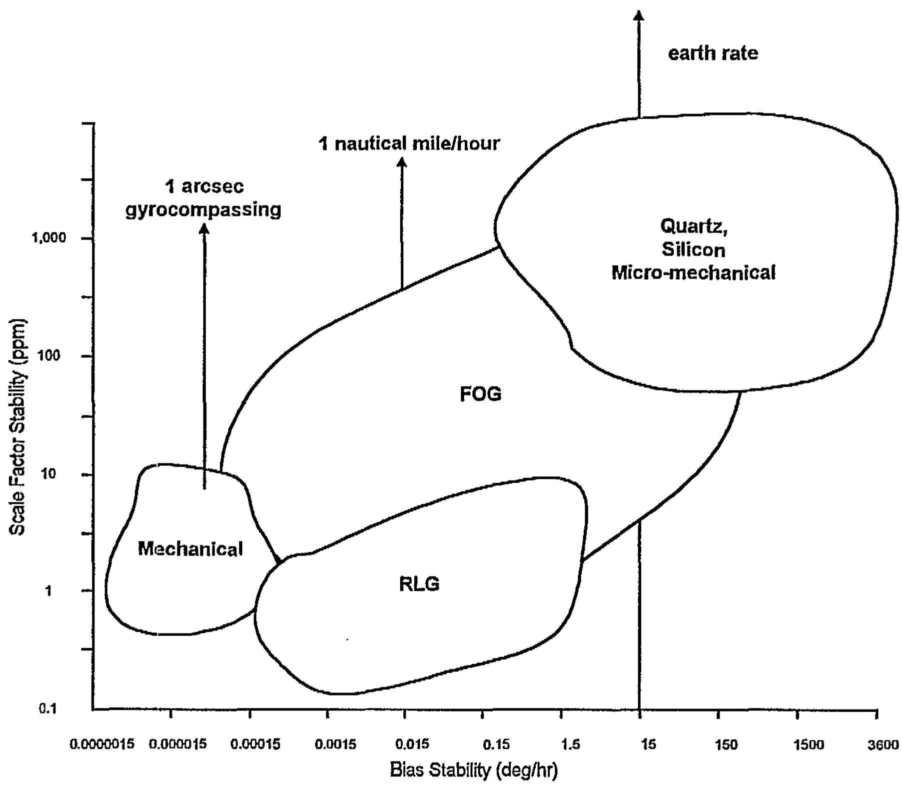

Figure 20-2 - Future Gyro Technology

Current accelerometer applications are shown in Figure 20-3. As can be seen mechanical accelerometers are also superior in terms of stability.

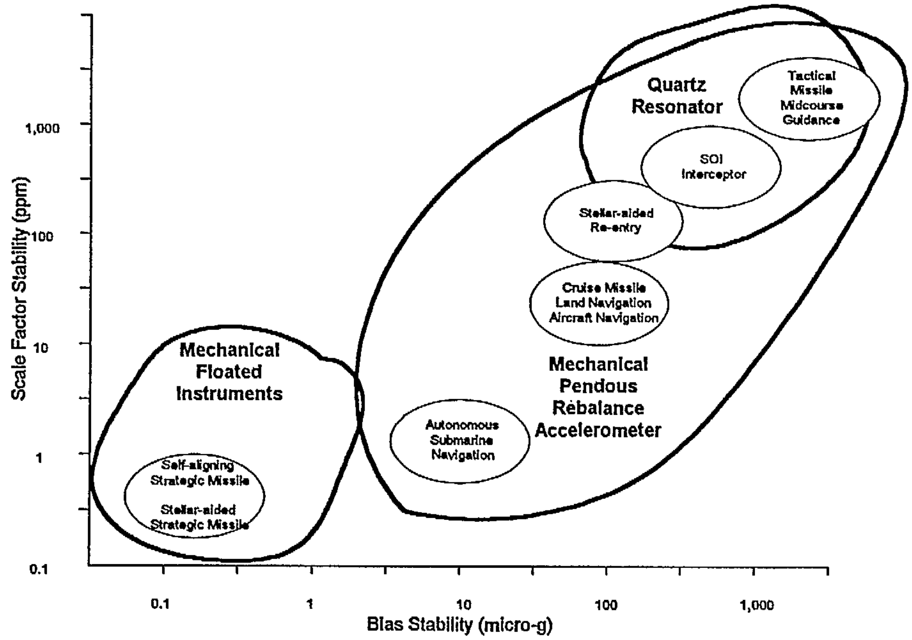

Figure 20-3 - Current Accelerometer Technology

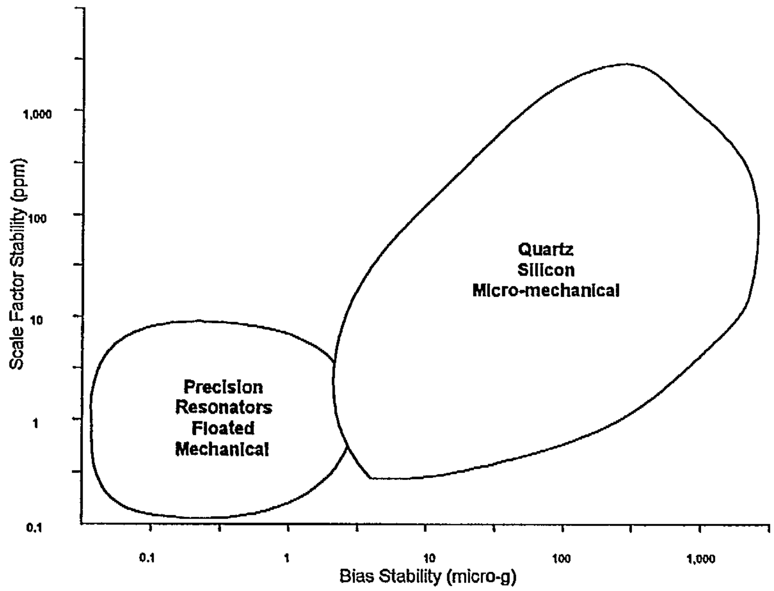

Figure 20-4 - Future Accelerometer Technology

Future accelerometer technology is shown Figure 20-4. The high precision applications will revolve around resonator technology, while lower accuracy and lower cost applications will develop around quartz, silicon and micromechanical methods. As an example Delco has a very accurate resonator system today that is very small, but costs about $10,000 per axis per sensor, which precludes its use from the automotive industry.

The anticipated cost per axis to meet the requirements of the automotive industry are shown in Figure 20-5.

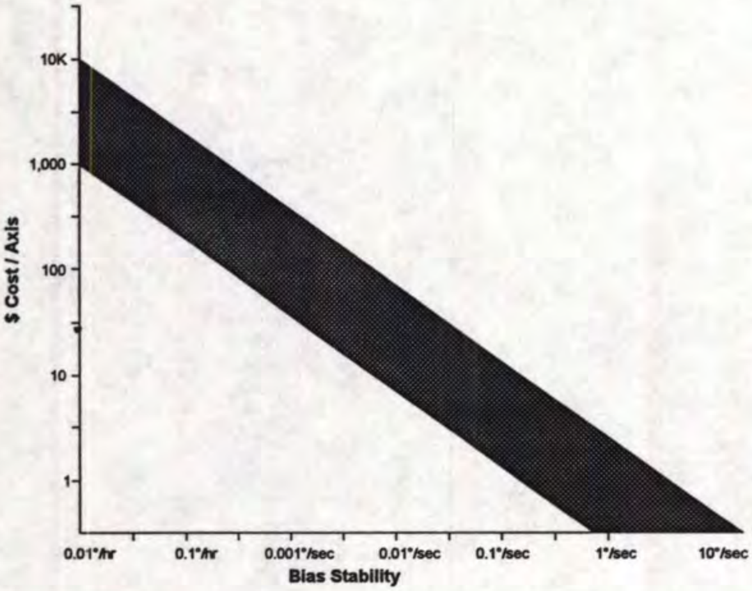

Figure 20-5 - Cost per Axis

20.2. SUMMARY AND CONCLUSIONS

The following are pertinent summary and conclusion items:

- Many commercial navigation applications will be met using GPS alone, but significant number will need integration with dead reckoning or with inertial units.
- For inertial units to be accepted in ITS circles, the target cost per axis for the automotive industry will have to be several dollars each; so that for a pair of two-axis units, two for rate gyros and two for accelerometers, the total cost will be about $25 in large quantities.
- Low cost inertial systems could be used to supplement GPS for AVL applications if the cost becomes cheap enough.
- Low cost inertial devices will probably be incorporated for collision avoidance and other requirements ahead of navigation in the automotive industry.
- Future cost of fiber optics systems is expected to decrease, thereby expanding applications.
- Some companies are proponents of fiber technology while others are pushing micro-mechanical developments.
- Cost, stability and size are major considerations.

- Canadian companies will continue to develop applications using GPS and other sensors, but will not be manufacturers of inertial systems.
- The automotive industry will incorporate inertial devices as they can be mass produced at a low cost.
- Manufacturing plants will likely be setup in Japan and Mexico in the future to serve the mass market production requirements.

20.3. REFERENCES

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Part VI: ITS Navigation Systems Being Built Worldwide by Type

Overview

Presently there are over 300 navigation systems (individual products, patents, prototypes) under development worldwide with new entrants surfacing continuously. Navigation systems are typically divided into five distinct classes following closely the 1988 Paris based Organization for Economic Cooperation and Development (OECD) Study Report which documents the needs for navigation related information for travelers, dispatchers, drivers, and managers. The classes of systems to choose from are autonomous, advisory, fleet management, inventory and portable - see Figure VI-1 .

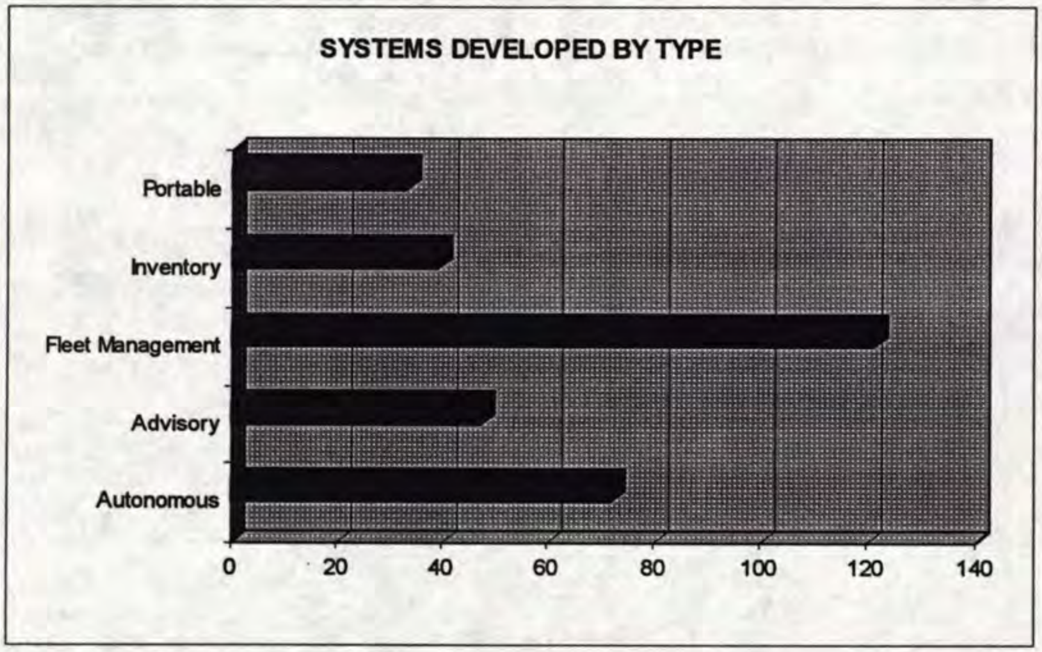

Figure VI-1: Number of Each Type of System on a Worldwide Basis

The first three types are classified according to communications technologies employed . Autonomous systems have no communications, while advisory systems initially were defined to have only one way (receipt of say traffic information) communications and fleet management have two way communications. The inventory and portable classes were added to respectively reflect the specialized usage and the important portability characteristic of some new navigation systems. The inventory category captures those systems that relate to time and coordinate tagging of road related information. The portable category contains those products which are simply natural extensions of PDA's (Portable Data Assistants, e.g., palmtops and laptops) to PNA's (Personal Navigation Assistants). The boundaries between these categories has become more and more blurred as products evolve; this paradox will be illustrated immediately below. The basic technologies employed, uses of each class and a list of developers will be given herein.

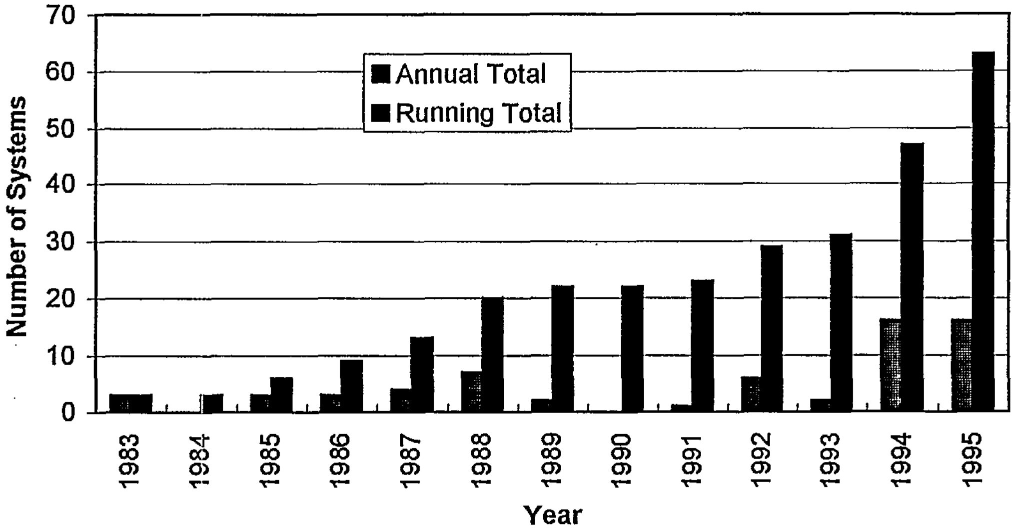

Figure VI-2: Japanese System Development

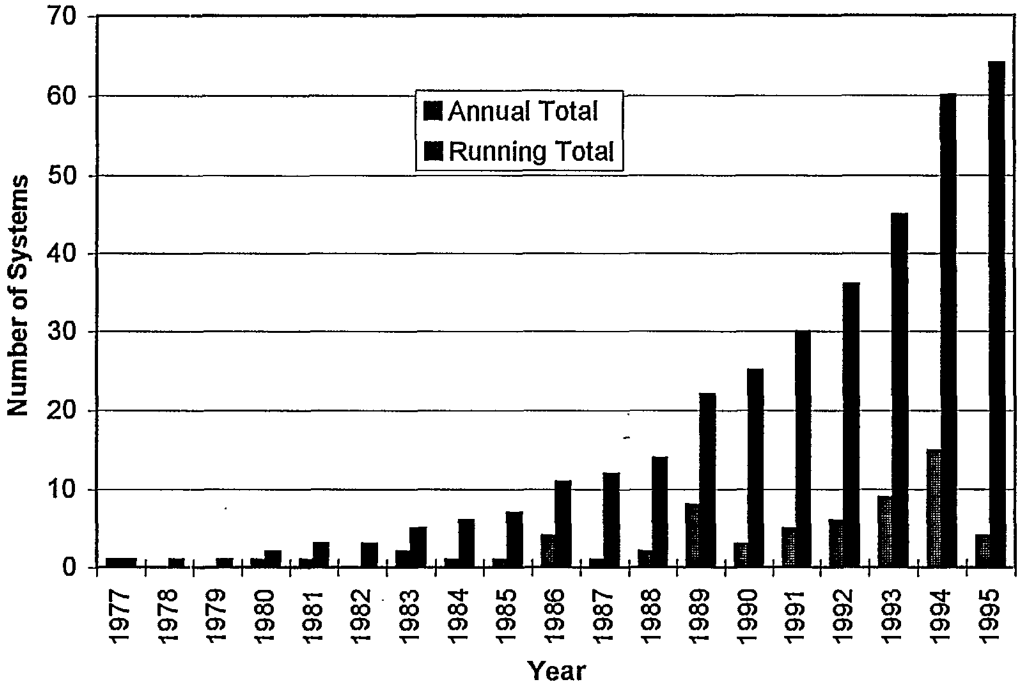

Figure VI-3: European System Development

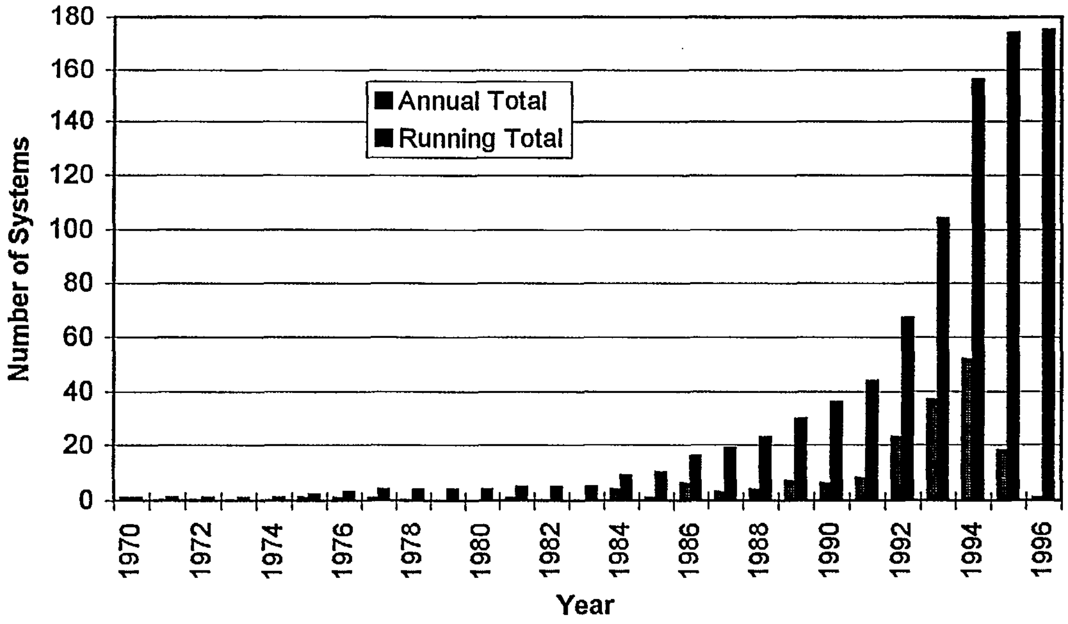

Figure VI-4: North American System Development

On a worldwide basis there are a total of 312 individual product-systems being pursued at the patent level, as prototypes, and as production systems. Figure VI-1 contains a breakdown according number of each type of system - fleet management systems are the most numerous totaling 121, while there are 72 autonomous, 47 advisory, 39 inventory, and 33 portable. About 100 systems are historical in nature.

The number of new ITS Navigation systems developed each year in Japan, Europe and North America is shown in Figures VI-2, VI-3 and VI-4. A complete list of all these - a listing of about 200 companies developing navigation systems - and the types of systems produced are contain in the IVNS Navigation Systems Database, Version 5, Intelligent Databases International Ltd., Calgary, AB, Canada (http://www.navnet.com).

21. AUTONOMOUS SYSTEMS

21.1. DESCRIPTION

Autonomous systems are usually installed in stand-alone vehicles and are comprised of on-board positioning devices such as GPS and Dead Reckoning, and a map database - see Figure 21-1 and Figure 21-2. No communications link is available with the outside world. These systems often provide map-related features such as best route calculation and route guidance to a destination. They are highly useful in areas which are unfamiliar to the driver. For example, a salesperson from out of town can rent a car from Avis or Hertz equipped with such a system and would be able to fit in more appointments per day. Tourists are another category of user that would find such a system indispensable.

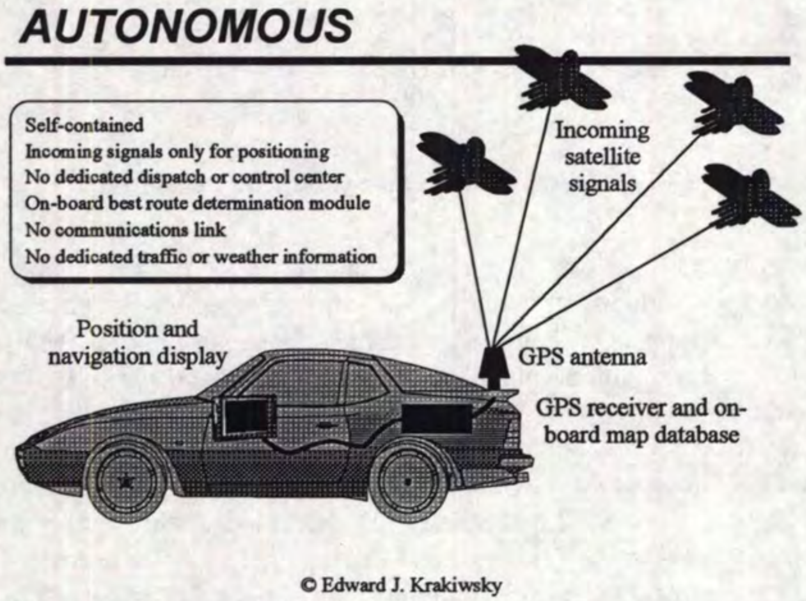

Figure 21-1: Concept of an Autonomous ITS Navigation System

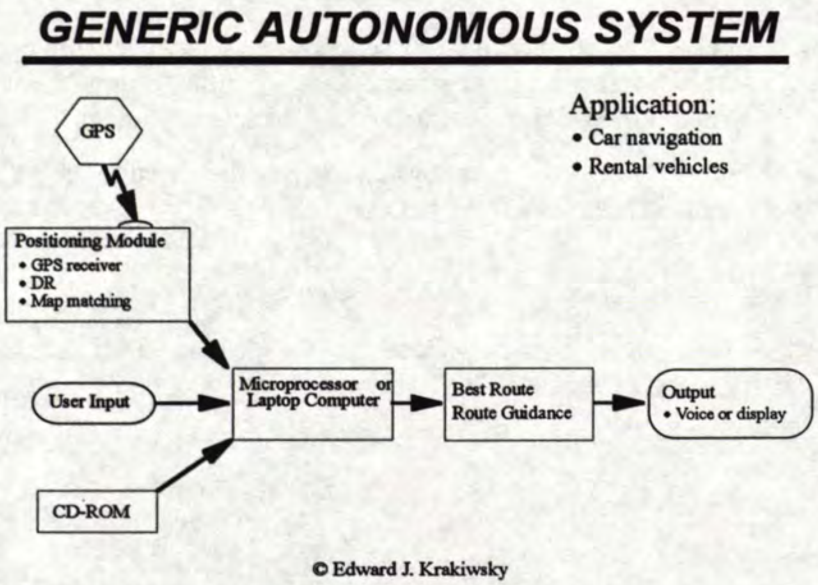

Figure 21-2: Flow Chart of a Generic Autonomous System

21.2. STATISTICS

The private car owner in North America has been slow to adopt autonomous systems and Figure 21-3 indicates that only a few such systems are available on the market. Japanese companies, however, have produced numerous autonomous systems primarily for domestic sale.

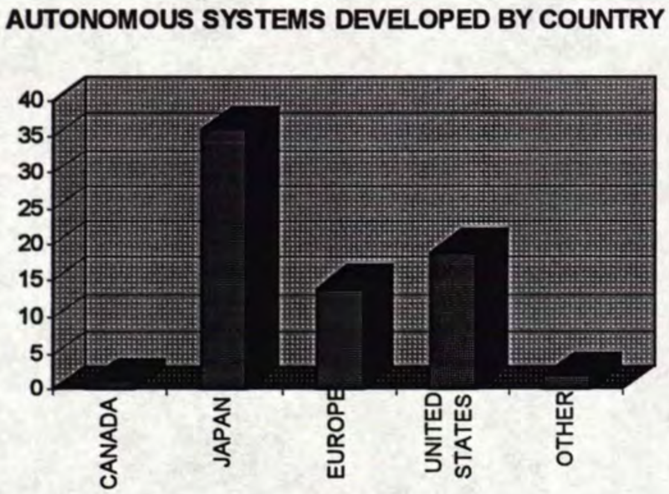

Figure 21-3: Autonomous Systems Developed by Country

21.3. SUMMARY AND CONCLUSIONS

The following are items of importance to Autonomous ITS Navigation systems:

- Japan is the leader with over 30 systems, while the USA is second with under 10 systems developed.
- Canada's position is weak in the development of such systems, however, the opportunity exits for Canadian firms to make alliances with Japanese and US firms to implement these systems now that the Canadian road network database will be available sometime in 1997-8 time frame.
- About 200 companies producing autonomous systems are documented in the IVHS Navigation Systems Database, Version 5 (http.//www.navnet.com).

21.4. REFERENCES

E.J. Krakiwsky, IVHS Navigation Systems Database™, Version 5.0,Intellegent Databases International Ltd., Calgary, Alberta, Canada, 1996 (http://www.navnet.com).

22. ADVISORY SYSTEMS

22.1. DESCRIPTION

An advisory navigation system is essentially an autonomous system with communications (Figures 22-1 & 22-2). Advisory system vehicles receive updated information regarding traffic and weather information, and even routing advice from a control center. The control center, in this context, is a service center that supplies information to those vehicles with the appropriate equipment, but does not manage the vehicles (as in fleet management). Additionally, specialized communications can be used to provide the vehicle with GPS range corrections for improved accuracy. Advisory systems primarily use a one way communications system such as RDS or RBDS (FM sub carrier), one way paging or beacons.

Some European and Japanese based systems employ two way communications where the vehicle's travel time along a given road segment is fed into the traffic model resident in the control center. These vehicles are known as probes and are one important source of traffic related information needed for generating traffic flow patterns and thus the proper functioning of advisory systems.

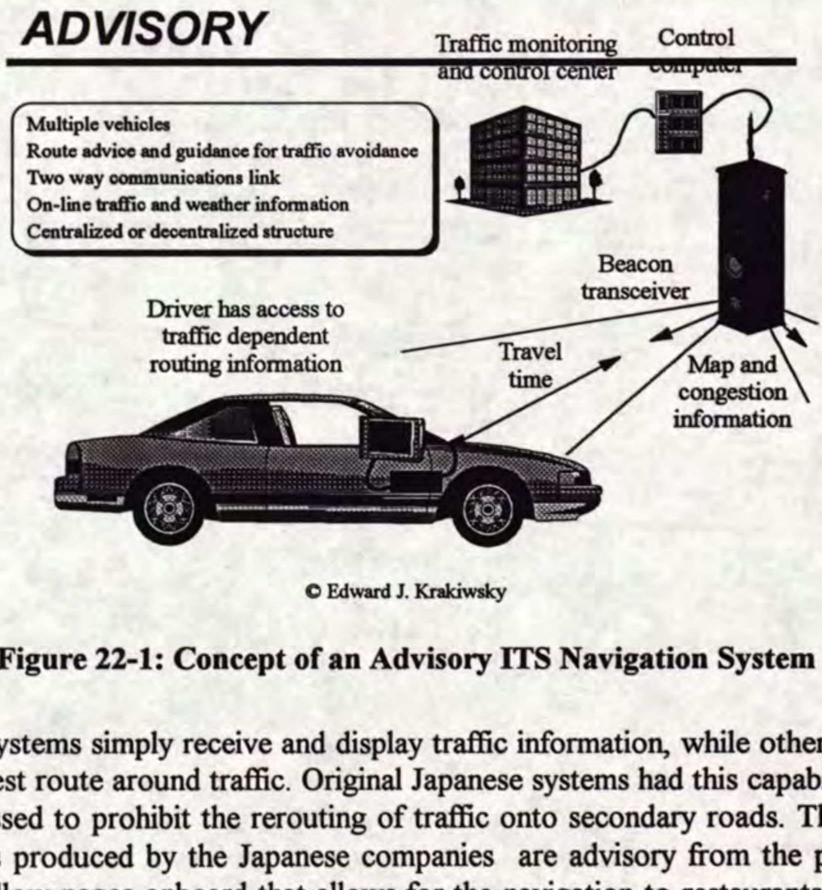

Figure 22-1: Concept of an Advisory ITS Navigation System

Some advisory systems simply receive and display traffic information, while others are capable of computing the best route around traffic. Original Japanese systems had this capability but a recent law has been passed to prohibit the rerouting of traffic onto secondary roads. Thus, most of the advisory systems produced by the Japanese companies are advisory from the point of view of having digital yellow pages onboard that allows for the navigation to restaurants, businesses and historical points of interest. Navigation around traffic is performed by inspection of the incidents shown on a map. Clearly, this type of system would be a benefit for anyone who has to drive in highly populated areas with high traffic congestion.

22.2. STATISTICS

Japan has numerous highly developed advisory type navigation systems because of their comprehensive Vehicle Information and Communications System (VICS). The combined-total sales of autonomous and advisory type systems in Japan has been about one million units, while in the USA and Europe about 10,000 units have been sold in each region.

Japan is well poised to begin to sell into the US market and a few Japanese firms have already introduced products and others are in the planning and development stages. Advisory systems listed for Europe are not as well developed as is Japan but several autonomous types are being designed such that when the communications and traffic dissemination infrastructure is completed, they can be extended into being an advisory type system. By 1997, there will be a wide selection.

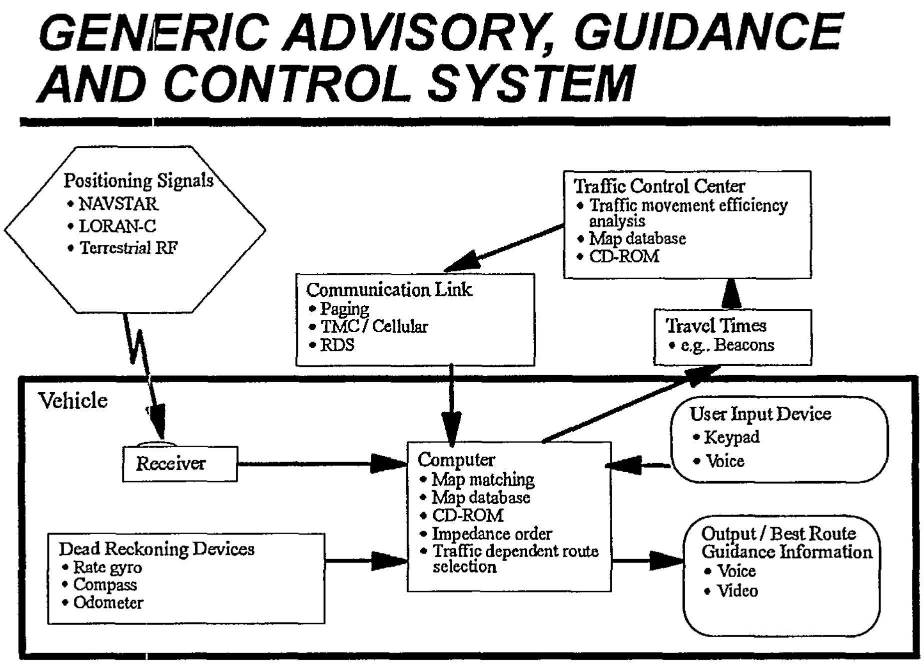

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Figure 22-2: Flow Chart of a Generic Advisory System

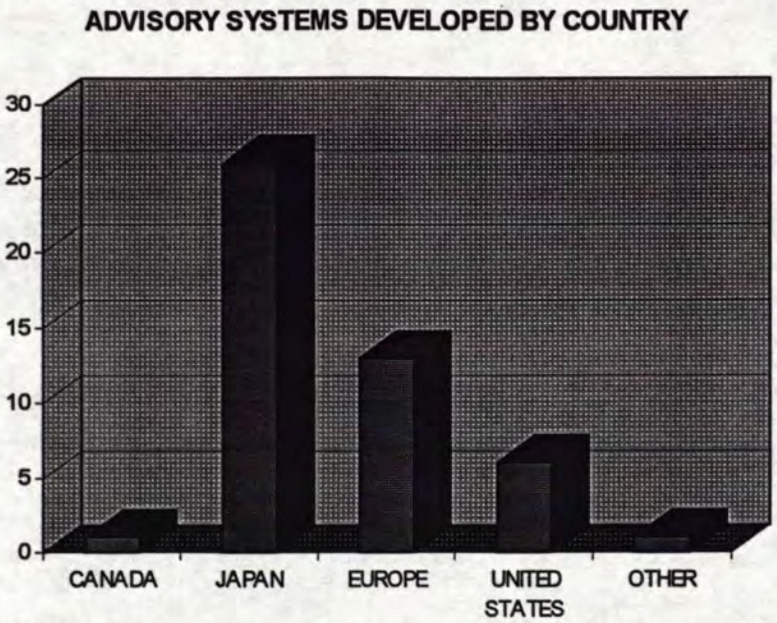

Figure 22-3: Advisory Systems Developed By Country

22.3. SUMMARY AND CONCLUSIONS

The following are issues related to Advisory type ITS Navigation Systems:

- Again Japan leads the world in the development of Advisory type systems with over 25, Europe follows with about ten and the USA trails with about 5.
- Canadian firms need to make alliances with companies from these three areas for both domestics implementation and then exportation to other parts of the world.

22.4. REFERENCES

E.J. Krakiwsky, IVHS Navigation Systems Database™, Version 5.0, Intelligent Databases International Ltd., Calgary, Alberta, Canada, 1996 (http://www.navnet.com).

23. FLEET MANAGEMENT SYSTEMS

23.1. DESCRIPTION

Fleet management systems consist of fleets of vehicles linked to a vehicle management control center via communications link. Positioning sensors are usually onboard the vehicle while the map database is usually at the dispatch center. Route guidance is normally performed at the dispatch, and transmitted to the vehicle. Some systems incorporate both voice and data communications. These systems require two way communications to allow the current position of the vehicle to be relayed to the control center and for route guidance and other information to be downloaded to the vehicle.

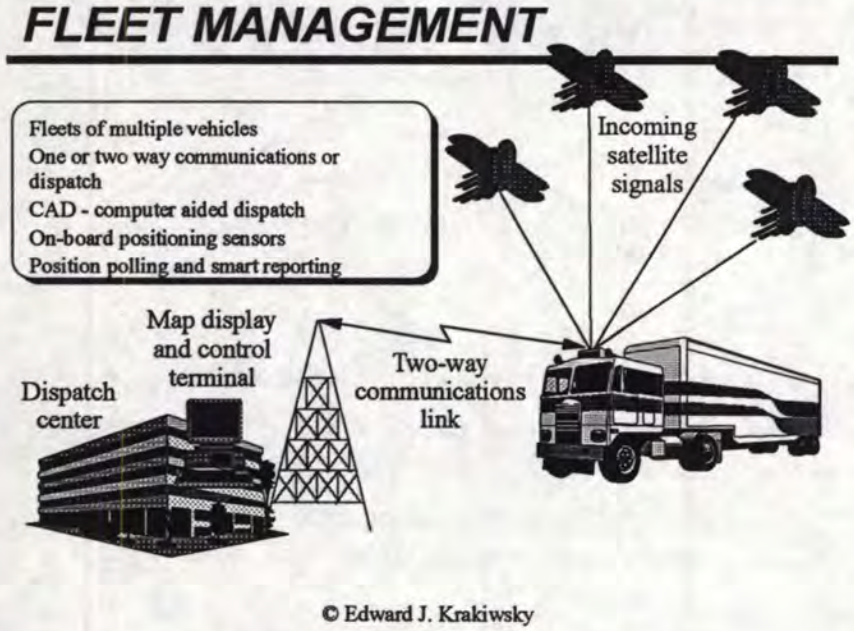

Figure 23-1: A Generic Fleet Management IVHS Navigation System

There are subclasses of fleet management systems; those for continental and intercontinental tracking which may require inter-modal (e.g., land and sea) type systems; wide area regional tracking such as in the truck fleet market; and urban based systems. The market is even further fragmented into sectors, e.g., in the urban environment, specialized systems are directed at emergency vehicles, courier companies, utility services, and public buses to mention just a few. It should be noted that the fleet management market is the most developed of the five types of systems. For example, one given fleet management system in the United States has sold to 100's of trucking companies representing more the 20,000 individual trucks. There are no solid figures for the total number of trucks under fleet management tracking and navigation control, but it must be in over one million in the United States alone.

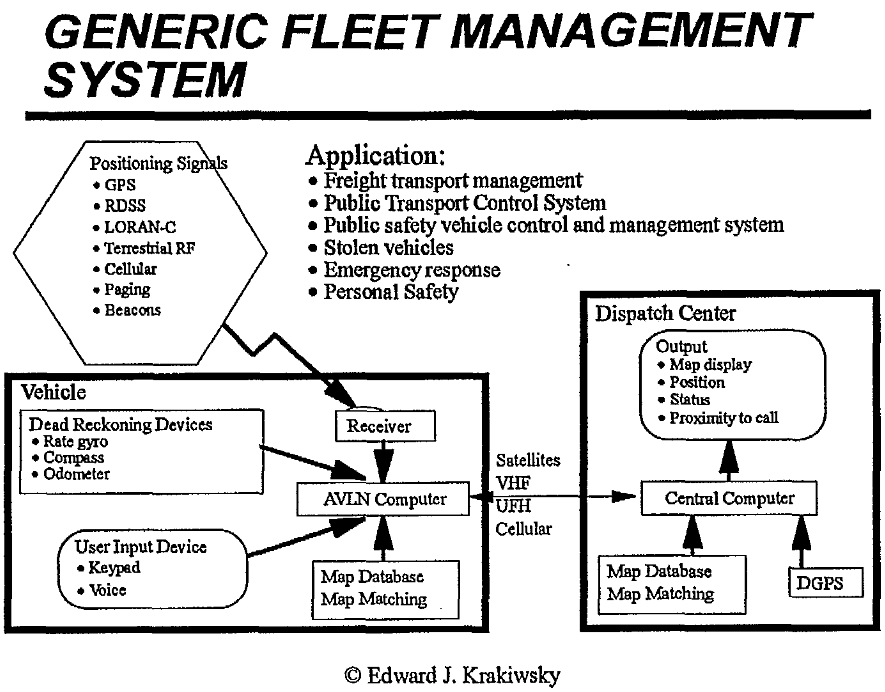

Figure 23-2: Flow Chart of a Generic Fleet Management System

Managing for just efficiency is not the only driving force behind fleet management systems. Security and theft have surfaced as dominant market pull factors. Several firms are offering systems that can activate a specialized service with the simple push of an icon in your vehicle; depending upon the service paid for, an ambulance or tow truck can be called to your rescue, or even the police to recover your stolen car. There are several of these systems on the market and rapid expansion is taking place in mobile security arena- a natural expansion of the home security business.

23.2. STATISTICS

Shown in Figure 23-3 are the number of fleet management systems developed by country. The United States leads with about 70, Europe is second with over 20, while Canada have produced about a half a dozen. Japan is conspicuously missing as they have concentrated on autonomous and advisory type systems. However, they are beginning to focus on fleet management type systems.

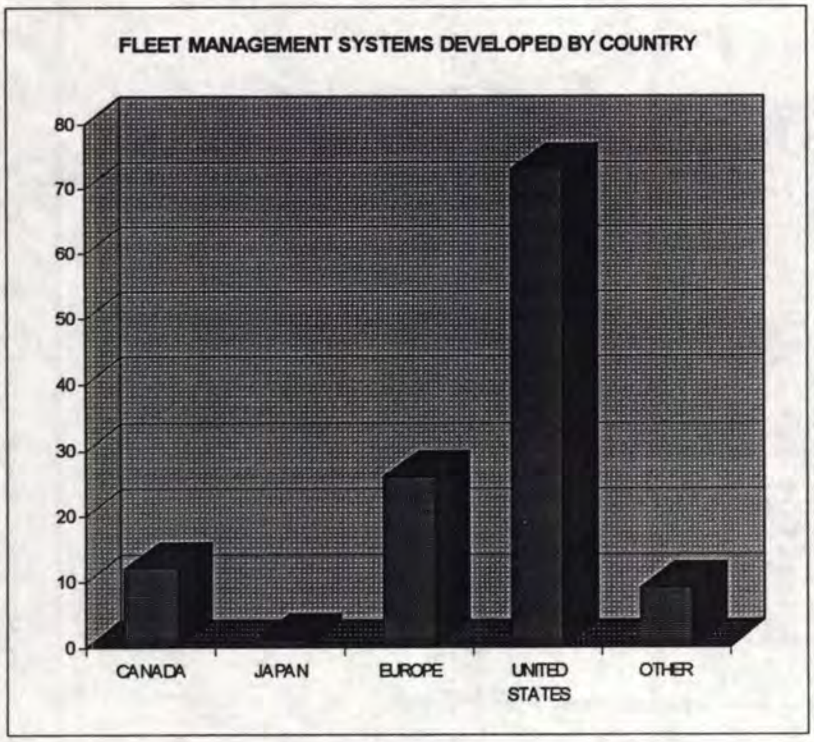

Figure 23-3: Fleet Management Systems Developed By Country

23.3. SUMMARY AND CONCLUSIONS

The following are important items related to fleet management systems:

- United States leads the world, Europe is second and Canadian firms have been reasonably active in this domain.
- Japan is gearing up for entrance into this type of system via their autonomous and advisory type systems in which they have been very strong.
- The Canadian opportunity is in fleet management types of systems coupled with innovative use of new communications systems like GEOs and LEOs, cellular and two way paging.
- Canadian firms should take a very close look at autonomous and advisory type systems built in the USA, Europe and Japan with the eye to incorporating them into fleet management type systems.

23.4. REFERENCES

E.J. Krakiwsky, IVHS Navigation Systems Database™, Version 5.0, Intelligent Databases International Ltd., Calgary, Alberta, Canada, 1996 (http://www.navnet.com).

24. INVENTORY SYSTEMS

24.1. DESCRIPTION

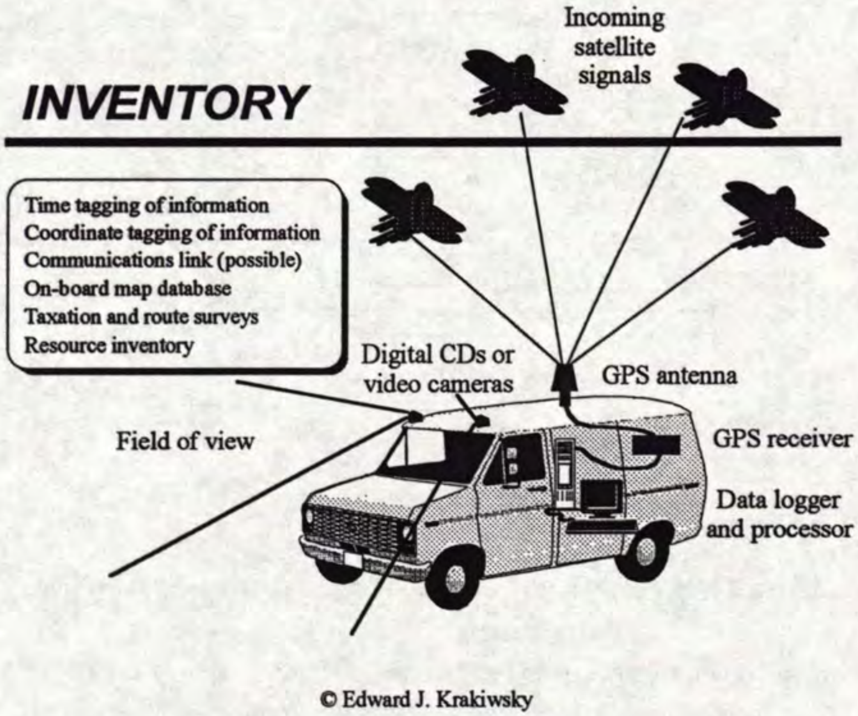

Figure 24-1: Concept of an Inventory ITS Navigation System

An inventory system usually includes autonomous vehicles equipped with video or digital cameras to capture, time, and coordinate tag, site information necessary for road inventory or any other surveillance purpose. Other sensors contained in inventory type systems are used to measure everything from cellular signal strength to road surface integrity, and this information is then tagged with position and location information from the navigation system for placement into Geographic Information Systems (GIS).

Inventory vehicles may have a communications link with a control center to assist in planning, coordinating and transferring of information from the field. Also, a communications link may be used to send GPS differential range correction data to the vehicle for the purpose of improving the accuracy of the positioning to the 1 - 2 meter level.

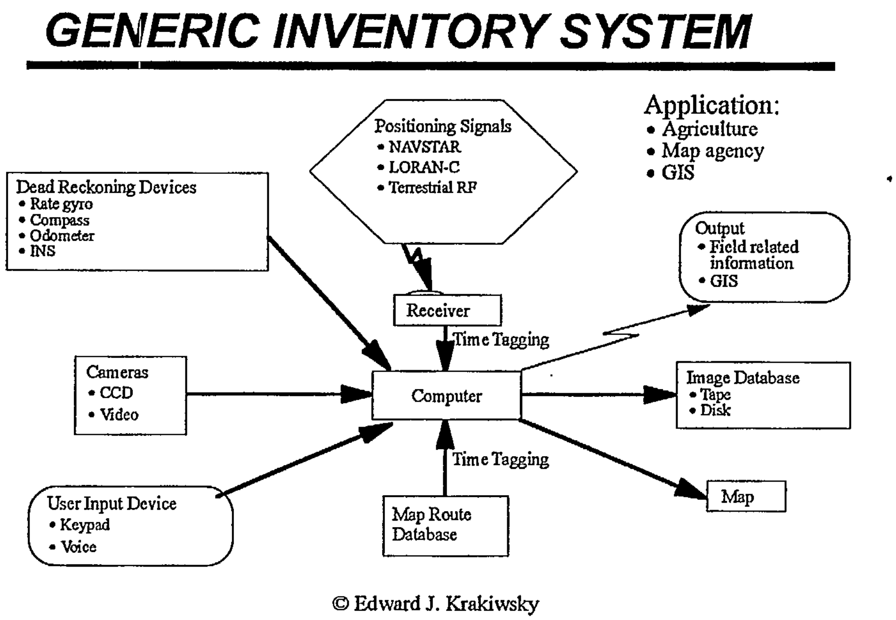

Figure 24-2: Flow Chart of a Generic Inventory System

A very import feature of inventory systems is the type of data that they collect and the form in which it is stored. Some have time and coordinate tagged video images, while others have infrared imagery. Still others can process data with onboard spectral analyzers for applications in signal strength surveys. Furthermore, the collected data is processed by GIS packages to produce contours of signal strength values for assessment as to the quality of data communications.

24.2. STATISTICS

Clearly, inventory systems are application specific and have specialized GIS databases associated with them. The IVHS Navigation Systems Database, Version 5, contains numerous firms who are producing inventory systems that are fixed to the vehicle and even those that are portable and thus can be carried on foot.

The United States is by far the largest producer of Inventory type systems. Canada has several type systems which is indicative of system integrator type firms.

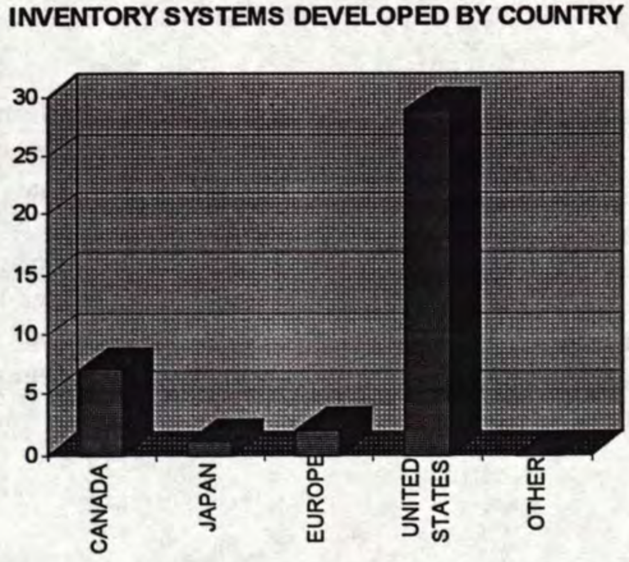

Figure 24-3: Inventory Systems Developed By Country

24.3. SUMMARY AND CONCLUSIONS

The following are issues related to inventory type systems:

- The large United States showing in this category is due to GPS manufacturers producing hand held GPS-GIS units for coordinate tagging information.
- Canada has a reasonable showing which indicates that this is an area in which Canadian firms can compete domestically; expanding these products to the international market is where the growth will be.

24.4. REFERENCES

E.J. Krakiwsky, IVHS Navigation Systems Database™, Version 5.0, Intelligent Databases International Ltd., Calgary, Alberta, Canada, 1996 (http://www.navnet.com).

25. PORTABLE SYSTEMS

25.1. DESCRIPTION

Finally, portable systems are the fastest growing category. For many applications, hard wiring the system to a vehicle is not optimal, and may be unacceptable. Therefore, small and inexpensive GPS receivers are turning Personal Data Assistants (PDA's) into Personal Navigation Assistants (PNA's). There is also a trend to use cellular communications with a PNA to achieve vehicle-personnel tracking. Low Earth Orbit (LEO) satellites are now being employed for wide area hinterland tracking with the advantage of requiring only small-low powered transceivers. This will enable seamless, intermodal and global tracking of vehicles and personnel with palm and laptop computers. LEO-GPS units are being built to be both portable type systems and to support global fleet management and tracking.

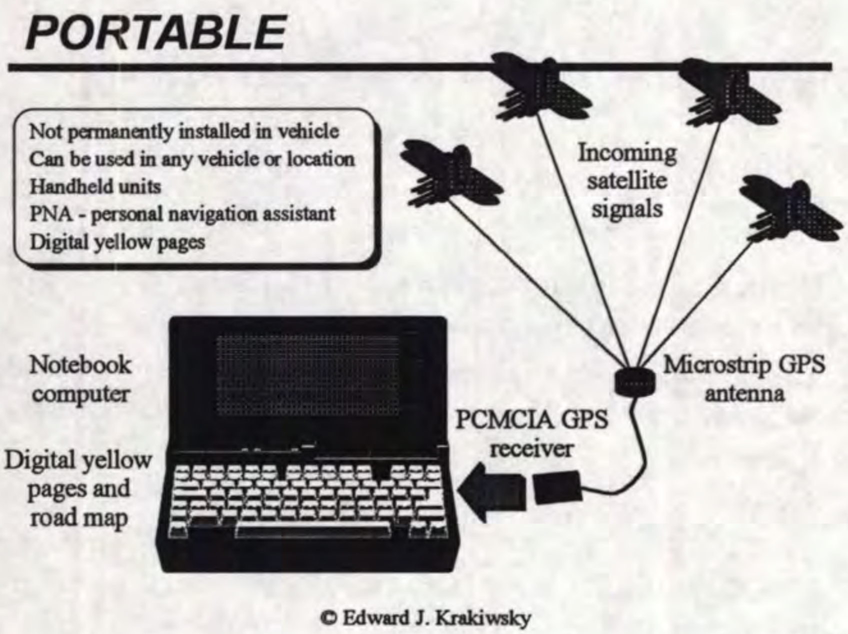

Figure 25-1: A Generic Portable Navigation Assistant

Some police departments are being to turn to portable type systems as opposed to systems that are hard wired to their vehicles. The reason for this shift is that these Portable Data Assistants (PDA's) can be used for report preparation and transmitted by modem right from the field. Information from dispatch could also be downloaded. These PDA's can then be turned into a PNA (Personal Navigation Assistant) with the use of GPS PCMCIA cards and in computer maps. Also, traffic information can be received via modems-pager devices that are interfaced with the laptop. The PNA can also be used to compute the fastest route and officers guided to locations quickly. These portable systems would increase efficiency and reduce costs.

Another use of portable systems is by a businessman who has all their contacts in a computer data base. It would allow them to click and drag an address from their personal database of contacts-prospects to the navigation software and have the location immediately plotted on a map and a route of travel computed. Health professionals could also benefit from this technology. For example a field nurse could be guided from one location to another by a PNA-PDA, prepare reports for the doctor, gain information on patients and send reports to the doctor - all enroute to the next patient. Portable systems with special application specific software are part of the growing market that is being serviced by the firms listed in the IHVS Navigation System Database, Version 5.

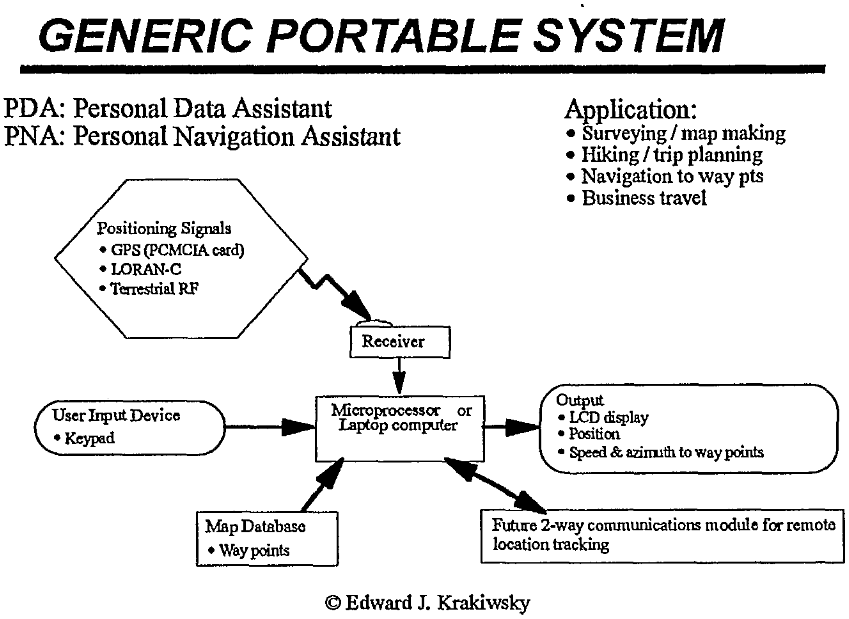

Figure 25-2: Flow Chart of a Generic Portable System

25.2. Statistics

Again the United States has a strong showing in the portable category because of the large number of GPS manufactures. Japan's involvement looks low, but several of the US firms have alliances with Japanese firms who have introduced US firms to manufacturing facilities in Japan.

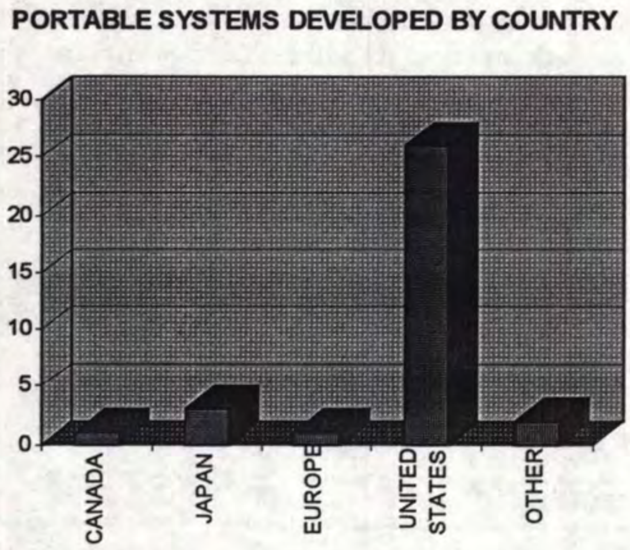

Figure 25-3: Portable Systems Developed By Country

25.3. SUMMARY AND CONCLUSIONS

The following issues relate to the development of portable systems:

- United States firms dominate the development of the portable systems.
- Canadian firms should forge alliances with US firms and write software for specialized applications.
- Integrating GPS and GIS into palmtop and laptop computers is another niche for Canadian firms.

25.4. REFERENCES

E.J. Krakiwsky, IVHS Navigation Systems Database™, Version 5.0, Intelligent Databases International Ltd., Calgary, Alberta, Canada, 1996 (http://www.navnet.com).

Part VII: Summary, Conclusions and Recommendations

26. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

26.1. PART I: ITS AND NAVIGATION RELATED TECHNOLOGIES

Intelligent Transportation Systems is the new and emerging multi-billion dollar market. The opportunities for Canadian companies are large for a combined Canadian and export market scenario.

The following general summary and conclusions are made vis-à-vis the role for positioning and navigation related technologies in ITS (Chapter 2):

1. Positioning and navigation is regarded as one of the key enabling technologies, along with communications, computers and mobile information databases, in the development of ITS products.
2. Canadian activities in positioning and navigation, as well as mapping, have always been ranked at an international level and thus there is a solid foundation upon which to develop an ITS related industry utilizing this expertise.
3. Positioning and navigation hardware components are being manufactured outside of Canada by large international conglomerates; Canadian firms are largely performing system integration and software development.

The following general recommendations are made vis-à-vis navigation and ITS (Chapter 2):

1. Industry Canada and Transport Canada regard positioning and navigation (including digital map databases) as strategic to the economic development of Canadian Industry.
2. Industry Canada and other Government Agencies support Canadian firms to create strategic alliances with local and international firms for the express purpose of developing ITS Navigation Systems related products for the local and international markets.

26.2. PART II: SATELLITE RADIO FREQUENCY (SRF) BASED POSITIONING SYSTEMS

The following main summary and conclusion items form the basis for recommendations dealing with satellite-based positioning systems:

1. Standards, protocols and interfacing issues for GPS have been handled well by the navigation and electronics industry and few impediments to development if any exist.
2. Compatibility and inter-operability within NAFTA countries is automatic as GPS is truly a global positioning utility allowing for GPS related products to operate anywhere in the world.
3. Canada has unusual strength in the GPS education and research arena as it has two world class universities (The University of Calgary and University of New Brunswick).
4. Canada has two GPS Receiver manufactures in Canadian Marconi and NovAtel which adds considerable strength to the various Canadian GPS teams.

5. Canada has numerous GPS product developers and system integrators who have and are developing a host of GPS related applications and are poised to introduce their products in the about to take off GPS market (see list in Chapter 3).

6. Canadian firms have more than the required level of expertise and products to meet domestic needs, but often the Canadian launching pad for these products is not being supported or is not available. The NRC-IRAP program is an exception to this rule.

7. The two impediments to international exportation of Canadian GPS technology is the slowness of acceptance in Canada of this technology and the apparent inability of Canadian concerns to purchase it.

8. The slow market development in Canada for GPS products has caused Canadian firms to seek USA and international markets, thereby adding high costs of marketing to their overall budgets. This fact places high importance in supporting these firms in international marketing initiatives.

9. GPS infrastructure for differential GPS (DGPS) services is strong in Geomatics Canada, Ottawa as well as in industry via Pinpoint Ltd., Toronto and DCI, CA.

10. Canada contributes financially via the Canadian Space Agency to the European Space Agency which is a lead player in GNSS, thereby making it possible for Canadian companies to be involved in this new space positioning and communications effort.

11. GNSS is a longer term initiative (circa 2000-2005), however, considerable funds are presently being expended on design and studies and some level of Canadian presence is required. Industry Canada should partner with the Canadian Space Agency to look into this matter and create the opportunity for Canadian firms to participate.

12. GNSS will be backward compatible with GPS - meaning that somehow it will be possible to leverage all the GPS equipment and applications over to GNSS.

13. GNSS will be regionally owned and operated by the civilian community; this begs the questions "what should the Canadian involvement be ?". Finding the answer to this question is an initiative that Industry Canada should support.

14. Canadian positioning and navigation needs both domestically and internationally for exportation of our products makes an involvement in GNSS mandatory.

15. Presently, ITS continental communications and communications in remote areas is most economically achieved by GEO's.

16. Canada is a key player in GEOs via TMI Communications, Ottawa who have a strong alliance with AMSC, Reston, VA. Each has their own mobile satellite (MSAT) to back one another up, but TMI has yet to launch their satellite. Thus, the positioning capability has yet to be implemented.

17. QUALCOMM, San Diego has had a great deal of success employing both GEO communications and positioning. Their European alliance in EtelTRACS has assisted in spreading this technology around the world.

18.Through TMI (and resellers Bell Mobility, Glentel and InfoSat) and AMSC, Canadian firms have a ready made vehicle to form strategic alliances for building applications using GEO-based technology.

19.Economical satellite-based communications and positioning will be offered by the several LEO-based systems towards the end of the decade.

20.Presently, Orbcomm Canada and Orbcomm USA are the only functioning LEO based systems with two satellites launched to serve static applications such as SCADA in remote areas and asset management.

21.LEOs will have inherent communications and positioning coupled together, however, for higher accuracy GPS will be combined in a the same black box as the communications device.

22.LEO systems are being launched as infrastructures with alliances made with solution providers - who will resell time and build applications for end users. Canadian firms have the possibility to be strategically positioned (via Teleglobe Canada and Orbcomm Canada) to be system integrators and solution providers of LEO-based positioning and navigation systems worldwide.

23.Odyssey will offer personal communications of voice and data in hand held units costing about $300 by the turn of the century. Connections to the Internet is also an important dimension of this futuristic technology.

24.Canadian firms have an entry into global personal communications technology via Northern Telecom and Aerospace Ltd. who are participants in Odyssey.

Recommendations emanating from the above conclusions regarding GPS, GEOs, LEOs, MEOs and HEOs are the following:

1. Given Canada's prowess in GPS in both the governmental and corporate sectors, Industry Canada should foster innovative programs for getting this space-based technology into products for Canadian consumption and then for the export market. The specific sectors to be targeted are outlined in the GPS conclusions given above.
2. Given Canada's leadership in GEOs via the MSAT of Telesat and TMI, coupled with the wholesaler network in place (Bell Mobility in Montreal, Glentel in Vancouver, and InfoSat in Burnaby), Industry Canada should work with the private sector in creating products that utilize GEOs.
3. Given Canada's leadership in LEOs via Orbcomm Canada and Teleglobe Canada, Industry Canada should work with the private sector in creating products that utilize LEOs. These are exportable, because these same LEOs orbit the entire Earth and are used by some 75 other jurisdictions (wholesalers) around the world.
4. Given CANCOM's equity position in the Starsys LEO, there is a ready made opportunity for Canadian companies and this should be supported by Industry Canada.

5. Industry Canada should support studies in MEOs and HEOs to ascertain their impact on GEO and LEO based systems and products as well, it should be determined what future products they may bring.
6. Industry Canada is encouraged to support studies into the civilian European GNSS1 and GNSS2 systems via the Canadian Space Agency as the latter contributes to the European Space Agency who is designing and studying the markets for GNSS.

26.3. PART III: TERRESTRIAL RADIO FREQUENCY (TRF) BASED POSITIONING SYSTEMS

The following main summary and conclusion items form the basis for recommendations dealing with TRF-based positioning systems:

1. Loran-C coverage is now complete in most of North America except for the northern part of the continent. Its advocates believe that it can be used as an independent system to add redundancy to integrated navigation systems - mainly for marine and air navigation systems.
2. Loran-C is a sunset technology with limited growth, thus Canadian firms have very limited opportunities in this domain.
3. Terrestrial paging-based communications and positioning systems are numerous and present a huge opportunity for Canadian firms, however, the competition is high.
4. There are no Canadian, paging based positioning systems, but the Toronto Dominion Bank investment in the Air Touch Teletrac system may be an opportunity worth exploring and supporting.
5. The use of paging for communications in ITS navigation systems is growing and is a technology worth considering because of its low cost.
6. Canada has a promising development of cellular positioning in Cell-Loc, Calgary. There soon may be a ruling in the United States by the FCC, (911 cellular communications), that may require the position-location of the mobile caller to be known, i.e., its coordinates computed.
7. There are seven other cellular-based positioning developers (all in USA) which will be competing for the market.
8. Canadian firms should study how innovative applications could be built around paging and cellular-based positioning technologies for there is a large market with significant growth potential.
9. Given the soon to be available digital maps in Canada, the above mentioned new positioning technologies have all the necessary components for a successful product - positioning, communications (uses a standard cellular phone or communications modem) and maps.
10. AM and FM positioning is a novel idea with several patents in place but there is little commercial activity and no Canadian involvement. Only limited testing has taken place meaning that the technology is low on the R&D curve.

11.A very interesting application is in the area of personal positioning inside buildings and the imbedding of these types of positioning modules into palm and laptop computers.

12.There are several international based AM-FM based positioning based systems, however, there is no Canadian developer.

Recommendations emanating from the above conclusions regarding terrestrial RF based positioning systems are as follows:

1. Industry Canada should support the relevant firms mentioned immediately above should explore ways in which to integrate mobile communication of data and positioning (locating) information into future paging-data related products.
2. Industry Canada, in concert with the Canadian telecommunications companies and the developers of positioning by cellular, (Cel-loc, Calgary) foster the development of applications of this core technology to an array of products for end users.

26.4. PART IV: DIGITAL MAP DATABASES IN SUPPORT OF TRACKING AND NAVIGATION

The following main summary and conclusion items form the basis for recommendations dealing with digital map databases:

1. Locations relative to physical features are given by maps and thus are an indispensable component of ITS navigation systems along with the coordinates from positioning sensors.
2. There are several map related functions that are needed in ITS navigation systems and they are: address matching, map matching, best route calculation and route guidance.
3. Digital maps for ITS navigation systems have varying requirements depending upon what type of system, namely: fleet management, autonomous, advisory, inventory and portable.
4. Digital maps for ITS navigation systems must be seamless, digital in form for intelligent querying, follow international standards and work in real-time.
5. Japan has led the world in removing digital map databases of road networks as an impediment to the development of ITS navigation systems by forming an association to foster the development of a map database for all of Japan (one million km or roads with 20K km of new roads being added per year).
6. The map database was made available to all member to develop applications and systems; this led to an explosion in applications and products. The experience gained through this effort has positioned Japanese firms to enter the European and North American markets. This movement is planned for 1997 and one already sees movement in this direction through the purchase of Etak by Sony, the setting up in Los Angeles of Nippondenso, Sony products already operating in California.

7. Japan has totally integrated the navigation functions and displays into the electronics of modern vehicles; maps are on CDs and read with the same hardware as the audio system, and then shown on the same CRT as the car TV. Traffic information is being broadcast to vehicles and correlated with map information for route selection. In short, Japan has taken a holistic-integrated approach to ITS navigation systems.
8. Forming alliances with Japanese firms should be a top priority for Canadian agencies and companies.
9. NavTech and Etak are the main digital road network map suppliers in the United States and compete head to head. NavTech is multiple owners including AAA and Phillips; it licenses its technology form SEI, Chicago. Etak is now owned by Sony.
10. NavTech has focused on producing navigable maps which contain most turn restriction data; and plan to have most of the major cities complete in 1997.
11. Etak has focused on coverage (non-navigable maps) and has maps for most of the major cities in the USA. They, however, also have embarked upon producing navigable maps for selected areas.
12. Bosch and Phillips lead the development of digital map standards with the issuing of the GDF (Geographical Data File) back in about 1988; others involved were Daimler-Benz and Renault.
13. Both Bosch and Phillips have developed ITS navigation systems of their own: Berlin system by Bosch and the CARIN system by Phillips.
14. Bosch has joined the European Data Pool whose members include Tele-Atlas, Intergraph and Etak, with Etak retreating to service the UK.
15. Phillips has joined a competing group which includes EGT (European Geographic Technologies) which it partly owns with NavTech. EGT was originally to join the EDP but has gone on its own with Phillips.
16. The NavTech - Etak division in Europe mirrors the same competition set up in the USA.
17. With NavTech and Etak each setting up shop in Toronto in 1996, the same split will be present in Canada; Canadian firms will have to pick their sides with the understanding that Sony now owns Etak.
18. The development of a seamless database of the Canadian road network is about to take shape as several governmental organizations and firms are poised to take advantage of the opportunity. The main federal agencies are Geomatics Canada, Canada Post and Statistics Canada. The provinces which have shown leadership are Ontario, British Columbia, Alberta and Saskatchewan.
19. Canadian firms who have developed applications using road network databases are Giro, Pulsearch, QC Data, Compusearch, Premier, AVeLTEK Systems, International Road Dynamics, and DataTrax.

20.Mapping firms poised to supply seamless Canadian roadnetwork databases are Etak (owned by Sony) and NavTech (partially owned by AAA and Phillips)- both have established offices in Toronto in 1996.

21.The first opportunity for Canadian firms is to participate as sub-contractors in the development and preparation of the basic road network data for the major data holders listed immediately above.

22.The second opportunity for Canadian firms is to make strategic alliances with one of the two main suppliers - Etak or NavTech, and use their data to develop application specific products and deal with end users. Firms can also make arrangements with Geomatics Canada, Canada Post and Statistics Canada, but this route has not proven to be fruitful in the past as cost of the basic map data has been kept too high. This may change now that Etak and NavTech are on the scene in Canada.

The main recommendation related to the mapping area is the following:

1. Industry Canada declare that the soon to be created databases of the Canadian Single Line Road Network be regarded as a strategic data source upon which to develop ITS related products. IC and related agencies should foster the development of products by Canadian firms working in strategic alliances with international firms with the aim to launch their products in Canada but gain growth through exports.

26.5. PART V: SENSORS FOR RELATIVE POSITION DETERMINATION

The following main summary and conclusion items form the basis for recommendations dealing with dead reckoning relative positioning sensors:

1. Differential wheel mounted odometers allow for change in azimuth determination as well as distance traveled and in modern vehicles (circa 1990s) the anti-lock breaking system outputs the necessary data. Maintenance is especially difficult in vehicles that are often in off road conditions.
2. Transmission odometers are concealed and installed in the transmission where the speed odometer cable is connected. Errors sources are primarily due to wheel slippage and changes in wheel circumference due to tire pressure and velocity changes.
3. Many new vehicles with anti-lock braking systems installed provide a direct pulse output that may be connected to directly.
4. Some companies have built a special gear tooth which they have connected to each wheel with anti-lock braking to provide differential odometry.
5. GPS velocity measures can be used to calibrate the odometers continuously.
6. Magnetic compasses are very sensitive to external magnetic field disturbances such as bridges, railway tracks, overpasses. Spurious readings as large as 180° are often encountered. Tests have shown the presence of large errors due to the operation of power windows and air conditioning. Most companies have abandoned the use of a compass in AVL applications. Opportunities for Canadian firms are very limited in this domain.

7. Rate gyros require an initial reference heading and are extremely useful in ITS navigation systems for determining the change in heading of a vehicle.

8. Vibration gyros are sensitive to temperature fluctuations and vibrations. Typically errors of 1°- 2° are encountered, though this may increase significantly, if uncalibrated. The drift is generally linear.

9. Fiber Optic Gyros (FOG), with a decrease in cost, offer the greatest potential for future heading sensors. Vibration gyros are currently the lowest in cost and are being used in a number of automobile makes and models. Low cost sensors will most likely be manufactured in Japan due to their high level of electronic manufacturing capabilities. Delco and Rockwell are manufacturing gyros aimed at the automotive industry in the US. Bosch and British Aerospace are producing low cost gyros in Europe.

10. Most land dead reckoning systems now use a rate gyro as a change in heading sensor. Some gyro manufacturers are now able to accept input from other sensors such as odometer and backup light switch. This information is then passed though one interface to central processor.

11. Japanese technology is likely to dominate low cost AVL systems in the future. They have had a much wider acceptance in Japan and they are much further ahead in terms of commercialization.

12. Canadian companies will likely not be involved with the manufacturing of gyros, but may incorporate them into custom navigation systems.

13. Many commercial navigation applications will be met using GPS alone, but significant number will need integration with dead reckoning or with inertial units.

14. For inertial units to be accepted in ITS circles, the target cost per axis for the automotive industry will have to be several dollars each; so that for a pair of two-axis units, two for rate gyros and two for accelerometers, the total cost will be about $25 in large quantities. Low cost inertial systems could be used to supplement GPS for AVL applications if the cost becomes cheap enough.

15. Low cost inertial devices will probably be incorporated for collision avoidance and other requirements ahead of navigation in the automotive industry. The automotive industry will incorporate inertial devices as they can be mass produced at a low cost.

16. Future cost of fiber optics systems is expected to decrease, thereby expanding applications. Some companies are proponents of fiber technology while others are pushing micro-mechanical developments. Cost, stability and size are major considerations.

17. Canadian companies will continue to develop applications using GPS and other sensors, but will not be manufacturers of inertial or any other dead reckoning sensors.

18. Manufacturing plants will likely be setup in Japan and Mexico in the future to serve the mass market production requirements.

The following recommendations are made vis-à-vis relative positioning sensors:

1. As dead reckoning sensors are not manufactured in Canada, strategic alliances need to be made with international developers of this technology to assist system integrators, and Industry Canada should support Canadian firms in establishing these relationships.
2. Industry Canada is encouraged to sponsor market studies for determining the use of the up coming, low cost inertial navigation units(INUs) and how they can be integrated with GPS to develop products for new markets.

26.6. PART VI: ITS AND NAVIGATION SYSTEMS BEING BUILT WORLDWIDE

The following main summary and conclusion items form the basis for recommendations dealing with ITS Navigation systems being built worldwide:

1. Japan is the leader in the development of Autonomous type systems with over 20 systems, while the USA is second with under 10 systems developed.
2. Canada's position is weak in the development of such systems, however, the opportunity exits for Canadian firms to make alliances with Japanese and US firms to implement these systems now that the Canadian road network database will be available sometime in 1997-8 time frame.
3. Again Japan leads the world in the development of Advisory type systems with over 25, Europe follows with about ten and the USA trails with about 5.
4. Canadian firms need to make alliances with companies from these three areas for both domestics implementation and then exportation to other parts of the world.
5. United States leads the world in the development of Fleet Management type systems. Europe is second and Canadian firms have been reasonably active in this domain. Japan is gearing up for entrance into this type of system via their autonomous and advisory type systems in which they have been very strong.
6. The Canadian opportunity is in the development and implementation of Fleet Management types of systems coupled with innovative use of new communications systems like GEOs and LEOs, cellular and two way paging.
7. Canadian firms should take a very close look at autonomous and advisory type systems built in the USA, Europe and Japan with the eye to incorporating them into fleet management type systems.
8. The large United States showing in the category of Inventory type systems is due to GPS manufacturers producing hand held GPS-GIS units for coordinate tagging information. Canada has a reasonable showing which indicates that this is an area in which Canadian firms can compete domestically; expanding these products to the international market is where the growth will be.
9. United States firms dominate the development of the portable systems. Canadian firms should forge alliances with US firms and write software for specialized applications.
10. Integrating GPS and GIS into palmtop and laptop computers is another niche for Canadian firms.

11.Prior to 1992, Japan led the world in the development of these systems. In a few years after former President Bush's declared $600 million dollar ITS program (and matched by industrial contributions), the USA passed Japan.

12.After the USA and Japan, Canada along with Germany and the UK are prominent developers of these types of ITS systems.

13.Many ITS Navigation systems are reaching second and third generation status. This increased level of sophistication will soon be reflected in ITS navigation solutions.

Recommendations for ITS Navigation systems are the following:

1. Industry Canada support market research for the purpose of developing of new systems for markets not covered by existing ITS navigation systems. As well, market research should be performed with an eye to match existing ITS Navigation systems to ready made markets in Canada and internationally.
2. Industry Canada declare ITS navigation systems (about 200 active products worldwide) as valuable ingredients for solving ITS related problems and support their introduction into ITS.
3. Industry Canada foster the dissemination of information on ITS Navigation Systems being built worldwide to Canadian firms so that they are aware of opportunities and their competition on a global basis.

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