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## **Communications and Positioning Systems in the Motor Carrier Industry**

**Dimitris A. Scapinakis**  
**William L. Garrison**

**PATH Research Report**  
**UCB-ITS-PRR-91-10**

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COMMUNICATIONS AND POSITIONING SYSTEMS IN THE  
MOTOR CARRIER  
INDUSTRY

Dimitris A. Scapinakis  
William L. Garrison

# Table of Contents

|  |     |
|--|-----|
| Table of Contents                                      | i   |
| <b>List of Figures</b>                                 | iii |
| List of Tables   | iii |
| Abstract   | iv  |
| Acronyms and Abbreviations                             | v   |
| Preface  | vii |
| 1 INTRODUCTION   | 1   |
| 2 THE TRUCKING INDUSTRY                                | 3   |
| 3 POSITION REPORTING AND COMMUNICATIONS TECHNOLOGIES   | 8   |
| 4 POSITION REPORTING SYSTEMS                           | 11  |
| 4.1 PROXIMITY SYSTEMS                                  | 12  |
| 4.2 RADIODETERMINATION SYSTEMS                         | 14  |
| 4.2.1 LORAN-C  | 15  |
| 4.2.2 Satellite Based Systems                          | 15  |
| 4.2.2.1 The Global Positioning System (GPS)            | 17  |
| 4.2.2.2 QUALCOMM'S QASPR                               | 19  |
| 4.2.2.3 Geostar's RDSS Proposal                        | 19  |
| 5 MOBILE COMMUNICATIONS SYSTEMS                        | 21  |
| 5.1 LANDBASED SYSTEMS                                  | 21  |
| 5.1.1 Meteor Burst                                     | 21  |
| 5.1.2 Telephone and Cellular Systems                   | 22  |
| 5.1.3 Voice Radios and Beyond                          | 24  |
| 5.1.4 On-Board Recorders                               | 26  |
| 5.2 SATELLITE BASED SYSTEMS                            | 27  |
| 5.2.1 Qualcomm's OmniTRACS                             | 29  |
| 5.2.2 Geostar  | 32  |
| 5.2.3 The American Mobile Satellite Corporation (AMSC) | 33  |
| 5.2.4 INMARSAT   | 34  |
| 5.3 EUROPEAN DEVELOPMENTS                              | 34  |
| 5.4 EMERGING SYSTEMS AND SYSTEM PROPOSALS              | 36  |

|  |    |
|--|----|
| 6 USES AND EXPERIENCES .....   | 41 |
| 6.1 SHORT HAUL OPERATIONS .....  | 43 |
| 6.2 LONG HAUL OPERATIONS .....   | 46 |
| 6.3 THE HELP PROJECT .....   | 49 |
| 7 LESSONS .....  | 52 |
| 7.1 FLEET <b>OPERATORS: AUTOMATE OR INFORMATE?</b> .....   | 52 |
| 7.2 THE AUTO-TRUCK HIGHWAY SYSTEM .....  | 56 |
| 8 CLOSURE .....  | 61 |
| REFERENCES .....   | 62 |
| APPENDIX: TOWARD IVHS ORIENTED MONITORING OF THE TRUCKING INDUSTRY'S<br>ADOPTION AND USE OF POSITION AND COMMUNICATION SYSTEMS . | 66 |

## List of Figures

|    |   |    |
|----|---|----|
| 1  | The Trucking Industry . . . . .                                 | 4  |
| 2  | Major Uses of Trucks . . . . .                                  | 7  |
| 3  | Example proximity systems . . . . .                             | 13 |
| 4  | Mobile Satellite Communications . . . . .                       | 28 |
| 5  | Keyboard and Display Unit . . . . .                             | 29 |
| 6  | The Qualcomm System . . . . .                                   | 30 |
| 7  | The PROMETHEUS Project . . . . .                                | 37 |
| 8  | Communications systems used by fleets of all classes . . . . .  | 42 |
| 9  | Market Penetration by Selected Communications Systems . . . . . | 43 |
| 10 | Market share of selected communications technologies . . . . .  | 44 |
| 11 | Crescent Applications . . . . .                                 | 51 |
| 12 | Screen from a level I computer program . . . . .                | 54 |

## List of Tables

|   |  |    |
|---|--|----|
| 1 | Positioning and Communications Systems Discussed . . . . . | 10 |
|---|--|----|

## Abstract

Until recently, truck drivers and their dispatchers have relied on public telephones and voice radio systems to communicate with each other. Today, however, vendors are beginning to offer new technologies for determining the positions of trucks and communications to and from trucks. Eighteen systems and their implications for the industry and intelligent vehicle highway systems (IVHS) activities are reviewed in this paper.

Some of the newer communications and/or positioning systems are in the proposal stage. Others are available with not yet fully developed capability or only in limited markets. Some other systems, such as cellular telephones or modern voice radio, represent recent improvements of existing systems. New satellite based systems offer the most comprehensive coverage, but they are relatively expensive and tend to be favored by large, irregular route truckload carriers which have reported significant increases in productivity from system use.

Regardless of the technology used, the challenge for truck fleet operators is the full integration of the information provided by the systems with their operations. In the transition to a high degree of information integration, three distinct steps or levels can be identified. First, the dispatcher's work is eased and made more efficient. The communications system plays a key role because the basic source of information is the moving vehicle. Then, information is shared between different departments within the trucking firm. Finally, interorganizational links between the trucking firm and its customers are established. Firms in the industry have always strived for information integration at these levels. What is new is the possibility of a much higher level of information automation and integration.

The implications of trucking industry trends for IVHS programs may be summed up in two observations. Managers of trucking firms are interested in improved productivity, service improvements, and cost reductions. Highway agency professionals are interested in improved facility operations. But the mutual interests of firms and IVHS-interested agencies appear to fall through the cracks, so to speak. Trucking firms are achieving higher and higher levels of information-enabled integration. The potential for integration of information from the trucking industry has not yet been considered by the IVHS community.



## Acronyms and Abbreviations

|          |   |
|----------|---|
| AAR      | Association of American Railroads                           |
| ACTS     | Advanced Communications Technology Satellite                |
| AEI      | Automatic Equipment Identification                          |
| AMSC     | American Mobile Satellite Corporation                       |
| ATA      | American Trucking Associations                              |
| AVI      | Automatic Vehicle Identification                            |
| AVLS     | Automatic Vehicle Location System                           |
| CDMA     | Code-Division Multiple Access                               |
| CTA      | California Trucking Association                             |
| c v o    | Commercial Vehicle Operations                               |
| DRIVE    | Dedicated Road Infrastructure for Vehicle Safety in Europe  |
| EDI      | Electronic Data Interchange                                 |
| EMBARC   | Electronic Mail Broadcast to a Roaming Computer             |
| EUROFRET | A European System for International Road Freight Operations |
| FCC      | Federal Communications Commission                           |
| FLEET    | Freight and Logistics Efforts for European Traffic          |
| GPS      | Global Positioning System                                   |
| GSM      | Groupe Special Mobile                                       |
| HELP     | Heavy Vehicle Electronic License Plate                      |
| ICC      | Interstate Commerce Commission                              |
| IMO      | International Maritime Organization                         |
| IVHS     | Intelligent Vehicle Highway System                          |
| JIT      | Just-In-Time  |
| LEO      | Low Earth Orbit   |
| LTL      | Less-than-Truckload   |
| MIS      | Management Information System                               |
| MSAT     | Mobile Satellite  |
| MSS      | Mobile Satellite System                                     |
| NMF      | Network Management Facility                                 |

|            |   |
|------------|---|
| OBR        | On-Board Recorders  |
| PCN        | Personal Communication Networks   |
| PPS        | Precision Positioning Service   |
| PROMETHEUS | Program for European Traffic with Highest Efficiency and Unprecedented Safety |
| QASPR      | Qualcomm Automatic Satellite Position Reporting                               |
| QCOM       | Qualcomm Communication Manager  |
| RDSS       | Radio Determination Satellite System  |
| RTI        | Road Transport Informatics  |
| SMR        | Specialized Mobile Radio  |
| SPS        | Standard Positioning Service  |
| TDMA       | Time-Division Multiple Access   |
| TL         | <b>TruckLoad</b>  |
| VISTA      | Vehicle Information Status Terminal Accessory                                 |
| VTS        | Vehicle Tracking System   |

## Preface

The research reported in this document began in the Fall of 1990 and was largely completed by the end of July 1991. The work divided broadly into two monitoring and two analysis efforts. Technology development and the technology adoption process were monitored. Analyses were made of implications for the trucking industry and for IVHS activities. A report describing the work plan was circulated for discussion shortly after work was initiated (**Studies of the Adoption and Use of Location and Communication Technologies by the Trucking Industry**. UCB-ITS-PRR-91-2).

The research was fascinating, yet frustrating. It was fascinating because the challenge was to make sense of diverse stories. There are many types of trucking firms operating in diverse markets. Suppliers of positioning and communications devices are competing by offering differing products and services. There is limited information on technology adoption and use, and the information that is available has a "first impact" character. At the same time, IVHS programs are beginning to consider commercial vehicle operations, building in part from established programs such as the Crescent/Heavy Vehicle Electronic License Plate (HELP) program.

Technology development and use extends beyond IVHS and the trucking industry. The uses of automatic identification technologies have expanded in all industry sectors. For instance, bar codes are found on the identification bracelets worn by hospital patients and on the motherboards in personal computers, in addition to their familiar appearance on grocery and many other products. Several years ago ocean containers began to be tagged with identification devices, and the devices are becoming the standard for both rail and trucking,

The diverse and expanding activities tell many interesting stories, yet the research was frustrating. The research problem was to tease out the themes running through the stories, and that proved not to be easy. The diversity of the trucking industry and the technology yielded many stories to be told--so many that when writing this report a tightrope had to be walked between extensive description and not enough said. More difficult was the task of interpreting exciting stories, some of which were about firms using new technology to great advantage. Another story was about a neural-network, high resolution scanning system for equipment identification. Crescent, Advantage I-75, and other IVHS-related activities also told exciting stories. In particular, the evolution of the Crescent project said a lot about what needed to be done to take technology off the shelf.

It was tempting to tell such stories, but inappropriate because the evidence was fragmentary and

incomplete. It was not clear how the stories and inferences from them represent industry, technology, and IVHS trends. It is too early to know, or even guess, how these stories will proceed to their ends. For instance, will the interests of the IVHS community and the trucking community diverge or converge? Will many technologies bloom or will a single predominant technology push all others aside? Again, it's too early to either know or make good guesses about these matters.

Given 'this situation, wait-and-see is a tempting strategy. But it might be a costly strategy, for trucks are major highway facility users and potential recipients of benefits from IVHS programs. Perhaps the appropriate strategy is to watch and identify and interpret trends as early as practicable.

# COMMUNICATIONS AND POSITIONING SYSTEMS IN THE MOTOR CARRIER INDUSTRY

## 1. INTRODUCTION

The convergence of telecommunications and computing has led researchers in many fields to investigate and speculate on development possibilities. Transportation researchers have increased their interest in the relationship between transportation and information technology. Today, many expect communications to facilitate the flow of vehicles on urban road networks. Some researchers focus on issues of travel substitution and travel complementarity. Will interactive computing substitute for the journey to work? Might improved communications interact with and reinforce the need for travel? Within the context of the freight transportation industry, attention is usually on increasing productivity and improving company management. All these issues are different aspects of the same problem: How can emerging technologies contribute to a better transportation product?

Advancements in telecommunications technology have made it increasingly affordable for commercial vehicles to be equipped with communications devices. Devices vary from simple voice radios to sophisticated satellite transceivers. Regardless of the technology used, the first outcome of technology adoption is improved communication between drivers and dispatchers (i.e., more timely and precise, as well as less costly). In the motor carrier industry environment where competitive pressures are great, the second outcome is the merging of improved communications capabilities with complementary efforts to improve productivity and services. These complementary internal efforts include computer aided dispatching, improved equipment monitoring, and driver training and monitoring. There are also complementary activities between trucking firms and their customers, such as electronic data interchange and tight scheduling of shipment movements to meet customers' needs.

The chief purpose of the investigations reported here is to explore a third outcome of the adoption of improved communication devices: the complementarity of the industry's activities and highway agency IVHS efforts in the U.S., Japan, and Europe aimed at managing congestion problems. Congestion problems include recurring congestion in urban areas and event-caused congestion in both urban and rural areas. Both short and long term efforts to improve congestion management are underway.

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To explore the possible complementarity between trucking industry activities and IVHS activities, the study began by reviewing the technologies available to the trucking industry, their adoption and use, and possible broad impacts on the trucking industry. In the discussion to follow, the technology review is reported following a brief overview of the trucking industry. Position finding systems are described first and then the major mobile communication services are identified and their capabilities noted. Developments in Europe and emerging systems are also mentioned. An exhaustive technology survey was not achieved because new products and services are constantly coming on the market, especially from vendors who package services from existing technologies. However, the systems mentioned are the prominent ones and are representative of the emerging capabilities.

The next section looks at the experiences of the users and examines how well the available systems fit the needs of fleet operators. Satellite systems are emphasized because the bulk of operating experience with the most recently developed technologies is with mobile satellite communications systems. The HELP project is also mentioned. Then, we turn our attention to the lessons that are to be learned from the experiences of the early adopters. Three levels of integration are described as a way for fleet operators to realize the full benefits of the new technologies. A discussion of the broader implications of information technologies and further research follows.

The research on which this document stems from the literature, interviews, and a survey. The reader will discover that there are a number of available and proposed technologies systems, and the situation is in flux. In some areas, there is considerable speculation, but not much hard data. While there are engineering-type data on technologies, data on technology adoption, benefits, and uses are often impressionistic. One is reminded of the vaporware mentioned when claims for computer software programs “to be ready yesterday” are discussed! The literature based research involved checking from multiple sources and striving for reasonable interpretations.

The results of a survey of technology adoption and use assisted in interpreting the findings from interviews and the literature review. The survey is discussed in the Appendix where the development of an **IVHS-oriented** truck technology monitoring system is stressed.

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## 2. THE TRUCKING INDUSTRY

Truck services grew first in urban areas and in rural farm-to-market services as trucks substituted for the horse and wagon. Intercity trucking grew later as the state-federal primary road system was developed in the late 1920s and 1930s. New services began to grow, and an examination of market shares indicates that market capture from railroads was essentially completed by the late 1960s. Although on ton mile measures the industry ranks somewhat below railroads, pipelines, and inland waterways, trucks are the dominant freight mode when tons loaded or payments for freight services are measured (Figure 1).

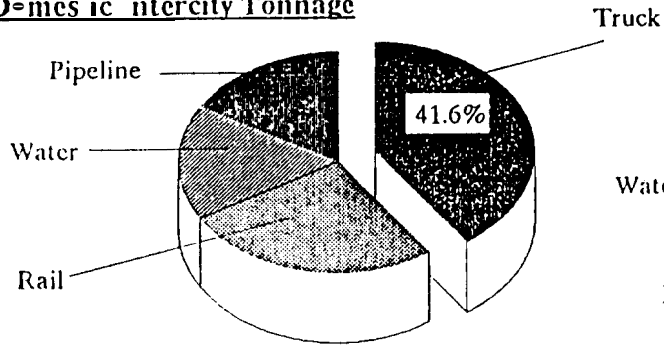
The emerging trucking industry organization was frozen by ICC and state regulation introduced in the 1930s. There are regular route common carriers, contract carriers, parcel carriers, etc. Some firms offer national services, others operate in regional or commodity market niches. With respect to prices, services and conditions of entry into the business, regulation followed the railroad model. The presence of private carriage, owner operators, and agricultural haulers did, however, result in some regulatory deviations from the rail model.

The Motor Carrier Act of 1980 essentially eliminated restrictions on the entry of firms into the trucking business. Established firms could enter new markets as they wished and new firms could enter the business almost at will. As a consequence of the latter, the number of firms reporting to the ICC increased from about 18,000 in 1980 to about 40,000 in 1988. Deregulation also reduced pricing restraints. The result was a period of considerable industry turmoil that continues today. The result important here is fiscal pressures on firms as the trucking business has become increasingly competitive. In 1988 the failure rate for trucking was 134.5 per 10,000 establishments, exceeding the 98 per 10,000 establishments rate for all businesses. With increased competition, profits are low. This dampens the ability of firms to invest in new technologies. At the same time, competitive pressures force firms to increase productivity and seek technologies and operating improvements that will enhance the effectiveness of services offered.

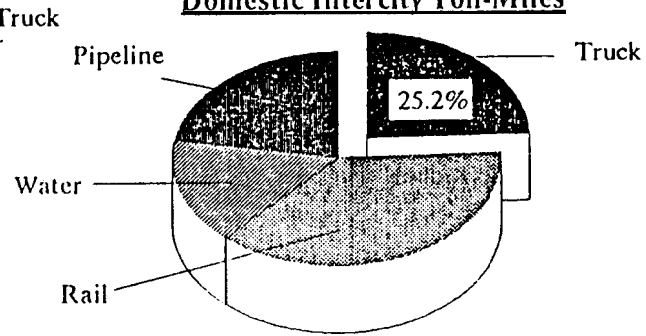
The American Trucking Associations publishes annual motor carrier reports based on data from the Interstate Commerce Commission. Summarizing data for 1,567 carriers of property reporting to the Commission, the 1989 Report indicated a return on capital of 5.82 percent. This limited return on capital has been the situation in the industry and its subdivisions for the last decade. One result has been aging

# The Trucking Industry

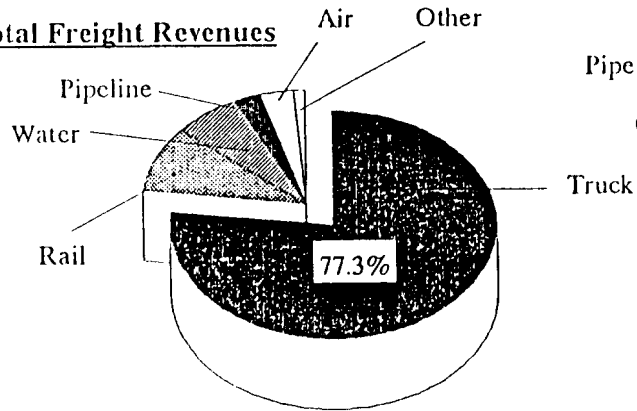
Domestic Intercity Tonnage



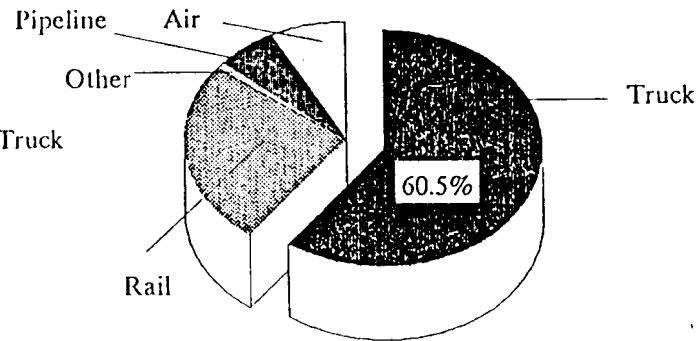
Domestic Intercity Ton-Miles



Total Freight Revenues



Revenues of Federally Authorized Carriers



Source: Eno Foundation for Transportation, September 1990

Figure 1: The Trucking Industry [I].



of equipment, and, as stated, the lack of capital productivity has a problematic effect on investment in new technologies. Technologies with high rates of return are needed.

With respect to steps available to improve productivity, a recent unpublished consultant's report suggests, in order of usefulness:

- Preventive maintenance
- Driver education
- Incentive systems
- Vehicle-specific fuel monitoring
- On-board communications systems
- Computer management of maintenance
- Computer-aided dispatching
- Scheduling to avoid traffic
- High capacity equipment
- Trip computers
- Electronic data interchange
- Owner operators
- Full service leasing

We have reproduced this list in spite of the non availability of the source document and lack of information on how usefulness was measured, because it is representative of the topics stressed in the trade literature.

Discussing these steps to improve productivity with firms, respondents repeatedly refer to 1 and 2 percent improvements as steps are taken. However, there are costs associated with actions, and the returns may not be additive. Would there be gains from increased preventive maintenance if equipment was full service leased? Would the gains from computer-aided dispatching be constrained by scheduling to avoid traffic?

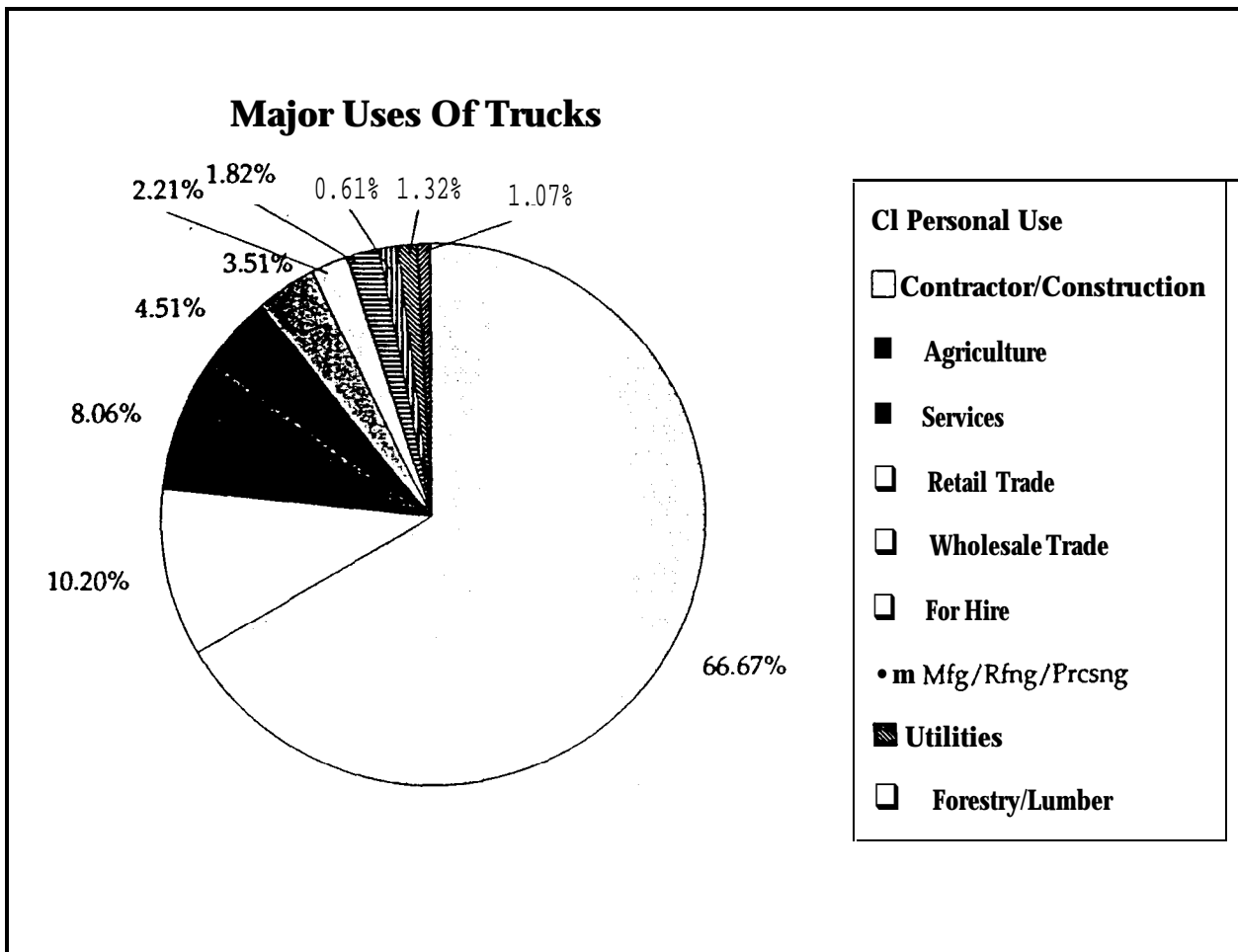
Seven of the thirteen steps make use of computer and information technologies, which are the focus of this study. The expectation of the researchers is that the consequences of the uses of these technologies depend on interrelationships. The consequences of technology uses will be great if ways

are found to interrelate technology uses. This is a synergy, or the-whole-is-greater-than-its-parts, expectation.

In the environment in which the industry is operating, service differentiation is the key, especially for small carriers. On the demand side, production and distribution have been reorganized by the adoption of flexible manufacturing techniques and Just-In-Time (JIT) inventories. (A recent survey of shippers reported that 70 percent of manufacturers have or plan to soon have a JIT scheme in place[1].) Experts agree that there is a strong trend towards integrated logistics, where procurement through material flow and consumer delivery are managed holistically[2]. In this environment, the reliability and quality of transportation services is often as important to shippers as price [3].

Transportation managers of firms and managers providing third-party services emphasize integrated or interactive activities. Today, the themes circulating among logistics managers and found in professional literature, such as **the Journal of Business Logistics**, stress the integration of transportation and marketing, uses of electronic data interchange, and the relationship between transportation services and direct buying strategies. This emphasis on integration goes beyond JIT services, and it envisions trucking services integrated with many facets of production and distribution activities. Again, interaction and integration have priority.

To this point we have referred to the industry that provides for hire trucking services using about 800,000 trucks. The discussion in this report will continue that emphasis because this sector is seen as the largest market for communications and positioning technologies. Trucks are used in many ways other than for hire, with by far the largest proportion used for personal purposes (Figure 2). However, some of the not for hire categories, such as the trucks used by electric utilities, provide market niches for advanced technologies.



**Figure 2 : Major Uses of Trucks.** (The shades of gray may be difficult to discriminate. **Read clockwise** from the noon position following the order of the listed systems.)

### 3. POSITION REPORTING AND COMMUNICATIONS TECHNOLOGIES

Transportation services are provided away from the headquarters of firms and out of sight of management. In the early days, extensive rules backed up by enforcement procedures worked to ensure effective services. With time, communications and position reporting technologies were adopted in order to improve control, deal with unexpected events, and increase service flexibility. Because these technologies **were expensive** they were first adopted by aircraft, ships, and trains. With many small units, trucking firms were limited to occasional telephone calls to dispatchers by drivers, as well as radio voice systems.

Today, however, original equipment vendors or third party value-added vendors are beginning to offer technologies suited for use by trucking firms. These technologies support position-reporting and message exchange.

The position of the vehicle is generally reported to a dispatcher with minimal involvement on the driver's part. Position is most often calculated using one of the radiodetermination systems which take advantage of the propagation properties of radio waves (although systems exist which use other media such as surface acoustic waves).

The dispatcher and the driver may also exchange operations messages (e.g., when rescheduling a pick-up). Tractor or trailer operating parameters, such as reefer temperatures, are an example of data-only message exchange. Systems also exist that record operating data--from fuel consumption to the number of pick-ups and deliveries--which can later be downloaded to a computer for further analysis. These on-board recorder systems will be briefly examined in a later section.

Radiodetermination and mobile communications are two terms frequently mentioned in the literature which broadly correspond to the positioning and communications services previously cited. (Positioning systems do not necessarily use radiodetermination principles to determine positions.) Communication takes place in both radiodetermination and mobile communications systems. The distinction between them is historical and alludes to differences in frequencies, technical requirements, and functions. The terms were first used in the context of air and maritime transportation and this is reflected in the following definitions.

**Radiodetermination** is the determination of the position, velocity or other characteristics of an object, or the obtaining of information relating to these parameters, by means of the propagation

properties of radio waves [5]. A radio determination system can be either terrestrial (e.g., LORAN-C) or satellite based (e.g., TRANSIT, GPS). When the latter is the case, the term radiodetermination satellite service or RDSS is used.

Radionavigation is radiodetermination for the purposes of navigation. Navigation seeks the safe movement of a vehicle from one point to another. Navigation systems are designated as safety-of-life systems and are continuously available within their intended area of coverage. To avoid any interference, exclusive frequency bands are allocated to such systems (they are under a so-called protected status). Navigation is normally performed in the vehicle, of course.

Radiolocation (sometimes **also** referred to as radiopositioning) is radiodetermination used for purposes other than those of radionavigation. The vehicle may not need to obtain its position from the radio aid, as would be the case of a truck moving along a road known to the driver. Rather, the position is calculated to serve the needs of a central station, say, a trucking dispatcher. A system offering radiolocation does not need to be continuously available. Radiolocation systems are not thought of as safety-of-life systems and are not given protected status for frequency allocation purposes. They may share their frequencies with other systems, and may cause interference problems. A radiolocation system may be simpler to set up than a radionavigation system, although this depends on the particular application.

**Mobile Communications** refers to communications with a moving terminal. The transmission may be either via a satellite network, in which case the term mobile satellite service or MSS is used, or a terrestrial relay network (e.g., cellular phones). The data carried may be in forms such as voice, text, or location coordinates. The size, shape, and power requirements of terminals and antennas depend on the intended application. For instance, a bulky, highly reliable, and expensive terminal can be installed in a tank ship that costs millions of dollars. In contrast, a compact, light, low-power unit would be more suitable for a truck cab.

The Federal Communications Commission (FCC) when allocating frequencies made a distinction between RDSS and MSS on the grounds that they serve different customer needs. It ruled that RDSS was primarily intended to provide radiodetermination information with some ancillary message capability [6]. MSS on the other hand, was primarily a system providing voice and rural radio. While technically correct, the distinction is somewhat artificial and the link between RDSS and MSS may grow stronger

in the future as was demonstrated by Geostar, whose system was primarily used for messages even though the company had an RDSS license.

**Table 1: Positioning and Communications Systems Discussed**

| <b>Positioning Systems</b> | <b>Mobile Communications Systems</b> |
|----------------------------|--------------------------------------|
| Proximity Systems          | <b>Ground Based Systems</b>          |
| LORAN-C                    | Meteor Burst                         |
| GPS                        | Public Telephone                     |
| GLONASS                    | Pagers                               |
| QASPR                      | Cellular Telephone                   |
| Geostar                    | <b>CoveragePLUS</b>                  |
|                            | Magnavox                             |
|                            | II Morrow                            |
|                            | METS                                 |
|                            | <b>Satellite Systems</b>             |
|                            | <b>OmniTRACS</b>                     |
|                            | Geostar                              |
|                            | AMSC                                 |
|                            | INMARSAT                             |

Table 1 presents the technologies that will be reviewed in the next two sections. We start with position reporting systems. The examination of mobile communications systems follows.

## 4 POSITION REPORTING SYSTEMS

Position reporting systems for land vehicles were first developed for fire, health, police, and transit services. Then, suppliers began to further develop technologies and target the trucking market. The most recent developments are for the Intelligent Vehicle Highway System (IVHS). The discussion to follow concentrates on technologies for truck operators, with comments on IVHS to be presented in a later section.

None of the available systems can be classified as all-purpose, meaning that they can locate a vehicle continuously and accurately at any time and any place. On expense and lack of necessity grounds, one could argue against the optimality of such a system. On the other hand, many experts agree (e.g., [7]) that there seems to be a convergence towards a small set of technologies. This is also the trend among manufacturers (e.g., [8]).

Over the years, several technologies have been proposed to locate a vehicle: dead reckoning systems; map matching systems; beacon systems using a number of low-power beacons; hyperbolic systems (e.g., LORAN-C) using radio beacons; satellite systems (e.g., GPS); and hybrid systems (e.g., roadside beacons with dead reckoning and map matching). Because of their applications to maritime/air navigation and surveying, hyperbolic and satellite systems are used extensively throughout the world. Hyperbolic systems, however, were not designed for use over land and may not cover inland locations of interest. Satellite systems may not be visible in urban areas because of tall buildings, bridges, tunnels and other obstructive structures.

Vehicle positions need to be calculated for either of two reasons: route guidance or monitoring. The accuracy requirements of calculations depend not only on the intended application but on the environment as well. Vehicles in urban areas with dense streets and address systems have the highest accuracy requirements, while trucks in rural areas have the lowest.

Route guidance is one of the most important aspects of IVHS research and still is in experimental stages. Several Delphi studies (e.g., [9]) have projected that the majority of commercial vehicles will be using interactive (two-way) route guidance systems by the year 2005. Proximity beacons, dead reckoning, map matching or a combination of these are the preferred technologies for route guidance systems.

The systems that will be described in the next sections are most suitable for monitoring purposes. Nothing of course precludes their application in route guidance schemes to provide, say, periodic initialization of a dead reckoning system. Proximity systems which offer an indirect means of location-finding are presented first. Next, radiodetermination systems are examined. After describing ground based systems, the section ends with an overview of satellite systems.

#### **4.1 PROXIMITY SYSTEMS**

Proximity systems are most often mentioned in discussions of road pricing, automatic toll collection, and container or trailer identification. The term proximity derives from the fact that the vehicle is identified when it passes within the proximity of an electronic “signpost” (Figure 3). Although the technology seems finally to be reliable, issues regarding invasion of privacy may have to be settled before these systems are accepted by private motorists. In its simplest form the technology consists of a tag containing the necessary electronics to uniquely encode a vehicle. Identification information can be read by roadside interrogation units, as may additional data such as vehicle classification, the type of shipment, its origin, and its destination. Tags may be passive or active, depending on whether they must be excited by the interrogator before they transmit. Some tags are also capable of receiving, storing and processing information. In this case, the term “smart card” is often used.

The roadside units may take several actions after reading a tag. For instance, these units may notify a dispatcher that a vehicle has just crossed that point of interrogation or charge the vehicle owner a certain amount for tolls or fuel taxes. Vehicle position is extracted indirectly from the known location of the roadside units. The distance between the interrogators determines how often a position is reported.

Tag-based systems have been developed using various technologies: radio frequencies, surface acoustic waves, microwaves, magnetic induction, and modulated backscatter [11]. Radio systems have the advantage that the interrogator can be located even in a satellite, but they discriminate between tags poorly and are susceptible to interference. In November 1990, a system based on the modulated backscatter technology promoted by Amtech was adopted as an international standard by the container shipping industry. Previously, the same technology had been approved as an Automatic Equipment Identification (AEI) standard by the American Trucking Associations (ATA) and the Association of American Railroads (AAR).

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Many toll authorities plan to install automatic vehicle identification systems for electronic toll collection. The Dallas North Tollway, in routine operation since 1989, is already a user of the technology. All 60 toll booths have been equipped with radio interrogators and about 20,000 vehicles carry credit-card-size transponders inside their windshield. Another popular application of the technology is the tagging of containers and railcars. A conservative estimate from the trade press would set the number of tagged containers at least 20,000 and that of railcars at least 15,000. These figures are likely

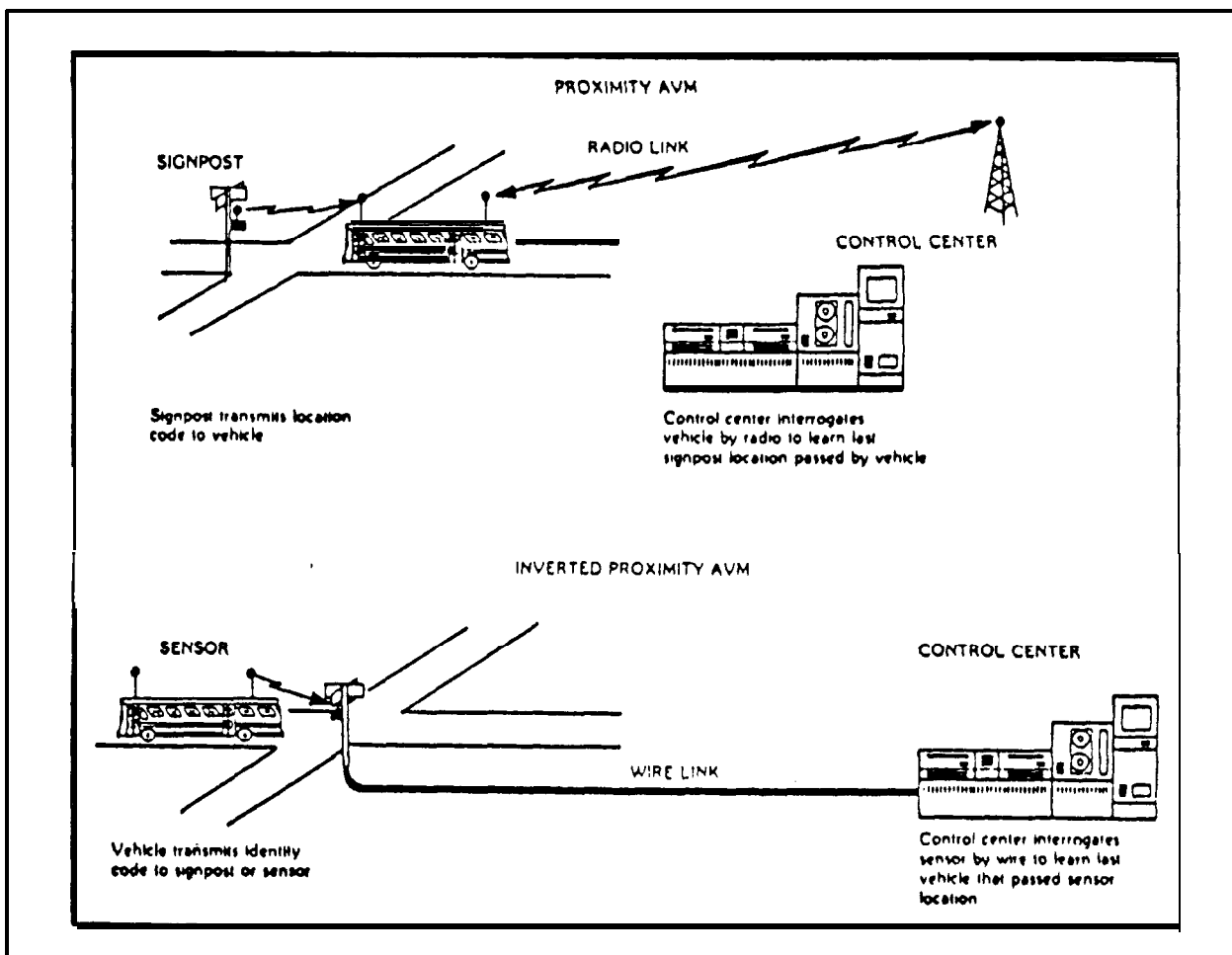


Figure 3: Example Proximity Systems [10].

to go up for two reasons: the AAR is studying the mandatory tagging of all equipment [12] and the technology promises to solve the continuing problem of container inventory and tracing. In the past,

several mass transit authorities worldwide tested similar systems to locate buses, adjust their schedules, and inform the public as to when a bus is arriving. Recently, such systems have been widely introduced in Japan [13].

Smart-card systems are more often used (especially in Europe) as debit cards to make phone calls, pay for gas or purchase mass transit tickets rather than in-traffic operations. A successful application of smart-card technology has been at a toll collecting site in Italy [14]. Finally, the DRIVE project PAMELA is designing equipment to facilitate two-way data communications between vehicles and roadside stations using smart-cards. The on-board unit features an intelligent interface bus, allowing it to pass data directly to and from other dashboard equipment [15]. This would allow, for instance, a computer system at headquarters to receive data through roadside stations from on-board recording devices or to send commands to control engine functions.

## **4.2 RADIODETERMINATION SYSTEMS**

Although radiodetermination systems have the advantage of providing absolute positions in space, the radio signals must reach the vehicle in order for its position to be determined. Thus, urban built-up areas or rugged terrain may cause reception problems. Still, several such systems are in use or have been proposed. The systems used most often by the trucking industry are described in the following sections.

LORAN-C is perhaps the best-known ground based radiodetermination system. Two-way mobile communications systems making use of radio towers to relay messages (either data or voice) can also supply position information because the exchange facility that keeps track of callers needs to know where the callers are located. Digital cellular phone systems (to be introduced as early as next year) provide the same information by analyzing the digital signal. The accuracy is said to be up to one car length.

In addition to the ground-based technologies, satellite systems are to be examined. The most prominent among them is the Global Positioning System (GPS). The section closes with the examination of two proprietary systems: Qualcomm's QASPR and Geostar's RDSS proposal.

#### 4.2.1 LORAN-C

LORAN-C is a well known hyperbolic positioning system. It has been used in aircraft and marine navigation since 1959. In recent years, high-performance receivers at moderate cost have been developed and are used by bus and truck fleets, public utilities, and police departments. LORAN-C receivers measure the time differences between arrival of pulses from pairs of ground stations (one of which is the master station) [16]. Their accuracy is from **100m** to **1,500m** (330ft to 5,000 ft) depending on the circumstances.

The LORAN-C transmitter chains are operated by the U.S. Coast Guard and have recently been expanded to cover inland locations of interest. European coverage is currently limited to the Mediterranean area and northern part of Europe although this may change in the future. The U.S. Department of Defense requirement for the LORAN-C system will end in 1994, at which time the overseas stations will be transferred to the host nations [ 17]. Civilian use in the continental U.S. will not be affected (although a station in Alaska will be permanently closed).

#### 4.2.2 Satellite Based Systems

Satellites are extensively used for position calculations because ranges (i.e., distances) can be extracted by signal processing. Theoretically, three measurements of distance to known points are needed to unambiguously locate an object in space. In practice, one of these measurements can be eliminated by either rejecting geometrically improbable solutions or by knowing, or approximating, the user's altitude (as is the case in maritime applications). Distances are indirectly derived from the time it takes a signal to travel from satellite to user. This introduces one more variable to the location finding problem: time.

The minimum number of satellites required to locate a vehicle is two (the same satellite can not be used twice without weakening the geometry of the determination). One solution calls for the user to have a clock aligned to that of the satellites' (assuming both satellites are on the same timebase). This approach however, introduces enough sources of uncertainty to require a third satellite for calibration. In another solution the user terminals are required to retransmit the signal to an earth station that has a

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clock. Although accuracy is improved, the number of users is limited because the terminals must transmit. This method was proposed in Geostar's RDSS system. In any case, users must know their height (the geocentric height and not simply height above sea-level).

Three satellites can give two ranges and hold a clock synchronized. However, users still need to input their height to get a two dimensional fix. With four satellites, three distance measurements and one time measurement are obtained. Thus, a three-dimensional position fix is obtained without any external references.

In summary, a system based on two or three satellites can only provide low accuracies, in the order of few miles, depending on the kind of height information provided by the user. However, these low accuracies may be acceptable for some land-based applications (e.g., when locating a truck in a remote area, as opposed to locating a rail car at a classification yard).

A civil navigation system using dedicated satellites has yet to be launched although specific frequencies have been allocated to RDSS systems. This is understandable if one considers the staggering costs of designing, manufacturing, insuring, launching and operating the necessary satellites. To achieve 90% world coverage from geosynchronous orbits (one of several orbits used by satellites) at least 10 satellites would be required [5]. With an average satellite life of 7 to 10 years, capital costs would be great and to cover costs, large number of users would have to be served. Geostar proposed such a system and was in the process of implementing it. However, its financial difficulties and eventual bankruptcy confirm the hardships facing anyone wanting to undertake the development of a satellite positioning system.

Two alternatives exist for a civilian system with dedicated satellites:

1. The use of navigation systems designed for and operated by the military;
2. The sharing of payloads with communications satellites.

These alternatives are not without problems. Military and civilian needs are not similar. Military designers have to take costly precautions against jamming. Satellites must continue operating even if ground contact is lost, and a broadcast system is necessary so that users need not disclose their positions. These considerations add to the complexity of a system such as the GPS. From an international

perspective, an open question remains as to whether the user community is prepared to accept a system which is under the control of the military of a single country.

In the second alternative, the use of transponders on board existing communications satellites and the different engineering requirements for location and communications need to be reconciled. Communications satellite systems do not need to keep track of the precise location of the space platforms. When using satellites to derive locations using satellites, however, the exact position of the satellites must be known. The **geometrics** of a geosynchronous orbit (popular with communications satellites) are such that the calculated location has a considerable uncertainty in latitude. Also, equatorial regions (about 5 from the equator) are at a disadvantage. In addition, satellite operators adjust the orbit so the satellite can better “see” an earth station [5]. These station-keeping manoeuvres must be known, otherwise accurate positions cannot be calculated.

Three satellite radiodetermination systems will be outlined in the following sections: the Global Positioning System (GPS), Qualcomm’s QASPR, and Geostar’s RDSS proposal.

#### 4.2.2.1 The Global Positioning System (GPS)

The Global Positioning System (GPS), also known as Navstar, is the most prominent of the satellite positioning systems. It is a military system that will eventually replace other federally operated radionavigation systems (e.g., OMEGA, TRANSIT, LORAN-C). GPS has many advantages compared to other satellite systems [6]:

1. GPS allocates frequencies more **efficiently** and uses only 2 MHz of bandwidth;
2. As a broadcast system, GPS can serve an infinite number of users. Other RDSS proposals (e.g., Geostar’s) were frequency-limited because they both received and transmitted data via satellites and, therefore, could only serve a certain number of users;
3. With GPS, the user would pay once to purchase the receiver and would not pay for the use of positioning information;
4. If it becomes the predominant technology, the cost of GPS receivers should drop substantially.

The system will ultimately comprise a constellation of 21 satellites (plus three operating spares) on circular orbits at about 20,000 km of altitude. The satellites are arranged so that four will always be visible from all points on the earth. The U.S. Department of Defense is expected to declare the system fully operational in 1993. By then it will be possible to get a three-dimensional position 24 hours a day. Position fixes are obtained now at the user's risk. Currently 15 satellites are operational, 10 of which are Block II satellites (eventually all 24 satellites will be Block II or later). These provide a minimum of 21.5 cumulative hours of two-dimensional positioning per 24-hour period, and 15.5 cumulative hours of three-dimensional positioning per 24-hour period [18]. The next satellite will be launched before the end of the summer of 1991.

GPS receivers are passive. Built-in microprocessors in the receivers not only determine the optimal set of satellites for use, but also perform calculations. The equipment is easily built, and is getting smaller and less expensive. A GPS receiver in the form of a board complete with its antenna, mounting bracket, cable driver software, and user manual has been priced at about \$3,000 in recent years. Currently, some receivers are available for about \$1,000, and industry experts expect that the price will eventually come down to about \$500. The most significant recent development has been the announcement of small, low-cost, multichannel receivers that can be integrated into other electronics equipment.

For national security reasons, civilian accuracy has been restricted to about 100 meters, making use of the Standard Positioning Service (SPS). Military users on the other hand, have access to the Precise Positioning Service (PPS). Some ways to boost accuracy include the use of processed satellite orbiting data (post-processed satellite ephemerides) and differential techniques (where positions are derived relative to precisely surveyed points). The limited availability of the PPS to selected civilian users is much discussed. However, accuracy is not the only controversy surrounding GPS. The question of user fees (none, for the time being) is an issue that may affect the operational success of the system. Lastly, as with all military systems, responsiveness to civilian users and the question of control are major concerns.

There has been recent interest in integrating the GPS with the GLONASS system, to improve the accuracy of both [19]. GLONASS is a Navstar-like Soviet radionavigation system, consisting of 12 satellites. Experts on both systems are conducting joint tests to determine how the U.S.- and Soviet-manufactured products perform in real-life environments. Preliminary data from tests on board

an airliner showed that the differences between the two systems were mainly due to the different earth models used by each [20]. Additional investigations of **GPS/GLONASS** interoperability will undoubtedly follow.

#### 4.2.2.2 QUALCOMM's OASPR

In February of 1990, Qualcomm, a vendor of satellite communications services, announced the introduction of the Qualcomm Automatic Satellite Position Reporting (QASPR) system to the U.S. market. This system is claimed to have an accuracy of better than 1000 feet under any circumstances, significantly improving the accuracy of position reporting when compared to LORAN-C systems. Using existing civilian communications satellites, it processes the signal from one satellite and monitors a beacon signal from a second. A vehicle can be tracked 24 hours a day anywhere within the continental United States. QASPR is part of Qualcomm's **OmniTRACS** mobile communications system.

#### 4.2.2.3 Geostar's RDSS Proposal

The FCC granted a license to Geostar for a private RDSS system in 1984. Geostar's technical design was also adopted as a baseline for RDSS systems. At the time the FCC held the view that providing spectrum for an alternative system to GPS was beneficial in that services could be tailored to the needs of the market. Presently, however, the company has ceased operations, and the future of Geostar is uncertain.

The Geostar system in its full implementation would consist of three geostationary satellites carrying the necessary transponders. User terminals would both receive and transmit but would not perform calculations or accurate timing functions. Precise timing signals would be transmitted from an operations center in Washington D.C., and then retransmitted by one of the three satellites. User terminals would receive the signals, synchronize themselves, and transmit their own signals. These signals would be picked up by all satellites and relayed back to the operations center along with other information such as user identity. When the signals reached the operations center their travel time and

other pertinent data would be extracted. That information would be routed to fleet headquarters after being processed at the central facility. Users, however, would have to input their geocentric height, information that may not be readily available. Geostar, then patented a satellite compass system which according to company **officials** will indicate position within 2 to 7 meters, using a portable **20-ounce** radio costing several hundred dollars (assuming mass production). Accuracy would be achieved using a nationwide digital terrain map stored in a ground-based computer. Heights would be calculated from the terrain map starting with an initial position estimate and iterating a number of times. Position information would be given in plain English, e.g., “You are 70 feet north of the intersection of East Road and West Street.” The time for a fix would depend on the accuracy of the initial estimate. The system’s accuracy may never be demonstrated, and the quoted 2 to 7 meters may be optimistic.



## 5 MOBILE COMMUNICATIONS SYSTEMS

Mobile communications services use either a terrestrial or satellite network to relay information from vehicles to dispatchers and vice versa. All systems allow a certain degree of message transmission (data or **voice**) **that** may **or** may not include position information. A satellite network can provide service to rural or **other** areas not covered by a terrestrial system. Therefore, the two networks are seen as complementary to each other and may result in an integrated telecommunications network.

In the following sections a variety of land and satellite systems will be described. Services offered by so called “system integrators” are not specifically mentioned. System integrators are companies which specialize in creating custom systems with off-the-shelf hardware and software products. Their services are currently geared towards large fleets with sophisticated dispatching needs. The discussion will close with a look at the European developments and some emerging technologies.

### 5.1 LAND-BASED SYSTEMS

Satellite systems tend to be expensive and geared toward nationwide coverage, a capability many trucking firms do not require. The need to maintain a line of sight with a satellite may also prove an impediment to pickup and delivery fleets that operate in urban areas. Other technologies are available for these fleets and these will be discussed.

#### 5.1.1 Meteor Burst

The use of meteor bursts is a newcomer to the field of mobile communications, although the technology itself has been in existence for more than 20 years. The in-truck terminals are similar to those used by **other** systems, and positioning is provided by LORAN-C. Meteor-burst technology offers an alternative at almost half the price of satellite systems. Transtrack Inc. is holder of the first FCC license to market the service to the transportation industry and already operates several tracking stations. Pegasus, although now bankrupt, followed suit and emphasized its ability to provide software which was

compatible with carriers' management information systems. A third contender is Broadcom, a R&D house in New Jersey. The company claims to have found a way to bring the time between two transmissions down to 30 seconds and states the possibility exists to reduce the time to four seconds.

Besides the lower cost, another advantage that meteor-burst has over satellite communications is the theoretically increased reliability. Because there is no space segment, all of the support equipment is on the ground. However, messages have to be short, only 32 characters long, and are constrained by the size of the burst, although longer messages can be linked over several bursts. Furthermore, satellite messages can be transmitted in as little as 15 seconds, while meteor bursts typically require several minutes (depending on the availability of a meteor burst). Time requirements do not facilitate interactive dialogue.

### **5.1.2 Telephone and Cellular Systems**

The telephone is the simplest of the communications technologies. Despite the surging popularity of new systems, the vast majority of the trucking business is conducted with a telephone and/or a voice radio. The telephone is mainly used by long haul drivers who have to make check calls at regular intervals. It is not uncommon for a driver to spend an hour a day of unproductive time trying to reach the dispatcher.

Voice mail systems and pagers enhance the usability of the phone. Simple voice mail systems are offered by all telephone companies. A more sophisticated voice mail system allows the driver calling from either a regular or cellular phone to not only access the firm's database, but modify information stored in it as well. In its current configuration this system is not linked to any positioning systems and is geared toward small scale regional operators.

Pagers have been available for some time. Currently, there are about 9 million subscribers in the U.S., 67% of whom use numeric and 4% alphanumeric pagers [21]. Pagers provide an inexpensive alternative for sending simple messages to drivers. Vendors are attempting to establish alphanumeric pagers as low cost data receivers. CUE Paging offers numerical paging which covers almost all the heavily populated areas. It offers a one-way link between dispatch centers and truck drivers who still require the facilities of a truckstop to get the messages through voice mail or fax. In combination with

CUE's dispatch software, the dispatcher can send messages to drivers using an IBM-compatible PC and modem. In addition, some trucks have been retrofitted with a pager equipped with a light that signals a message.

**Telefind** offers an alphanumeric pager that reaches almost 4,000 cities and towns nationwide. The dispatcher can send a message of up to 511 characters using an IBM-compatible PC. A portable printer in the cab provides a hard copy of the messages as they are received. Using a telephone connection the driver can transmit back information from an optional keyboard. Psion, a U.K. company manufacturing the Psion Organizer, offers a similar service: a pager that can connect to the Organizer so the user can receive messages. Motorola also plans to offer a store and forward system in the near future (named EMBARC for Electronic Mail Broadcast to A Roaming Computer). Finally, Hewlett-Packard unveiled in April 1991 a checkbook-sized MS-DOS compatible PC with a built-in spreadsheet program and the ability to receive messages of as many as 32,000 characters over pager networks. Motorola will supply the pager that plugs into the hand-held PC before the end of 1991.

A recent development has been the use of pagers to transmit traffic information so that drivers can avoid congestion. An experiment was recently completed in New York [22], and a California firm, Way To Go, has plans to launch a similar service commercially before the end of 1991. It will be based on pager technology and will cover the San Francisco Bay Area .

Although wireless, a cellular phone is functionally similar to a wired phone. The growth of cellular communications has been phenomenal in the past ten years (there are about 5.2 million subscribers in the U.S., 60% of whom use mobile units rather than portables and transportables [21]). A common problem with cellular radio systems is the extent of roaming they allow. Service agreements between cellular service providers are addressing this. Another problem is capacity, but the advent of digital cellular systems and new ways of multiplexing signals will significantly increase the efficiency of frequency reuse between adjacent cells, as well as the capacity of a single channel. Users have also complained about the reliability of data transmission (the cellular system has been optimized for voice not data), poor reception, sudden cut-offs, and limited reach.

Cellular phone use is penetrating to marginal users characterized as younger customers with less money to spend. Industry sources say that the average customer usage is 180 to 200 minutes a month, down 10 to 20 minutes a month from the previous year's monthly figures. Accordingly, the average monthly bill has fallen from \$110 to \$100 per month. To compensate, cellular phone carriers are trying

to increase **their** revenues by offering inducements to use the service more. This undoubtedly will benefit heavy users such as trucking fleets more than the casual caller. Another development has been the announcement by all three U.S. car makers of their decision to start selling and installing car phones through their dealers who will act as agents for cellular service companies in their areas.

### 51.3 Voice Radios and Beyond

Let us turn our attention now to voice radios. Their range depends on the existence of repeaters to achieve ground coverage. Therefore they are better suited for local operations (up to 200 miles, depending on the system). Most of these systems are shared between many operators, although some private systems exist where operators have the exclusive use of frequencies.

Motorola's **CoveragePLUS** is functionally very similar to the satellite systems but it costs from \$2,500 to \$1,000 less (depending on the configuration) and provides voice as well as data communications. It makes use of Motorola's Privacy Plus **Trunked** Specialized Mobile Radio (SMR) system. The company has networked many SMR zones. It is anticipated that transmission towers will soon be installed in all major traffic corridors, thus offering near-nationwide coverage. Software on a personal computer displays vehicles on a map in real time and facilitates communications. The system can exchange data with popular dispatching computer packages.

In its simplest form **CoveragePLUS** is a specialized voice radio featuring a telephone interconnect which allows the dispatcher to call the driver at any time. A **CoveragePLUS** duplex radio is a option which resembles a telephone and allows users to talk and listen simultaneously. It provides access to roaming and telephone interconnect services. If dispatchers and drivers are in the same local area a "local dispatch" service is offered in which the driver presses a push to talk button and can converse with the dispatcher. **Talk** groups can also be designated. A text terminal is used for optional data communications between drivers and dispatch centers. Eight preset status messages (e.g., "At Site", "On Break") can be sent or received. The terminal has a 69-key QWERTY keyboard and an 8-line by 40-character display for typing messages of up to 240 characters. Messages sent by the dispatcher can be stored (up to 1,920 characters) for later retrieval.

Position information is obtained with either LORAN-C or zone location. The LORAN-C option offers increased positional accuracy but it costs extra. Later, it may be replaced with a GPS receiver. Zone location comes standard with all radios. When a vehicle enters any SMR system it automatically registers itself with the network management facility. This information plus site location is relayed to the dispatcher. The location of the truck is thus known to the nearest town or city.

Small fleets without the resources to establish their own communications center can use Comdata's. Comdata is a reseller of Motorola's **CoveragePLUS**. Its system is called **DriverLink/24** and offers text messages, positioning and voice communications. Comdata has also initiated a "Load Matcher" program. Carriers, shippers and brokers post daily data on freight and equipment. Company officials assert that 15,000 loads are matched every month.

Motorola is not the only company trying to expand the use of **SMR's**. Fleet Call, a radio dispatch company, was granted authority by the FCC to build digital mobile communications systems in six large metropolitan areas: Chicago, Dallas, Houston, Los Angeles, New York and San Francisco. In these areas Fleet Call has already installed 150,000 units offering two-way radio services such as the analog dispatch and mobile telephone. Eventually, the existing large transmitters will be replaced with many small base stations. The company anticipates that large part of its future business will be data and document transmissions.

Three other companies also offer systems that integrate two-way radios or other land mobile communications systems with position finding hardware: Magnavox (known for its work on GPS), II Morrow (a subsidiary of United Parcel Service) and METS, better known for its geographic mapping and computer aided dispatch capabilities. Their systems are reviewed next.

The Automatic Vehicle Location System (AVLS) was introduced in 1986 by Magnavox and is used by public safety and commercial truck fleets. It integrates two-way radios with position finding hardware. The dispatcher tracks the fleet on a high resolution color map computer display. The range of the AVLS depends on the range of the radio system but two or more remotely operated base stations can be linked together. Position is determined with dead reckoning and is fine tuned with periodic reinitialization done by Transit satellites (a federally operated radionavigation system). Later, GPS satellites will be used instead. The on-board unit has a small display screen (2-line by 16-character) where the driver can review up to 10 previously received messages. Acknowledgement and panic buttons

are also provided and a full-text keyboard is offered as an extra option. The company claims that it can integrate the system with any computer-assisted dispatching system.

II Morrow ("**TwoMorrow**") states it has installed over 40 of its LORAN-C based Vehicle Tracking Systems (**VTS**). Any land mobile communications system may be used to transmit data or voice (e.g., two-way radio, SMR, cellular telephones). As with Magnavox's system a full-color display is used to track the fleet's vehicles. The on-board unit is a hand-held MS-DOS compatible computer with 63-key keyboard and an S-line by **40-character** display. Data entered into the computer can be stored and later transmitted to the dispatch center. Optionally, a Vehicle Information Status Terminal Accessory (**VISTA**) is offered. **VISTA** is a non-portable, on-board unit with a 4-line by 20-character display and a 20-key keyboard. It can be used to send predefined status messages to the dispatcher.

**METS**'s on-board device, called **TRACKER CPU**, acts as a powerful on-board recorder with an unusual feature: it can be hooked up to two or three different communications transceivers. Display terminals, keyboards and printers can be connected to the on-board unit. Positions are determined using LORAN-C signals and are transmitted back to the dispatching center using a patented process to improve accuracy. The **TRACKER CPU** also monitors vehicle data such as engine and trailer temperature, oil pressure, speed, etc. **METS** offers a variety of customized programs, reporting, and geographic mapping systems to facilitate dispatch. Its systems appear to be geared towards the needs of police and other emergency fleets.

#### **5.1.4 On-Board Recorders**

Another recent development has been the emergence of on-board recorders or on-board computers. Vendors promote their products as Vehicle Management Systems or Driver Management Systems. The significance of these systems is they collect real-time vehicle-related data and communicate these data back to the dispatching center.

An on-board recorder (**OBR**) is a dashboard-mounted device that stores data such as engine rpm, road speed, distance travelled, and time. Usually, a keyboard and a display are provided so the driver can input log related information such as his or her ID, state line crossings, and trip expenses. The data within the **OBR** are later transferred to a computer for analysis and report generation (e.g., on speeding

and excessive idling). The off-loading of the information is done using a variety of methods: the OBR unit is physically removed from the cab and plugged into a computer; an extraction cable is used to connect the OBR and computer; the data are stored in an electronic device such as a data cartridge or an “electronic key” which at the end of the trip is read by the computer; or the data are downloaded wireless from a remote location.

Wireless downloading has been introduced recently and is most interesting. In a typical set-up an OBR has the necessary ports to connect with the central off-ice computer via two-way radio or cellular phones. One vendor is planning to offer the service using CoveragePLUS for the communications link. Rockwell announced that its latest OBR will be integrated with the mobile satellite communications services it will soon be offering. As more fleets adopt advanced communications, marketers of communications systems may form more alliances with sellers of OBR’s.

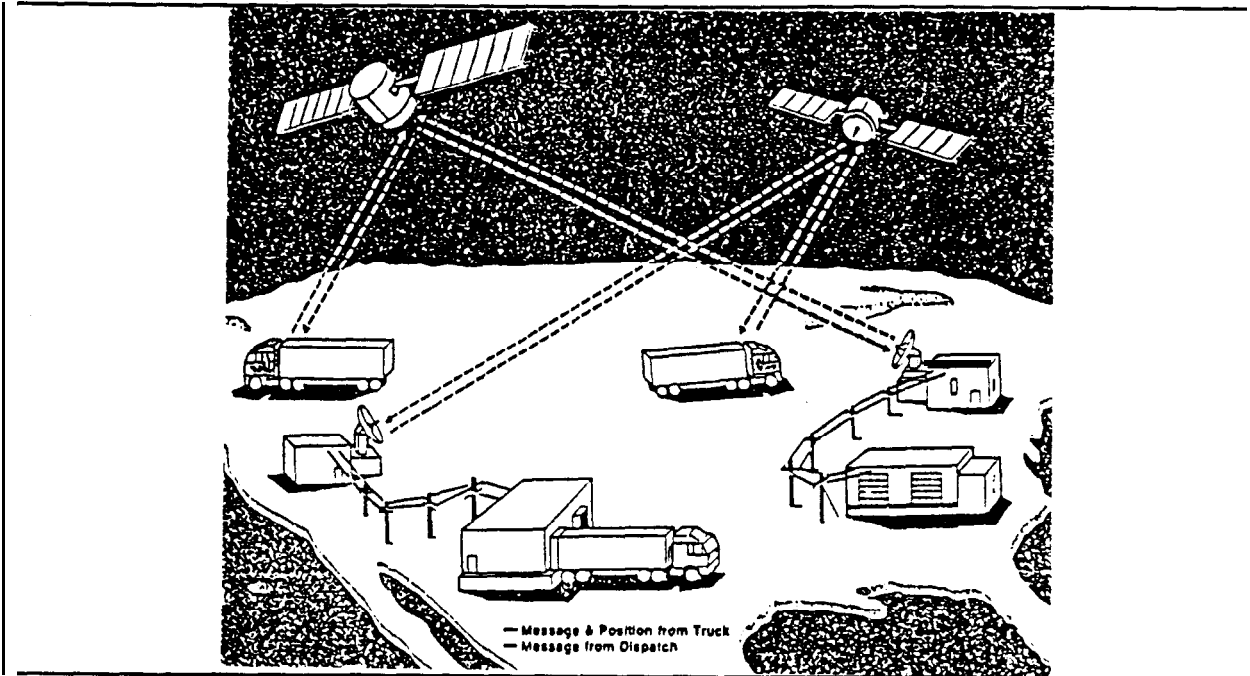
As mentioned earlier, the DRIVE project PAMELA is also projecting the need to interface the on-board unit with other dashboard equipment. Additionally, almost all European truck manufacturers are investigating ways of transmitting information from OBR’s and other input devices to the central office computers. DAF Trucks expects to market a system called Roadacom before the end of 1992. The communications link will be either terrestrial or satellite-based (INMARSAT’s Standard-C).

## **5.2 SATELLITEBASED SYSTEMS**

The field of satellite tracking and messages systems is very active and there are many demonstrations and proposals. These systems are more expensive than ground based ones (typically they cost at least \$4,000). However, they provide extensive coverage with minimal ground infrastructure and are ideal for rural or remote areas. The only potential problem is that the vehicle needs to maintain a line of sight between itself and the satellite(s), and transmission may be blocked in urban areas.

The equipment consists of a keyboard, an alphanumeric display (say, 40 characters by 4 lines) and the hardware necessary to calculate position and communicate with a main control facility (Figure 4 shows an example system, and Figure 5, a sample keyboard and display unit). It is through this vendor-operated network control center that non-verbal messages from vehicles go to fleet dispatchers and vice versa. The units usually come with a series of pre-formatted messages stored in memory.

Alternatively, the driver may compose a free-form message which is later transmitted by pressing a “send” button. The transmission is almost instantaneous. While the driver is away from the vehicle, the unit acts as an answering machine, storing the messages it receives. A pager may also be provided to alert the driver that a message is waiting in the cab.



**Figure 4: Mobile satellite Communications [23].**

Besides simple messages and positioning, value-adding services include: trailer monitoring (position, status, and activity log); remote engine monitoring; anti-theft systems; temperature monitoring for refrigerated units; and wireless downloading of information about driver logs, on/off-loaded freight, and other data stored in on-board recorders. Software supplied by the vendors handles communications with the vehicles while computerized maps show the status of the fleet at any time.

Currently, Qualcomm is the only major player left in satellite-based communications systems after Geostar’s failure. A new service, however, is being launched by the American Mobile Satellite Corporation (AMSC). In addition, INMARSAT, the London based international organization, is pushing its Standard-C terminals. These systems are described in the next sections.



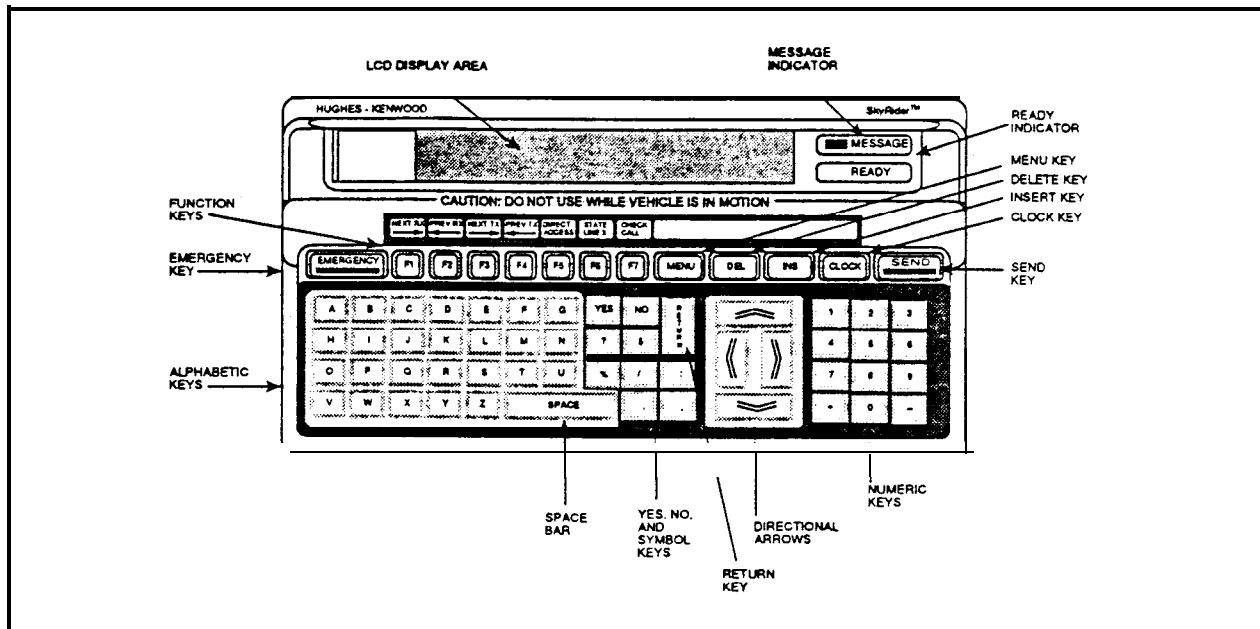


Figure 5: Keyboard and Display Unit [40].

### 52.1 Qualcomm's OmniTRACS

Qualcomm manufactures, markets and services the OmniTRACS system, the first to offer two-way communications and positioning services. This system began operational tests in 1988 and became commercially available in 1989. Instead of using L-band frequencies (designated for mobile satellite communications services), Qualcomm decided to use Ku-band frequencies. Ku-band communications are used extensively for telephone, TV, and private data networks and many Ku-band satellites are in orbit. Ku-band components are mass-produced and their cost is relatively low. Although typical users are those involved in transportation with trucks, company officials state that about 13 percent of OmniTRACS units are sold to other transportation modes.

The major technical problem in the design of OmniTRACS was the development of a specialized proprietary antenna. Qualcomm had to develop “quieter” signals that would not interfere with the existing telephone or TV signals using the same Ku-band frequencies. The antenna needed to be small

enough to mount on trucks at a cost operators could afford. Qualcomm teamed with OmniNet, which at the time had an RDSS license from FCC. After some initial failures, an omnidirectional Ku antenna was developed which supported two-way data transfer, alphanumeric messages, and position reporting. The antenna is mechanically steered and more complex than the ones used with other systems. Although it has moving parts, its physical reliability was proven after a simulated million-mile vibration test was conducted at the Navstar Technical Center. The company recently reported that the system is operating very successfully in varied environments [25].

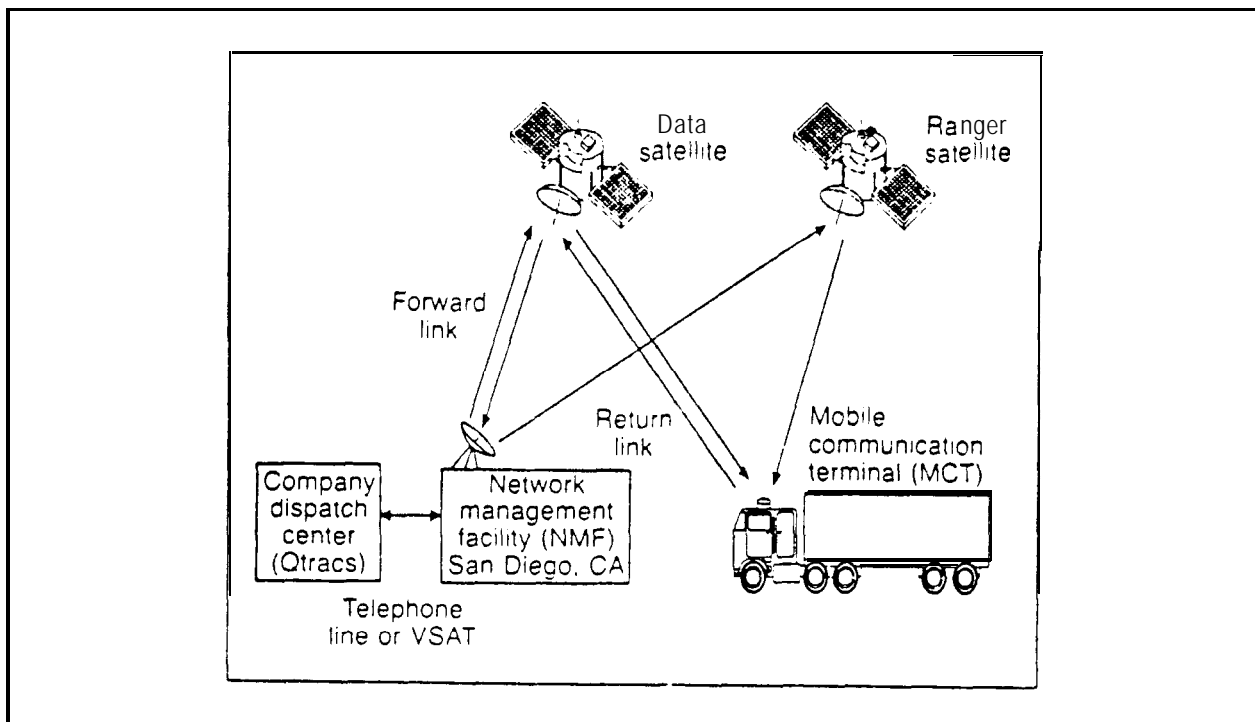


Figure 6: The Qualcomm System [24].

There are three basic elements to the Qualcomm system [25,26] (Figure 6). The on-board unit serves as the interface between driver and dispatch and consists of a portable computer, an outdoor unit, and a communications unit. The portable computer has a keyboard (either an ABCD or QWERTY type) with 69 keys and a 4-line by 40-character display which can be located on the dashboard. It stores 256 lines of in-bound messages. Messages typed by the driver or sent by the dispatcher can contain up to 1,900 characters. There is also a user-defined menu of 126 pre-formatted messages-63 for the driver and 63 for the dispatcher. The outdoor unit contains the antenna assembly and front-end electronics. It can be mounted either on the roof of the vehicle or on a mast. The communications unit does not

require operator access and can therefore be mounted anywhere in the vehicle. Although QASPR is now used to determine positions, the communications unit still houses a LORAN-C receiver in addition to other electronics.

A Network Management Facility (NMF) is operated in San Diego. All transmission traffic between truck driver and dispatcher is routed through this hub station. Unauthorized use of the system is prevented because users identify themselves prior to transmitting their messages. At that time they are also notified of pending messages. Individual, group, and system messages are also allowed. The NMF also acknowledges receipt of messages by mobile units and checks to prevent messages being reported more than once. If the acknowledgement is unsuccessful, retransmission is attempted several times within a pre-specified time period.

Software from Qualcomm or other vendors simplifies the interface between fleet computers and the OmniTRACS system. Qualcomm's software, called Qualcomm Communications Manager (QCOM), is installed on the dispatcher's computer system and runs concurrently with existing applications. QCOM handles all communications with the NMF. The user can receive or send messages and then continue working on the computer. Other features include: modification of the formatted messages, clustering of vehicles, date- and time-stamped message acknowledgement, separate handling of emergency messages, password protection, automatic routing of messages to appropriate dispatchers, and vehicle database and position history.

InTRACS/Atlas is a program that cooperates with QCOM. It provides a color map showing the position of a fleet's vehicles. With this integrated system in place, the user can switch between applications software (word processor, spreadsheet, vehicle routing programs, etc.) and the color map with a single keystroke. Both packages run on a variety of computer platforms.

Besides messages and positioning, other services are offered by Qualcomm. Trailer tracking and monitoring with TrailerTRACS is done by mounting a transmitter on the trailer. A receiver is mounted on the tractor and connected to the OmniTRACS system. This gives carriers the opportunity to monitor the status, position and activity log of a trailer. Temperature monitoring is also possible for refrigerated units. The software that makes use of TrailerTRACS is an integrated part of QCOM.

Another service is the OmniTRACS Driver Pager. With a range of 1,000 yards from the vehicle, this pager assures that the driver will not miss an important message. It can also be used as an alarm. A "Message Return Receipt" service has the system notify the dispatcher when a message has actually

been read. Finally, by pressing a "Panic Button" drivers can send a formatted message to the NMF, causing a telephone call to be initiated to appropriate fleet personnel to inform them of serious trouble at the location of the truck.

The cost of a Qualcomm unit is \$4,500 (March 1991). The monthly service charge for vehicle tracking is **\$35** per truck. To that a charge of 5 cents is added for each digital transmission and 0.02 cents for each character sent.

Qualcomm has successfully completed a demonstration program in Europe and an operational version of its system has been recently authorized under the name **EutelTRACS**. Qualcomm circumvented the regulated European telecommunications environment by not offering voice communications. It uses Ku-band transponders on satellites operated by EUTELSAT, an European telecommunications organization. Testing is underway in Japan where Qualcomm signed an agreement with C. Itoh and Co. Ltd and Nippon Steel Co., to form a joint venture to market and provide **OmniTRACS** systems and services. Qualcomm also operates in Australia.

### 5.2.2 Geostar

Geostar, after having being granted operation authority on L-Band frequencies, started out providing an **RDSS** system. In its full implementation the system would consist of three dedicated RDSS satellites. The so called System 3.0 was scheduled to become operational in the mid 1990's. In the meantime, System 2C, which allowed two-way transmission of messages between a fleet dispatcher and a truck driver, had become available. LORAN-C was used for determining positions of vehicles, pending full deployment of the RDSS system. Sony (2-Wayfarer) and Hughes (SkyRider) were the principal manufacturers of equipment which made use of the Geostar services. Railstar Control Technology produced SCANTRACK to adapt these units to serve specialized needs, especially railroad applications.

As noted earlier, Geostar faced severe financial **difficulties** and attempted to reorganize its operations under bankruptcy law proceedings without success. The trade press estimates that Sony (by far the major supplier of units for the Geostar system) had supplied 75 fleets, or 3,000 to 4,000 units [27]. It is not yet clear how the fleets will react to loss of Geostar services. Sony, however, offered to buy back the hardware at 85 percent of the original price. Undoubtedly some of the truckers will switch

to Qualcomm, for it would be difficult for them to stop offering their customers the enhanced services they had developed. Hughes may also gain some business through its participation in the American Mobile Satellite Corporation (AMSC). The future of **Geostar's** European venture with France's space agency (CNES) is uncertain. The system was to be named **Locstar** and be available before 1993. It would be totally compatible with the U.S. system and offer the same services.

### 5.2.3 The American Mobile Satellite Corporation (AMSC)

The American Mobile Satellite Corporation or AMSC is an FCC-mandated consortium of eight companies that were given monopoly rights on certain L-band frequencies allocated for MSS purposes (Geostar had an RDSS license, and **Qualcomm** used Ku-band frequencies which were not designated for MSS purposes). The AMSC license allows for the operation of a domestic mobile satellite (called **MSAT**) system covering air and land, and offering both voice and data. MSAT spacecrafts are expected to be launched after 1994, when their transmission capabilities will be orders of magnitude greater than any existing L-band satellites [28]. MSAT facilities will support many users on each channel providing a multitude of point-to-multipoint and point-to-point services.

AMSC will be responsible for the operation of the satellite network. Services will be offered by authorized service providers designated by AMSC. Until full implementation of the network, AMSC has leased satellite capacity from COMSAT (**INMARSAT's** U.S. representative) and is expected to launch commercial satellite tracking and messages services before the end of 1991. Its selling point seems to be the expansion capabilities of the system and the support it enjoys from large communications companies. The service will be named **StarDrive**, and will cover all of the continental U.S., Alaska and Hawaii. Fleets will be able to track their vehicles with LORAN-C and exchange digital messages with the drivers using terminals supplied by Hughes (a member of the AMSC consortium). After the MSAT launches, two-way voice communications, mobile telephone and mobile fax services will be added.

Telesat Mobile of Canada has been offering in Canada a data-only service since May 1990 [29] which may be expanded in the U.S. Rockwell (an authorized AMSC Service Provider) also has plans to offer its own AMSC-based satellite messages system called SATCOM. Rockwell's latest on-board computer (Tripmaster Data Port) will be optionally integrated in its systems. Users will be able to

remotely monitor, download and reprogram the on-board recorders. Tracking will be based on either LORAN-C or GPS. Rockwell's system will be universally available before the end of 1992 in an experimental, "First Service" mode. After AMSC launches the MSAT satellites, the system will pass to its "Full Service" mode.

In March 1991, a federal appeals court panel ordered the FCC to reconsider its decision to award the only license for mobile satellite services to AMSC. The decision raises questions about the long term status of AMSC and could delay the start of services by two to five years. The FCC has not decided yet as to its course of action.

#### **5.2.4 INMARSAT**

INMARSAT, the London based international organization, is offering data communications services to land mobile users with the Standard-C system [30]. A Standard-M terminal is also in development offering relatively low-cost voice communications.

Standard-C was developed to provide a two-way store and forward message service to the maritime community. Subsequent trials showed that the design was suitable for the mobile environment on land as well. Tests with many users followed, and an excellent record of success was achieved. A market of about 250,000 Standard-C units is anticipated by certain INMARSAT officials [31]. The feasibility of interfacing a GPS receiver to a Standard-C terminal has also been demonstrated. Units from several manufacturers have been type-approved by INMARSAT and a Japanese company has recently developed the first Standard-C terminal to offer optional position reporting using GPS.

Although Standard-C seems to be the mobile satellite communications system of choice in Europe [32], the future of Standard-C equipment is uncertain in the U.S. unless AMSC or COMSAT adopt it as a standard for domestic satellite communications.

### **5.3 EUROPEAN DEVELOPMENTS**

In contrast to the U.S., tracking and monitoring systems are only now being introduced in Europe. The probable cause for the delay is the regulatory environment which restrains potential service

providers, equipment manufacturers, and fleet operators. Other problems that contribute to the low market penetration or even non-existence of such systems include: the lack of standards, lack of pan-European coverage, and high system costs [33].

All West European countries have terrestrial mobile communications systems but because they use different standards the networks are incompatible. This will change with the advent of GSM (Groupe Special Mobile), the pan-European cellular network. Its implementation began in 1991 and is planned to reach full coverage before the end of the decade. Although satellite systems complement terrestrial systems, especially in remote areas, the GSM is not compatible with the emerging European satellite communications standard, INMARSAT-C. There are also European proposals for networks of cordless phones and radio messages systems.

European satellite operators (e.g., the European Space Agency and EUTELSAT) would like to see a regional European satellite mobile communications system. The European organization of telecommunications companies (CEPT) studied the feasibility of such a system and determined that the economics favor the use of a worldwide public system [32]. By public, it is meant that the system could be connected to the public telex and data networks (EutelTRACS and Locstar are closed user groups systems).

Two candidate systems were investigated for the provision of public land mobile satellite communications: INMARSAT-C and PRODAT. PRODAT was an experimental system that had undergone considerable and successful testing. Sponsored by the European Space Agency (ESA), it offered two-way data transmission satellite system for unidirectional wide-area paging and bidirectional low-rate data transmission. CEPT concluded that INMARSAT-C should be used not on the grounds of technical superiority, but because it was available immediately.

When it comes to IVHS activities, however, Europe is at least as active as the United States. Research on Road Transport Informatics (RTI, the European equivalent of the North American IVHS) is conducted within the framework of two large projects: DRIVE (Dedicated Road Infrastructure for Vehicle Safety in Europe) and PROMETHEUS (Program for European Traffic with Highest Efficiency and Unprecedented Safety). EUROFRET (A European System for International Road Freight Transport Operations) and FLEET (Freight and Logistics Efforts for European Traffic) are the two DRIVE projects more directly involved with freight operations. The most striking characteristic of European proposals

is their holistic approach. The approach seeks technologies and applications that address three operational areas: vehicle management, fleet management, and the logistics process (e.g., Figure 7 [34]).

While **EUROFRET**'s objective is the creation of a pan-European integrated RTI infrastructure, **FLEET** is more concerned with vehicle-dispatcher communications and the technologies that will enhance fleet management. **PROMETHEUS** is a "precompetitive" cooperation agreement between automobile manufacturers to develop computer-assisted driving and traffic management technologies. As part of the project, a series of tests and demonstrations will be performed to determine the best systems (satellite or terrestrial) and procedures for commercial fleet management.

Typical of the proposals put forward is the **Domier Fleet Monitoring System (FMS)**[35]. Dispatchers and drivers can exchange messages via several communications media (e.g., satellites, cellular radios, **trunked** radios) but **INMARSAT**'s Standard-C is in use. Messages can be adapted to fit a particular operator's needs. The **FMS** software package assists in message management, order and vehicle tracking, and interactive dispatching on a digital map. Generally, all system proposals envision the use of either **INMARSAT**'s Standard-C or the emerging pan-European digital cellular network as a means of communication.

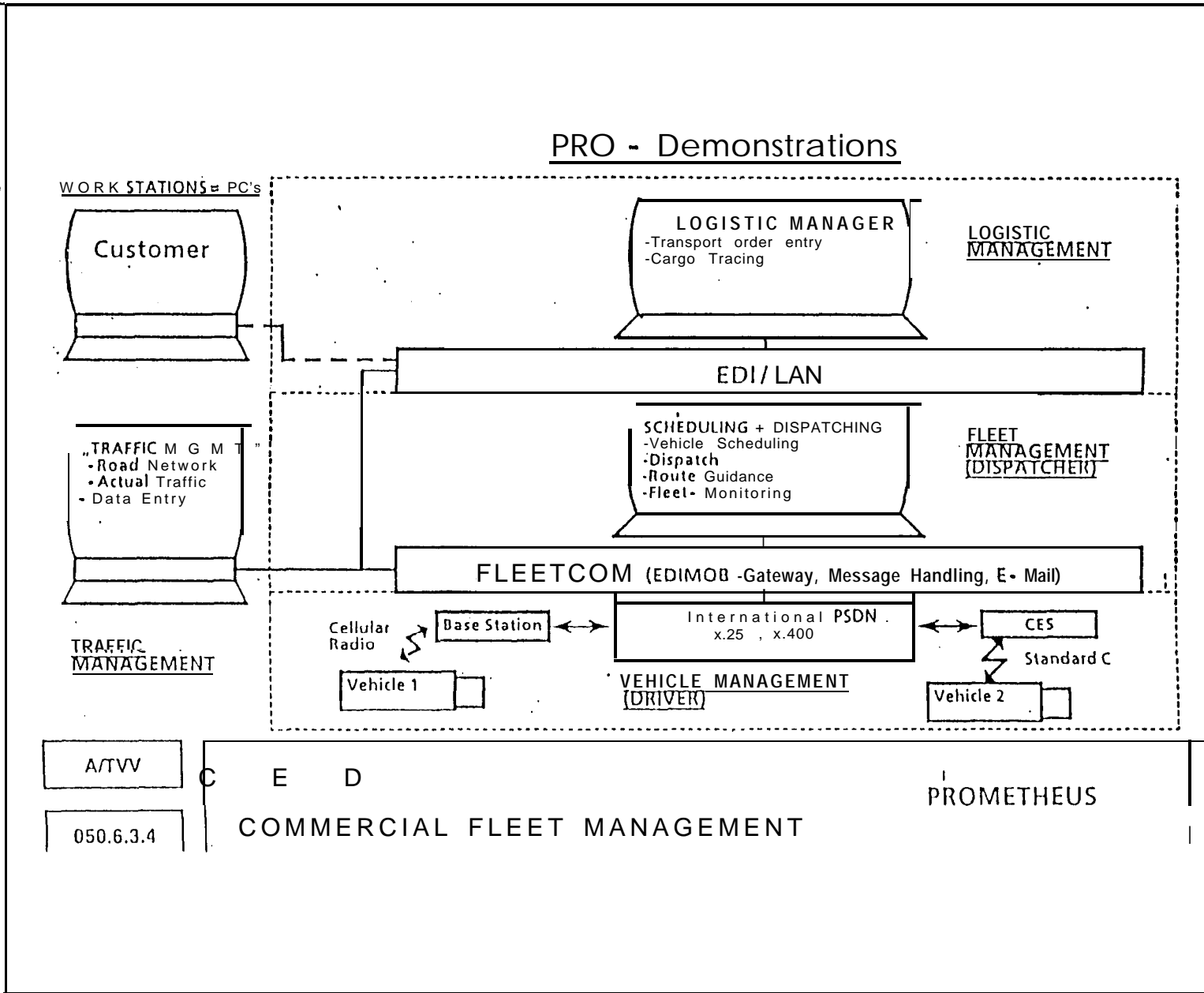
#### **5.4 EMERGING SYSTEMS AND SYSTEM PROPOSALS**

Telephone and other communications companies are examining wireless services and personal communications networks (**PCN**). In response, the **FCC** has awarded about 40 licenses (July 1991) to companies for the testing of personal communications services. Several of the licenses involve tests of **CT2**, or second generation cordless, networks. Such a service, called **Telepoint**, has already been introduced in Britain. The telephone handset costs about \$300 and customers (around 5,000 of them so far) can make, but not receive, phone calls as long as they are within a few hundred feet of a base station. Each base station can handle multiple cordless units but they do not support hand-off (i.e., a call cannot be handed off from one station to another).

The future of wireless services, however, lies in systems offering two-way communications. Proposals have been made to test equipment and services in areas with different characteristics in terms of terrain, population density and other factors. These areas include Atlanta, Baltimore, Boston,



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Houston, Los Angeles, Orlando, Philadelphia, Trenton N.J., Washington D.C., and West Palm Beach. According to industry executives, it is no longer a matter of technology, economies of scale are needed to provide services at attractive prices. Some problems exist, however: a predominant technology has not yet emerged; the radio spectrum is already crowded with many services (although the FCC is studying the reassignment of frequencies currently used by U.S. agencies); and the envisioned networks need huge capital investments.

A characteristic of this fledgling industry is that non-traditional players (e.g., small start-up companies and cable operators) are challenging traditional providers of phone services such as local phone companies and cellular carriers. At the mobile communications industry convention in 1990 cellular executives claimed that the **landline** telephone systems were in serious trouble and admitted that the cellular industry could disappear if it failed to capture PCN and CT2 technologies. Others argued that personal communications networks were inferior to cellular systems. One consensus that emerged was the need for a system where subscribers would have one phone number for the office, car, or home.

Phone companies and cellular carriers want to use emerging digital cellular networks to offer PCN services. Capacity problems can be solved by using a technique pioneered by Qualcomm called code-division multiple access (CDMA) and backed by AT&T, Ameritech, and Nynex, among others. CDMA systems are said to offer up to 20 times more call-handling capacity than the conventional cellular systems. CDMA works by assigning a special electronic code to each call signal allowing more calls to occupy the same space and be spread over an entire frequency band. In contrast, the current standard for future digital cellular systems (time-division multiple access, or TDMA) offers three to seven times the capacity of existing systems. It works by placing each call into a time slot and transmitting it within a single frequency.

Newcomers to the field (e.g., Millicom, PCN America, American Personal Communications) tend to favor the use of different frequencies and thousands of tiny cells. Their networks would use pocket-size, cordless handsets that would function much like cellular phones. A system of low-power, high-frequency transceivers would be deployed around cities to transmit and relay calls. The new systems are expected to require less power than existing cellular systems, allowing for lighter phones and opening doors for "pocketphone" services. The base stations would be at closer intervals than present cellular systems using more powerful radio towers.

Equipment manufacturers such as Ericsson, Motorola, and AT&T are exploring office niches. They expect that the corporate market will take off first, and have started offering PCN systems for offices. Even cable operators are active in the field, trying to determine whether their systems can carry phone calls. Most cable providers are focused on linking cable lines with local or long distance phone lines. In contrast, Comcast, a major operator of local cable-television systems that also owns cellular-phone networks, received approval in late June to test cable-cellular link-ups. Finally, in July of 1991, AT&T applied for permission to test whether its nationwide network of microwave towers can be used by pocket phone services. The facilities are available because the company started taking this network out of service in 1988 when it switched to fiber optic transmission lines and digital switches.

Although more specialized, the wireless data networks in use today are similar in concept to the PCN. They are privately owned, dedicated or shared-use public networks ("shared" in the common carrier sense). A variety of suppliers offer hand held devices that can be used to transmit/receive messages within a particular region. Motorola (ARDIS) and Ericsson (Mobitex) are leading suppliers of two-way shared-use public networks. Their systems have the advantages of speed and reliability in data transmission. To cover wide areas, however, they depend on the existence of an extensive ground infrastructure (e.g., base stations, area exchanges, and main exchanges). Examples of uses include: courier companies updating central databases, rental car companies facilitating transactions at the parking lot, utility companies dispatching vehicles for field services, and inventory controlling at warehouses or supermarkets.

A radically different proposal is being advanced by Motorola. In June 1990 it announced plans for a system called "Iridium," expected to become operational within the decade. A call from any portable cellular phone anywhere in the world--possibly outside the range covered by existing networks--will be routed through a constellation of 77 low-orbit small satellites. The system will use digital switching and transmission to handle both voice and data. Although Iridium will operate at different frequencies from existing cellular systems, it will be made compatible with them. Motorola expects the mobile and portable terminals that it will manufacture to cost around \$3,000. In its search for partners to help finance the huge effort, Motorola recently selected Lockheed as its major partner. INMARSAT and AMSC have also announced they would study Iridium. Besides engineering considerations, Motorola and its partners have another difficult problem to solve: obtaining radio spectrum from regulatory authorities around the world.

The idea of combining cellular and satellite networks is an interesting one and potentially very beneficial to users. Recently another **company**, Ellipsat, has also applied to the FCC for permission to launch a low earth orbit (LEO) satellite service. It plans to use the low altitude satellites to carry cellular signals, coded in CDMA, over long distances. Several other companies also plan to launch LEO satellite services.

Finally, NASA has been developing an Advanced Communications Technology Satellite (ACTS). The program has overcome development barriers, and currently NASA is trying to **find** private-sector experimenters for the two-year demonstration phase of the satellite's four year life cycle. Launch is scheduled aboard the Space Shuttle for May 1992. ACTS is being touted as a telecommunications problem-solver thanks to its new and sophisticated technology. The technology offers the possibility of hybrid digital networks linking satellite, fiber optic, and coaxial cable systems. The availability of various data rates could provide users with access to a full spectrum of video, voice, and data services. Use of the Ka-band has the potential to greatly enlarge the market for mobile communications. Recently, NASA announced that efforts toward the development of a new type of mobile terminal have been initiated. Whether these services will be commercially feasible will be determined in the demonstration phase.

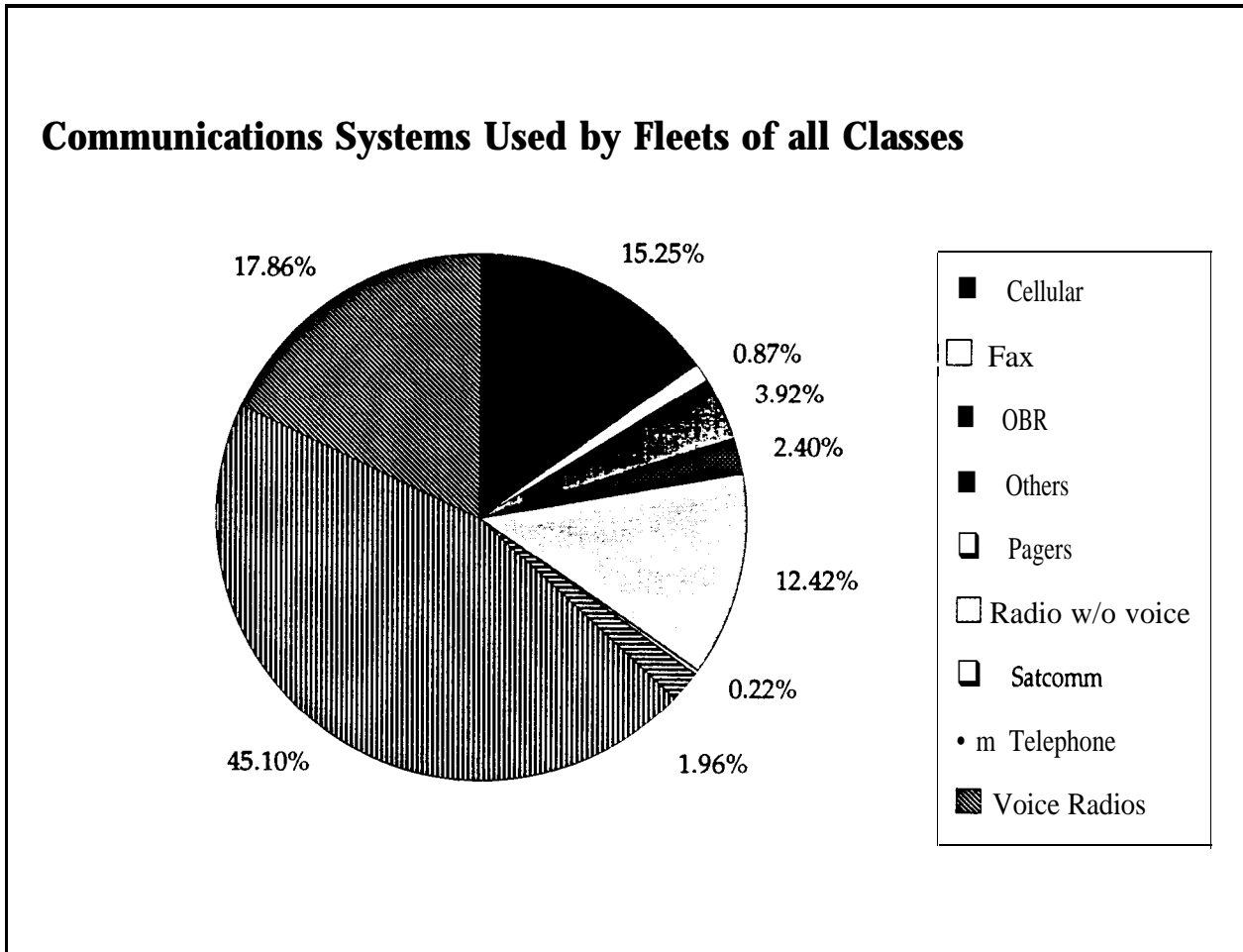
## 6. USES AND EXPERIENCES

A survey of trucking firms was conducted as part of our investigations of the status and use of technologies. The questions asked sought information on the communications technologies being adopted by truck operators and how these technologies are used. The survey was addressed to ICC-regulated motor carriers (approximately 40,000 firms in 1988; non-ICC regulated carriers include private, intrastate, and regulation exempt carriers). A sample was selected of 200 Class I carriers (those with revenues in excess of \$5m per year), 600 Class II carriers (those with revenues between \$1m and \$5m), and 200 Class III carriers (those with revenues less than \$1m) taken from all geographical areas. Class III carriers are underrepresented in the sample because the actions of Class I and Class II carriers are likely to have a much broader impact than those of Class III carriers. In addition, the larger carriers operate more trucks than small carriers, with a rule-of-thumb being one tractor operated for each \$100,000 of revenue.

The survey revealed that telephones, voice radios, cellular phones and pagers constitute almost 91 percent of the communications systems used by truck operators (Figure 8). Public telephones are by far the predominant technology with a share of about 45 percent. Voice radios come a distant second at about 18 percent market share. Although cellular phones and pagers represent approximately 15 and 12 percent of installed systems respectively, their usage has been growing much faster than other systems (Figure 9).

The large difference in market shares between telephones and other systems is partly because many fleets use telephones in addition to other communications technologies. The role of telephones, however, is diminishing. Figure 10 shows that in 1980 telephones and voice radios had a combined market share of nearly 90 percent while a decade later that had gone down to 60 percent. The big winner was the cellular phone, which was in the rapid growth phase of its product life cycle.

Let's look now at the experience of the users with advanced technologies. After all, companies buy hardware for a purpose--the capability to exchange information with their vehicles in near real time. To address the experience, it is helpful to segment the industry according to whether the length of the trip is more than 200 miles. This segmentation roughly corresponds to the capabilities and costs of the communications systems. However, the trucking industry is very diverse and nothing prevents a fleet from using any equipment that matches its needs. In addition, brokers of services may allow small fleets



**Figure 8: Communications systems used by fleets of all classes.**  
 (The shades of grey may be difficult to discriminate. Read clockwise from the noon position following the order of the listed systems.)

to operate sophisticated communications systems that they could not otherwise afford.

The short haul segment consists of operators who generally travel less than 200 miles from their base. The local operations of less-than-truckload (LTL) and truckload (TL) carriers are included here. The long haul segment consists of the line haul portion of an LTL trip and any TL carriers not operating locally. LTL carriers normally pick up many small shipments from shippers, consolidate them into truckload lots for the line haul, and deliver them via terminals to customers. TL carriers typically pick up a full truckload shipment from one shipper and deliver it without other loading stops to one or more consignees.

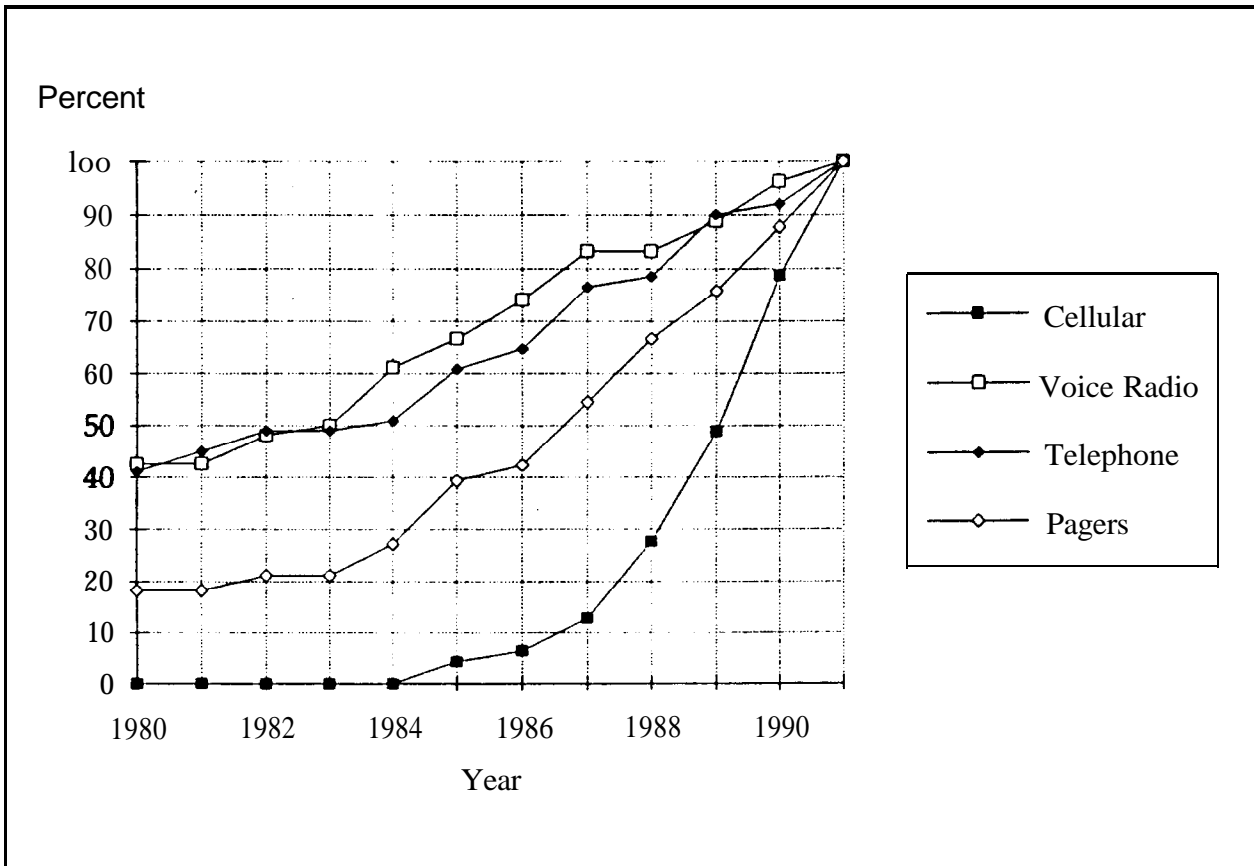


Figure 9: Market Penetration by Selected Communications Systems. To compare market shares, see Figure 10.

Emergency, police and other public safety fleets fall in the short haul segment. They need sophisticated equipment and services to effectively and efficiently dispatch vehicles. Although applications of emerging technologies in their demanding environments might give considerable insights, in the following sections these technologies are not assessed by how well they serve such specialized fleets.

### 6.1 SHORT HAUL OPERATIONS

In all, there are about 4 million trucks, excluding pickups, panels, utilities and station wagons, in the short haul segment [4] with about 400,000 of these for hire. The vast majority of the trucks use

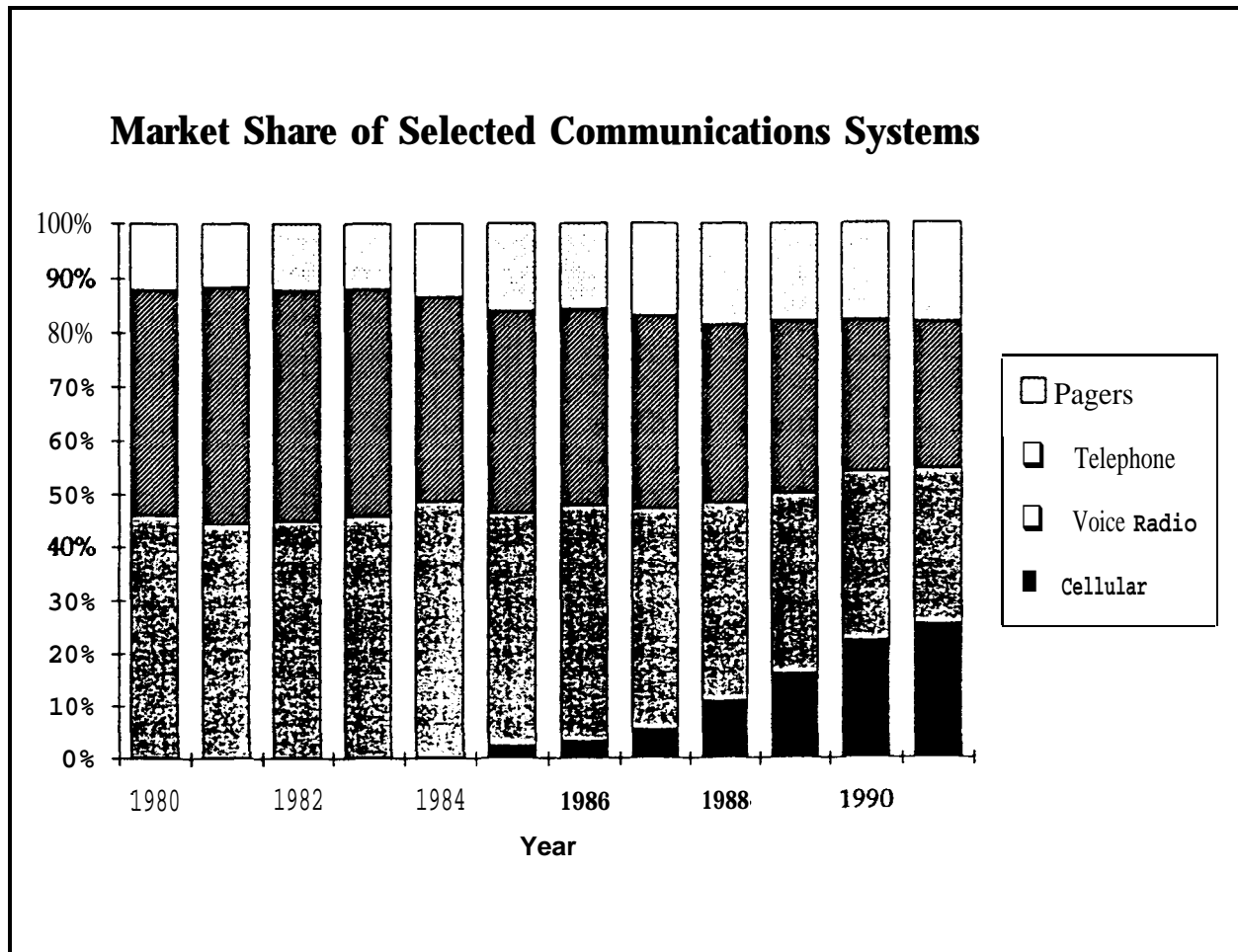


Figure 10 : Market share of selected communications technologies. (The shades of grey may be difficult to discriminate. Read downwards from the top following the order of the listed systems.)

public telephones or voice radios (the same is true in the European countries [33]). This reflects convenience, ease of use, and affordable cost (it typically costs a few dollars per truck per month to operate a simple voice radio shared system), although the technology is range-limited.

Using voice radios, the fleet manager and the driver can be constantly in touch and exchange messages reporting changes in schedules, expected time of arrival, directions to the shipper's dock, and traffic updates. New load information is generally not communicated because many systems do not offer privacy. The capability also exists to interface voice radios to telephones so that customers can talk directly to the truck driver. Fleets report that this option is valued by the customers. There are



indications that the situation could change rapidly. For instance, the California Trucking Association (CTA) has plans to offer competitively priced cellular services to its members. CTA officials feel confident that in one year after introduction of the new technology it will have replaced most of the voice radios in existence today.

Many of the systems discussed previously are not well suited for short haul services. Motorola's **CoveragePLUS** is uniquely suited for broad regional coverage. Their offering of position reporting and sophisticated software integrated with the fleet dispatch system appeals to some fleets operating, say, within 500 miles or more from their base. Although the technology has true nationwide potential, achieving that potential depends on cooperative, local area, two-way radio systems so it would be difficult to match the comprehensive coverage of satellites. Company officials do not release detailed data. They will only say that they have sold \$50 million worth of equipment.

Satellite systems are at a disadvantage in short haul operations: their capabilities can be duplicated by other systems at a lower cost without any reception problems. In addition, they do not offer voice communications. Consequently, most fleets using this technology are in the long haul business.

Data communication is common only among large and sophisticated companies, mainly couriers (excluding public safety fleets). Discussions with fleet operators revealed that within the context of electronic data interchange (EDI) they see a future for data communications between trucks and dispatch centers, but not necessarily in their own fleets (the general attitude was that voice communications would be used for many years).

The proprietary systems used by couriers and other small package transporters help them achieve high levels of internal efficiency and customer satisfaction. They consider the information collected locally as part of their product offering. In an advanced system, when a package is picked up all relevant information (e.g., origin, destination, names of consignor and consignee, value, weight) is transmitted through a hierarchical computer network to the courier company offices at the destination. This enables load planning at intermediate transfer points, as well as at the destination. During the trip the shipment is continuously tracked. Customers may have access to tracking information through the courier's tracking system.

Although some form of communications system is used by all firms, position reporting systems are not common in short haul operations. This may change with the widespread use of real-time route

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scheduling and the advent of navigation and route guidance systems. Some fleets have already automated their dispatching operations so that drivers call in, report their status, give their location, and get a new assignment. In a truly dynamic fleet management system, however, the position of the vehicle would be known at all times and would be matched with the demand for services. Such systems are used by public safety fleets (e.g., Detroit Emergency Response System, or DETERS which is jointly used by the police and fire departments of the city).

Another application of location reporting technologies, in this case proximity systems, is at intermodal transfer points (e.g., ports or rail/truck hubs). A truck enters a port, the container it carries is electronically identified and the container inventory database is updated. Problems often mentioned include untagged containers and a lack of common standards. Although an AEI standard was recently adopted, EDI formats used by the different parties at modal interfaces now vary.

## **6.2 LONG HAUL OPERATIONS**

The line haul trip of an LTL operation is usually between break bulk terminals. Drivers can legally drive up to about 10 hour shifts so the need for positioning and communications is only felt in cases of theft, accidents, or other emergencies. However, at least one large company has installed and uses technologies to respond quickly to shipper requests for quick pick-up and priority deliveries.

By contrast, in TL operations the trip may take several days and the routes are often irregular. Because drivers must give regular status reports and obtain new instructions, a communications system with nationwide coverage is needed to provide a continuous link between dispatchers and drivers. Most fleets still use public telephones to communicate with their drivers, sometimes in conjunction with voice radios, pagers, and voice mail systems. This usually means that the driver has to find a telephone, wait in line (most of the drivers call early in the morning), and try to reach the fleet manager whose line may be busy.

Wired telephones may be enhanced with nationwide paging and voice mail systems. Cellular phones and other radio systems, such as CoveragePLUS, can be used under certain circumstances but depend on the existence of an extensive ground infrastructure. Only satellites offer comprehensive nationwide coverage. As mentioned, a potential problem is in built-up environments where it may not

be possible for the vehicle to continuously maintain a line of sight with the satellite. Although travel in urban areas is a small percentage of total trips, most trips originate and terminate in urban areas. Ideally, a “dual” system would be the ultimate solution. Nevertheless, some fleets have reported fair reception in metropolitan areas.

The first adopters of the satellite technology were motivated by the savings in telephone bills and better utilization of equipment. Later, time-sensitive customers who wanted to better manage their logistics flows pushed for the technology. Now, many firms consider the satellite systems a source of competitive advantage (one company claims to compete in its service area with second day air delivery) and an essential business tool. Industry analysts have predicted that soon communications and positioning equipment will be necessary for the success of firms [36].

Discussions with fleet operators made it clear that their biggest frustration was trying to integrate data with their dispatch systems or with the increasingly popular on-board computers. Attempts to establish links with EDI systems were also mentioned as a frustration. Most fleets, however, report that the benefits far outweigh any integration problems encountered. Among the benefits as reported in the trade press are:

- Long distance phone calls are eliminated resulting in reduced phone bills.
- Service to time-sensitive customers is improved. Customers see the benefits and strongly push towards the installation of more systems.

A carrier gains competitive advantage by offering advanced communications services to its customers. A small firm can continue expanding without abandoning the personal touch in the services it offers.

Scheduling flexibility and real time information increase the number of trips per vehicle and reduce the number of empty miles. Carriers operating with trailer to tractor ratios close to 1 realize immediate benefits.

Drivers waste less time waiting at pay phones, sleep more, and earn more money. Many drivers consider the electronic terminal in the cab something of a status symbol. Their satisfaction leads to better labor relations and reduced turnover.

Improved driver accountability since drivers know they are not “alone” any more.

Increased safety.

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Vehicle maintenance costs are minimized if vehicle attributes bearing on maintenance are monitored.

Shipments of hazardous materials are continuously monitored so in case of accident the necessary actions can be taken. (The federal government has imposed strict reporting requirements for hazardous loads and forbids any unauthorized route deviations.)

Similar benefits have been observed in Europe after a series of field trials [35,37].

In the U.S. there are about 500,000 trucks travelling more than 200 miles from their base [4], and the satellite system suppliers have sold no more than 30,000 units (April 1991). Therefore, despite the positive experiences, not many fleets use the satellite technology. The following simplified calculations, however, suggest that it might not be difficult to justify the investment (the data were obtained from the references cited, the trade press, and discussions with users):

At \$4,500 the fixed cost of satellite equipment is about 4.5% of the cost of an average tractor (\$105,000 [38]). The operating cost which includes tracking service plus message charges is about \$50 per month per truck. Total cost is likely to be close to \$180 per month per truck when equipment leasing and maintenance costs are included. Figures released by the American Trucking Associations [38] indicate that in 1988 per mile tractor-trailer line haul costs were \$1.07 (\$1.19 for owner operators). If the drivers saved 2 miles a day by not having to search for a pay phone, in a month savings would be close to system operating costs. Furthermore, a tractor trailer rig is typically driven 10,000 miles a month. A 2 percent reduction of the line haul costs (attributable to the systems) would cover the total system costs.

This analysis does not include other benefits such as more efficient equipment use, improved service, and customer satisfaction, which are difficult to quantify. These impacts take time to develop and are not completely under the control of the carrier itself. Using an engineering cost model, one study concluded that under certain circumstances a cost reduction of about 8 percent would be feasible [39]. Vendors have also completed studies that show the pay-off period to be between one and two years, and an estimated **annual** cost reduction of \$2,828 per tractor [40].

Trucking fleets and their customers are not the only ones to benefit, however. The Ministry of Transportation in Ontario (instrumental in the design of the vehicle monitoring system employed in

Canada) calculated that the Ontario economy would increase GDP by CN\$10 million and would gain about 2,100 person-years of employment [29]. The calculation was based on a high degree of local manufacturing content.

### **6.3 THE HELP PROJECT**

The Heavy Vehicle Electronic License Plate (HELP) project was initiated by highway planners and managers in Arizona and Oregon who wanted to simplify the data gathering process. Agencies collect data to support highway planning, design, and management, as well as for monitoring the size and weight of trucks, speed limit enforcement, and tax administration. The HELP concept was to deploy emerging electronic technologies at state borders and other locations, in order to create an integrated system that would collect, communicate, store, and process data. The trucking industry, although at first reluctant to participate in the project, was attracted by the prospect of using the data for more efficient fleet management and reduction of reporting expenses at state points of entry.

HELP has mainly focused on three technologies: Automatic Vehicle Identification (AVI), Weigh-in-Motion (WIM), and Automatic Vehicle Classification (AVC). Additional technologies have also been investigated to determine whether they would enhance the program (e.g., satellite communications and on-board computers). Vehicles are identified using on-board transponders and roadside readers. The transponder tags are not compatible with the ISO standard used by the container shipping industry, for it was felt that a system with such data collection capabilities was not needed. WIM systems use in-pavement sensors to obtain the axle and gross weights of vehicles travelling at speed, while data for highway management and maintenance are to be provided by AVC systems. In contrast with AVI, neither WIM nor AVC need be standardized as long as they comply to a set of minimum specifications.

After detailed technical feasibility studies were completed, the Crescent demonstration phase started involving 14 U.S. states and 1 Canadian province (British Columbia). The name Crescent was given because British Columbia and many of the states participating are located along the west coast and the southern U.S. border inland to Texas, thus forming a crescent. There are approximately 40 equipped sites along Interstates I-5, I-10, and I-20 that will be used in the demonstration and at least 4,000

transponder-equipped trucks. Several potential applications have been identified, which are divided into three categories: data collection, enforcement, and vehicle management (Figure 11).

The demonstration phase is expected to last until the end of 1992, and it will be followed by a detailed evaluation. At this time no plans exist to deploy the system nationwide if proven successful. One of the issues that has not yet been fully resolved is to whom and under what conditions will the data be accessible. The database will include motor carrier name, address, and license number; vehicle owner and registration number; and a chronic offender flag and FHWA unsafe carrier flag). A private company has been contracted to manage the Crescent and perform the computer integration work. There seems to be a consensus that an independent organization responsible to both government and fleet operators should administer the system.

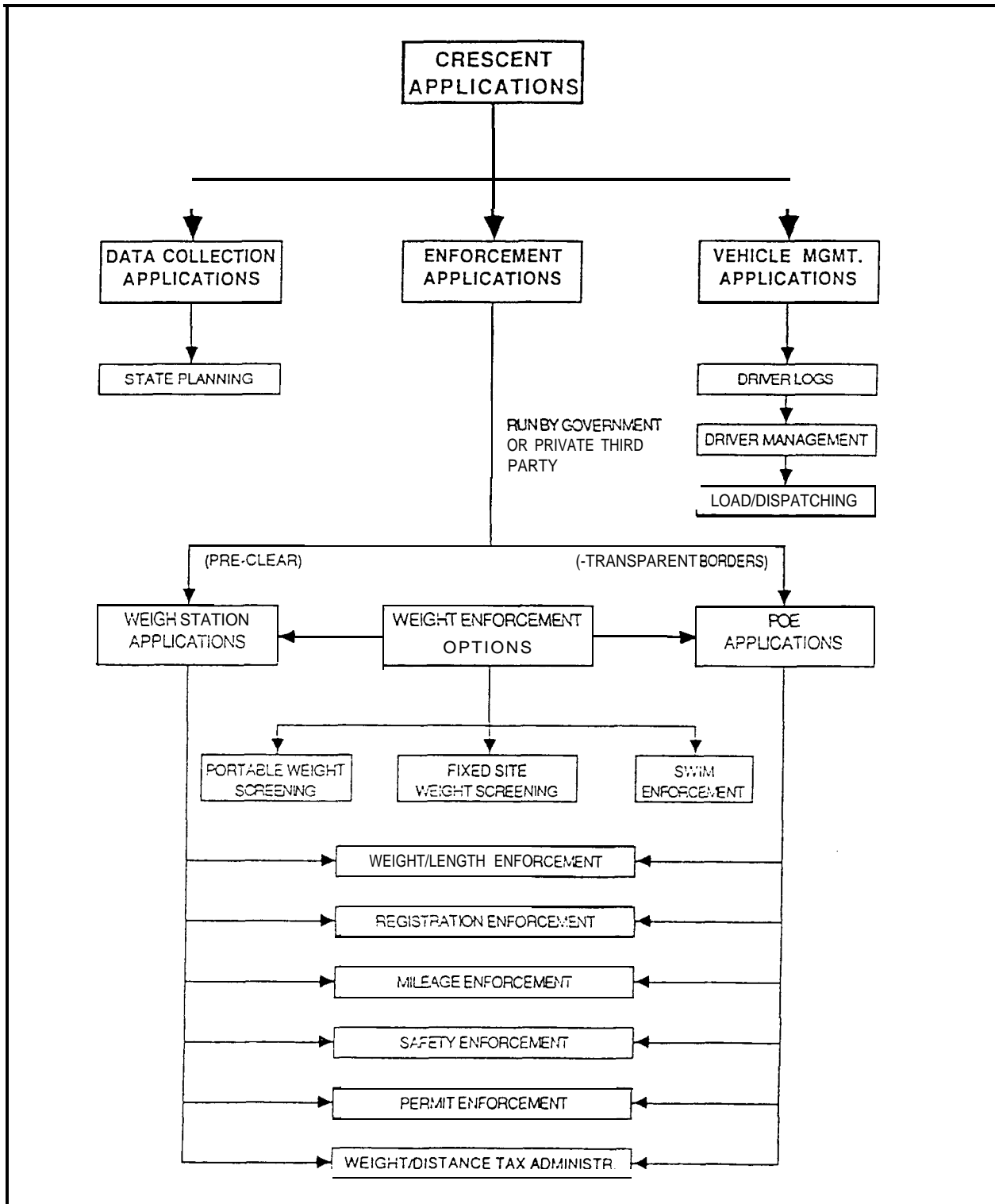


Figure 11: Crescent Applications [41].

## 7 LESSONS

Are there any lessons to be learned from the experiences of early adopters of position and communications systems? We will attempt to answer this question by focusing first on the fleet operators and then on the auto-truck highway system and IVHS.

### 7.1 FLEET OPERATORS: AUTOMATE OR INFORMATE?

The title of this section uses a word coined by Zuboff[42] to denote that information technology not only automates an operation but at the same time increases its explicit information content. It informs. For example, the technology that allows dispatchers to get in touch with drivers also generates information that can be used to assign loads to drivers, update organizational databases, or send electronic documents to customers. So data formerly stored in peoples' heads or in file cabinets are visible to all, and the production process, from freight solicitation to final delivery, becomes more transparent. This creates opportunities for insights, improvements, and innovations.

The complementary capacities of information technology must be explicitly recognized to take full advantage of advanced technologies. Automation is the first task of the informing process. It formulates and preserves what is already known and executed in an operation (e.g, a shipper calls in with a new load; two drivers might cover it; driver 2 is assigned to the load because it is expected that a new load will materialize near driver 1). The next step is the integration of the information generated into carriers' and shippers' information systems (e.g., maintenance activities are scheduled based on actual patterns of use; shippers notify carriers of anticipated loads, and carriers optimize the routing of their vehicles).

The creation and dynamic evolution of an integrated system is the cornerstone of an informing strategy. An integrated information system has three physical components:

1. Information, flowing among the different parties (e.g., shipper, dispatcher, departmental needs, truck driver).
2. Infrastructure that allows the flow of information (e.g., telephone lines, satellites, terminal units, computers, routing software, Management Information Systems).



3. Interface mechanisms linking the different parts of the system and providing the means of control (e.g., communications standards, regulatory requirements, the organization itself).

In the transition to a high degree of integration three distinct steps or levels can be identified, each with different requirements in terms of these three “I” ’s (Information, Infrastructure, Interface). The first task is to create an automated environment. The communications system plays a key role because the basic source of information is the moving vehicle. Then, information is shared between different departments. Finally, interorganizational links are established. Characteristics of the three levels are highlighted below:

#### **LEVEL I**

Phone calls or other traditional means of communications are replaced and routing and dispatching are facilitated. Productivity and customer service are improved. Data in simple format are exchanged with shippers (e.g., estimated time of arrival).

#### **LEVEL II**

Vehicle-generated information, such as fuel consumption, drivers’ logs, and data needed by the regulatory authorities, is transmitted to the dispatch center where, it is integrated to the company’s management information system (MIS). Route **planning** is optimized automatically, loads and drivers are assigned to trucks, trailers are assigned to tractors, maintenance activities are scheduled based on actual usage of tractors and trailers, and pricing reflects costs.

#### **LEVEL III**

Carriers use their communications systems to exchange various kinds of data with shippers, terminals, or intermodal transfer points. The data are more than routine information as in Levels I and II, consisting of description of the consignment, bills of lading, freight payment data, and so on. Use of electronic data interchange (**EDI**) is necessary. Shippers and carriers either operate their own **EDIs** or make use of the services and networks provided by third parties. The information received at each end is used by the receiving company’s **MIS**. In more sophisticated systems, carriers would position themselves between sellers and buyers of goods (e.g. suppliers and manufacturers or producers and

retailers). The details of the consignment would be known from the time the order was accepted by the seller.

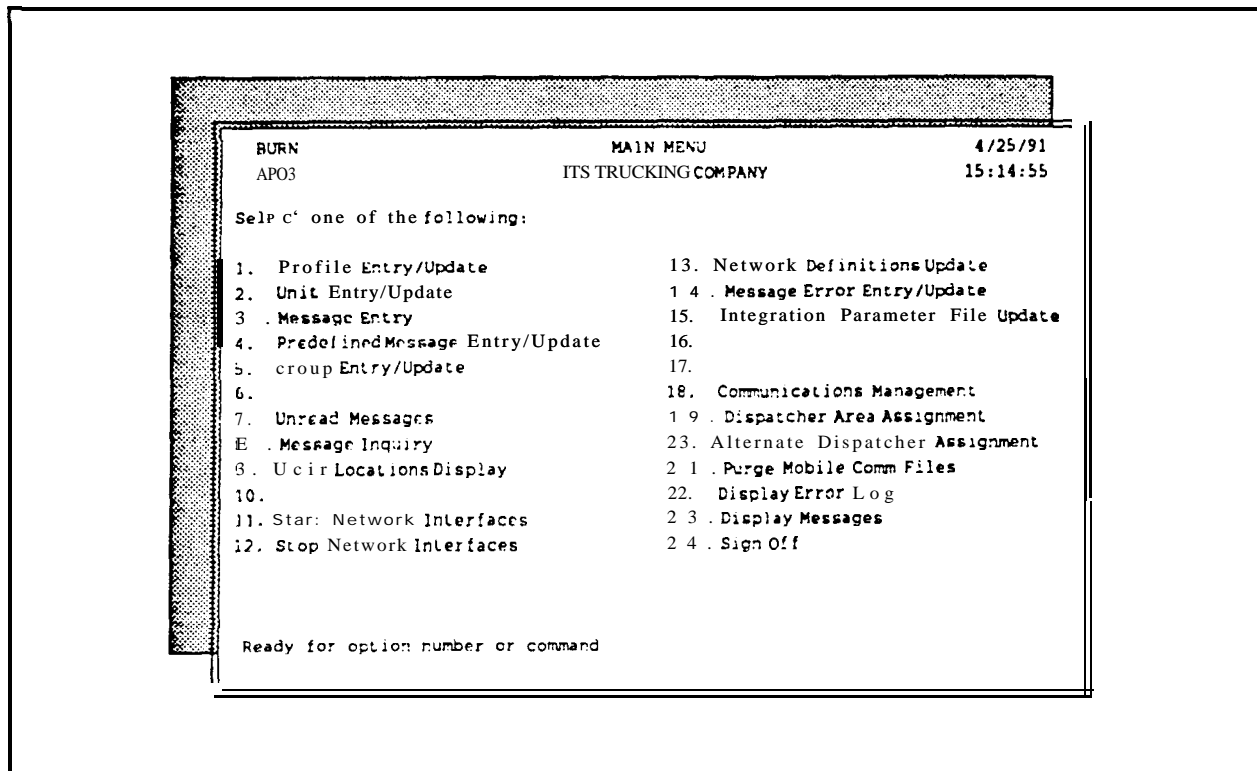


Figure 12 : Screen from a Level I computer program [43].

Many firms have achieved level I integration and many more will probably achieve it in the near future (a sample screen from a level I computer program is shown in Figure 12). Fewer firms have reached level II integration and these only to some extent. The main reason for this is the lack of software or hardware interfaces between the different aspects of the organization. The technology suppliers, however, are working on this problem.

Even fewer firms have achieved integration at level III which requires extensive use of EDI and MIS systems. There are about 9,400 EDI users in all industry sectors in the U.S. [44], and the number of EDI applications is growing at a rate of 30% to 40% a year [45]. More common are individual or exclusive systems linking carriers or groups of carriers with their customers. Recently, systems using

desktop PC's have begun to appear so that the use of expensive commercial EDI networks are able to be avoided (e.g., the Freight Network in the U.K. [46]).

An often mentioned, one concern about EDI is the security of the electronic documents being transmitted. Currently, there are two rival approaches, one sponsored by U.S. Government agencies and the second by the computer industry. Both involve giving documents an electronic signature which can be read by sender and recipient but not altered by either. After this issue has been resolved, the remaining barriers to more EDI penetration will be more legal than technological (e.g., Will an electronic document be legally binding the way a written document is now?).

Companies in other industries have considerable experience with interorganizational information systems (e.g., automobile manufacturers and their suppliers). In the transportation sector perhaps the most ubiquitous example is the airline reservations systems, which links carriers and their customers. Regulation by government or trade organizations may be necessary in wide scale systems to ensure fairness (recall that airline operators of computer reservation systems have repeatedly been accused of screen bias).

This discussion is not addressed primarily to trucking operators. However it does suggest steps to be followed toward achieving increased integration. First, it is desirable to look beyond the substitution of one communication-information technology for another for the presence of a new technology may offer new opportunities. Second, a systematic procedure should be established to seek opportunities for internal and external integration. It should be recognized that increased integration will require changes in organization and employee roles, and these changes need to be considered.

Third, the size of firm and/or multinational operations should not be a barrier to change. To make technological capabilities available, firms may pool resources and create joint systems. It was for just that reason that containership lines recently established the Ediship system providing a data access point [47]. This is a recent example of a long maritime tradition. Just after 1900 and in the early days of radio, international maritime conferences and agreements established working interfirm and international communications protocols. These included standards and provided for data exchange among firms. As mentioned, similar trucking industry activities are under exploration in Europe.

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## 7.2 THE AUTO-TRUCK HIGHWAY SYSTEM

The discussion now turns to the highway system. That this system is mature is evidenced by declining productivity (a general characteristic of mature systems [48]). Proposed solutions to the productivity problem include a new round of infrastructure investment (e.g., improved highways and bridges), better management of existing facilities (e.g., exclusive lanes for high occupancy vehicles, an emphasis on bus mass transit), relaxation of regulations (e.g., longer and heavier trucks), and the application of advanced technologies (especially electronics). Within this context, are there ways for the auto-truck highway system to benefit from the technology adoption by of motor carriers?

We begin the discussion with the observation that the internal efficiencies trucking firms achieve by adopting advanced positioning and communications systems might benefit the highway system in the short term: For example, an accident or equipment breakdown would be communicated immediately and thus cleared quickly. Furthermore, better maintenance would reduce vehicle breakdowns, more efficient scheduling would reduce the number of trucks on the road, and information on roadway geometric characteristics would improve safety. A reduction in truck-related congestion seems possible on certain heavily travelled routes as dispatchers provide congestion information to drivers.

The point was made previously that information technology is not mute, i.e., the devices that automate also register data about the automated activities. Might some of these data be useful to highway managers? The answer seems to be yes, but traditionally not much sharing of information has taken place at the interface between highway and truck operations. A motive is lacking. Truckers are motivated to increase the productivity and profitability of the firm. Highway managers are motivated to improve traffic flow and the need to protect the physical plant from overweight trucks. The interface of broader, mutual interests needs to be identified and exploited.

Differences between carriers' and shippers' interests were resolved when it was demonstrated that mutual gains would be achieved from the sharing of information. By comparison in the highway-truck case, actions of common interest with short term pay-offs need to be identified. For example, the network information accumulated at a highway traffic control center might be made available to dispatchers. In turn, dispatchers might provide traffic control centers with information on expected traffic generation, say, close to ports or rail/truck hubs.

## Positioning and Communications

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There is the Crescent-HELP project and similar efforts. These are viewed as useful, despite their omission in the discussion above. The activities provide traditional types of information to highway managers, such as vehicle class and weight, and automate some processes to the advantage of the trucking industry, such as information processing at points of entry to states. This information automates traditional processes. In the background is the possibility of information for implementing weight distance taxes, suggestive of a higher level of integration.

It has been observed that technology decisions in transportation are characterized by a certain degree of disjointedness, that is, in other words, a lack of system-wide thinking and action taking. Current technology activities illustrate this point for the highway system. Vendors have already developed a variety of communications and position-finding devices for trucks and in a few years a large number of commercial vehicles will be equipped with them. These vehicles will be dispatched using sophisticated, near real-time, routing algorithms. At the same time, highway agency research is underway to develop advanced technologies to manage congestion, help drivers find their routes, and improve safety. Commercial vehicle operators might be expected to form a core market for the latter technologies, and the technologies under development for the trucking industry might be usefully applied by highway agencies. Even so, the interfacing of truck and highway technologies is not much considered.

The danger exists that the two technology development efforts will not yield harmonious technologies. Trucking firms having made earlier commitments to other systems may resist new, different ones. The existence of a commercial vehicle operations group within IVHS research organizations would not guarantee that suboptimization will not occur. In addition to HELP project related activities, trucking activities in IVHS fall into two categories: they either deal with truck-related regulation (e.g., weight enforcement) or define the truck-specific parameters to be used in other IVHS projects (e.g., the database supporting traffic routing algorithms must include information on lane widths, bridge clearances, community ordinances restricting truck traffic, or truckstops).

This situation could well be changed. Technology and other standards have not yet been set, and researchers have a unique opportunity to influence the technology development path. Technologies that might serve both highway and trucking interests are not blocked by previous commitments to development paths.

Commercial vehicle operations are an integral part of DRIVE and other European programs, as discussed earlier. Does the European work suggest tasks for IVHS activities in the U.S.? Compared to

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the U.S., the European approach is **top-down**, and the approach is directed by the Commission of the European Communities at Brussels. That is understandable, for there are nation-to-nation differences in communications protocols, regulation, and other broad environmental factors bearing on the trucking industry. Also, there is relatively more regulation of the transportation industries and more of a tradition for central planning in Europe than in the U.S.. The necessity to consider trucking matters has involved IVHS programs in trucking subjects but the level of involvement is much greater in Europe than in the U.S.

Is there a case for a centralized IVHS-trucking activity in the U.S.? The argument for centralized is this: Many of the systems require large capital investments for implementation, and large capital investments would only be warranted if there were many users. If several systems divide the market, there is the risk that capital for the full deployment of systems will not be forthcoming. Even if systems are deployed, service may be more costly than would have been the case if a single system had been deployed. Therefore, centralized investigations and consensus are needed to determine the most suitable technology, operating, and pricing protocols. That technology should be selected for implementation and supporting standards set and/or policy decisions taken.

The present study was not oriented to the issue of centralization, of course, but we have one observation that bears on centralization. European professionals commented to these researchers along these lines. "The Americans are trying things out to see what works and what the market is. Europeans are trying to figure out what to do without the benefit of hard experience." Perhaps the message is that a good mixture of long term system thinking and hard experience ought to go hand in hand.

This paper will end with a discussion of the broader implications of information technologies. In our view the impacts of these technologies are not restricted to providing operational improvements for the transportation modes and facilities. In the trucking industry the challenge was and is to recognize the complementary capacities of information technologies--that they not only automate but informate a process, making it visible to all and setting the stage for innovations. What might this mean for transportation systems? We attempt to answer this question in the following paragraphs.

Information technologies are supporting the automation of highway traffic monitoring and control: traffic signals are adjusted to demand, tolls are collected electronically, motorists are given route diversion information, and possible over weight vehicles are identified while they are travelling at speed. In their informing capacity on the other hand, the technologies may generate a wealth of data such as

the mix of vehicles on a freeway; origin and destination patterns of daily commuters; the number of trucks entering a port at a time of day; road capacity and design compared to mix of traffic; facilities used at capacity and for how long; facilities never used at capacity; traffic generating patterns of suppliers to JIT manufacturers; extent of damage caused to pavements by vehicles; and so on. Trends may be deduced from 'the data. However useful automation might be, the challenge is to match modal services to dynamic system requirements which must be identified and continuously updated. This effort may be assisted in part by the data provided by the information technologies.

In the motor carrier industry vehicle tracking data are proving to be most effective when integrated with shippers' and receivers' information systems. This occurred when, following market signals, traditional ways of thinking were put aside. An equivalent change in traditional assumptions is needed in highway transportation in order to benefit from the informing capabilities of the new technologies. Only such a change would create an environment for innovation.

How can such an environment be created? The history of transportation shows that most improvements have been incremental, and small changes year-to-year have been the rule [49]. But on occasion innovations are adopted that induce rapid system change. Examples of such innovations include jet aircraft, the diesel locomotive, and interstate highway designs. Although such innovations induced rapid improvements in services, they still have an incremental character, for they fit the context of the system. As history indicates, the need for incrementalism constrains but does not necessarily prevent rapid progress. Rapid progress simply requires technologies that make a marked difference in services. Such technologies must be consistent with market trends and, more broadly, consistent with underlying socioeconomic trends.

These conditions are in mind when making the following two simple suggestions. The suggestions are examples that are consistent with recent trends. They are given to illustrate how developments in communications and the trucking industry might have implications for IVHS programs.

There is interest in personal communications systems. If the expectations of the proponents of these systems are realized, everyone might have their own personal number where they could be reached. The resulting network of radio towers might be a more efficient means to transmit information to motorists than the roadside beacons envisioned by IVHS.

The increasing reliance of manufacturers on just-in-time deliveries and the decentralization of production localities might lead to a need for fast and well-coordinated small scale flows of commodities.

New truck **traffic** might be generated close to factory plants. This extremely time-sensitive traffic may stress the highway network designed as a compromise between passenger and commercial vehicles (reports from Tokyo refer to extensive traffic congestion caused by trucks supplying just-in-time industrial plants in the vicinity of the city). This trend might speed the development of exclusive truck facilities around industrial locations, rail/truck hubs, or ports. These facilities might be an excellent market niche in which to test some of the emerging **IVHS** technologies, perhaps adjusted to the needs of a truck-only highway.

Again, the examples were give to illustrate how communications and trucking industry developments might have implications for IVHS programs. Of course, the experiences of motor carriers with advanced communications and positioning technologies are not extensive, and the full impacts of technology adoption are only beginning to emerge. Consequently, the discussion of interfaces for IVHS programs required considerable stretching and interpretation. Interpretations are, at best, preliminary. Even so, because the technologies are emerging, it is highly desirable to note some priority research topics that might affect the directions of their development.

First, it was noted that trucking technologies and IVHS technologies are being developed independently. Inquiry into identifying pay-offs for both IVHS and truckers might suggest technologies of joint interest well beyond those identified in the HELP study and other IVHS work.

Second, the integration-informing experiences of trucking organizations might be monitored and interpreted in light of downstream IVHS opportunities. Similar experiences should be considered for all highway users.

Third, and as this report has indicated, most information about emerging technologies bears on their technical performance characteristics and costs. Some information is available on benefits from technology adoption and use. It would seem desirable to expand the benefit information and, to the extent practicable, strive for information on benefits at systems levels.



**8 CLOSURE**

This discussion began with a description of the positioning and communications systems available to and being adopted used by commercial vehicle operators. The trucking industry is diverse and so are its needs. Fleets in local operations appear to need relatively more communications and less positioning than other fleets. In contrast, fleets in long haul operations (those travelling more than 200 miles away from their base) need both communications and positioning. Currently, voice radio and telephone are by far the predominant technologies. Data communications in short haul operations are used by few carriers, mainly large ones. Several fleets serving the long haul irregular route market have purchased satellite communications equipment. Their experiences have been positive but many carriers are asking that the technology suppliers increase work to integrate information from vehicles with all facets of fleet operations and industry services.

With respect to impacts on the trucking industry, three levels of information integration were identified, from the automation of the dispatching operations to the creation of interdepartmental and then interorganizational links.

This paper concluded with some considerations for highway operations managers and policy makers. The issue for highway operations managers is higher levels of information sharing at the interface between highway and truck operations. Actions of common interest beyond those already identified in the HELP program need to be identified and tested. The IVHS research community may find many ways to benefit from the experiences of fleet operators.

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## APPENDIX

### TOWARD-IVHS ORIENTED MONITORING OF THE TRUCKING INDUSTRY'S ADOPTION AND USE OF POSITION AND COMMUNICATION SYSTEMS

The convergence of the trucking industry's adoption of new technologies to improve services and productivity with IVHS efforts was discussed in the body of this report. The HELP project represents partial convergence of interests, but possibilities for the convergence of interests may be much greater than the interests the HELP program is identifying. Patterns of technology adoption and use by trucking firms are beginning to emerge, and steps to explore the possible convergence of trucking and IVHS interests appear timely.

A first step might be the continued monitoring of the activities of trucking forms, and a review of the survey undertaken in the research reported here may assist in clarifying the problems to be solved if the development of a monitoring system is undertaken.

Detailed inventories are available of domestic ships, rail locomotives and cars, and aircraft. Regulatory agencies maintain extensive data systems on firms and their activities, and agency data are published by industry associations and/or in trade journals. For instance, the Association of American Railways publishes ICC data on **firms**, and **Aviation Week and Space** Technology publishes data on airline equipment and firm profitability.

Such extensive and accessible information is not as available on trucks and the trucking industry. The American Trucking Associations (**ATA**) publishes ICC data on the finance and operations characteristics of firms for many of the approximately 40,000 firms regulated by the ICC in its **Motor Vehicle Carrier Annual Report**. However, there are between 100,000 and 150,000 owner operators, about 45,000 private motor carriers, and other operators as well. All trucks used on highways pay registration and weight fees, and truck registrations by state are reported in the **FHWA's** annual **Highway Statistics**. Truck inventory and use studies (cited earlier as Reference 4) provide census-type data on the population of trucks and their major use categories. For example, it reports that the 4.7 million trucks in California in 1987 undertook 62.5 billion VMT.

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Although valuable, these and other sources of information are much less rich than sources of information on other modes. Coverage is the main problem as not much data are available cutting across all activities. Investigations using samples may be used to obtain richer data, but there is the problem of drawing samples representative of appropriate populations. For instance, one can sample from ICC regulated **firms**, but that might not be the pertinent population for the subject under investigation.

A second problem is targeting appropriate units of observation, and the appropriate unit of observation changes depending on the question. The development of the technology and its marketing is undertaken by original equipment firms and third party vendors. Decisions about the adoption and use of technologies are made by trucking **firms**. The behavior of trucks equipped with communications technologies may be important for some IVHS purposes. These statements illustrate that the appropriate unit of observation varies, for example, technology suppliers need to be observed to monitor technology availability and trucks observed to monitor highway use attributes. This issue of the appropriate unit of observation is complicated by the lack of data fully descriptive of populations of firms and vehicles. For different purposes, different units of observation are needed and data descriptive of populations are limited.

Finally, the industry is quite heterogeneous. The **ATAs' Report**, for example, identifies about 40 types of carriers, from bulk tanks to local household goods carriers. In many cases, one would not expect different types of carriers to respond in the same way to a technological option.

Too much should not be made of these aspects of data availability and related problems, for there are difficulties in any data gathering situation. The researchers were aware of the situation at the initiation of the research, and the survey undertaken was viewed both as an attempt to develop information and illuminate the problems of obtaining information.

Turning to the survey activities in this research, the first survey step involved telephone interviews with equipment suppliers and trucking firms and visits to interview industry informants. These efforts were not very successful, especially telephoning. It was necessary to make many call backs, appropriate informants were difficult to reach, and there was a tendency for the information from informants to be non comparable from firm to firm. At best, a considerable effort was yielding interesting information that could not be treated in a systematic way. There was also the issue of the extent that firms contacted were representative of the populations of interest. Interested in decisions about technology adoption and use, firms known to be interested in new technology were first contacted, and

this led to identification of similar firms. To obtain balanced information, some firms known not to be active in technology adoption were contacted (a control group). But it was soon found that most non-adopters had not considered adoption in a systematic way; a few had decisions on hold waiting to see the experiences of others.

Telephone interviewing is a well established information gathering method, and it may well be useful if a monitoring system is developed. The experience of these researchers pretty much says something obvious: telephone sampling will require a good bit of preliminary design and, especially, a high level of understanding of the populations and the behavior being sampled. Also, it might require the establishment of a panel through personal contacts in order to assure useful responses to telephone calls.

As the work was going along the researchers contacted the American Trucking Associations for information and suggestions. Dr. Russell Capelle, Jr., of the Research and Statistics Division of the Associations provided data on the ICC regulated carriers, as well as providing information from his files on the technologies available to truckers. Mr. David Willis of the Associations' Research Foundation provided information on research he had accomplished, and suggested that the Foundation join us and execute a mail survey of firms. However, after some joint work on the questions to be asked, the Foundation decided not to participate in the survey. (The questionnaire used is attached to this Appendix.)

A commercial firm that maintains statistics on and a mailing list of trucking firms was contacted and asked to provide a sample of firms as described in the text of this report. The firm, Transportation Technical Services, Inc., of Fredericksburg, VA and New York, maintains the National Motor Carrier Data Base containing 30,055 records on firms that report to the ICC. The last update of the data base was November 15, 1990. Using the data base mailing list, 1,000 questionnaires were mailed. Usable returns of 253 questionnaires were received. Interestingly, about 5 percent of the mailing was returned by the post office as not deliverable. This may be a comment on the quality of the data base and/or the economic problems and turn over of firms in the industry. Fourteen firms stated that they would like to have a copy of the results of the survey.

Data were extracted from the returned questionnaires and preliminary analyses made. Because the survey was intended to provide quantitative information to support the results of the literature and interview work, final analyses were restricted to topics covered in the body of this report. The



researchers view the survey as useful, but do not think of it as definitive in any way. One problem is uncertainty about the relevance of population sampled. Although it certainly included the large firms in the U.S., the Motor Carrier Data Base contains only about three-fourths of the firms that report to the ICC, and, as stated, not all firms report to the ICC. Statistical tests for significance were run on some of the data to assure the validity of impressions given by the data included in the text of the report. Statistical tests indicate that the cellular and pager systems are being adopted at a greater rate than voice radio and ordinary telephones, and there is not much difference between the latter.

Perhaps a good way to describe our view of the survey is to say that it was a reconnaissance of some industry activity, with findings reported that complimented information from other sources. The approach used in our work is similar to the approach used by some researchers who work on trucking topics and thus it has general acceptance. For example, Paul R. Murphy, J. E. Smith and J. M. Daley's "Ethical Behavior of U. S. General Freight Carriers: An Empirical Assessment" (in **The Logistics and Transportation Review**, 27, March 1991) drew its sample from the same data base we used, and then analyzed the sample results using discriminant functions and t-tests. The difference is only that our discussion of findings did not extend to reports of tests of significance.

This Appendix will close with comments that might be useful if further investigations are undertaken.

The first question is what to look for, what is the goal of the work? To paint the situation, topics mentioned in the text of the report will be mentioned again in a terse fashion.

1. Suppliers are offering "1,001 technological delights" to the trucking industry. Some of these are on the drawing board or just entering market niches.
2. Firms are selecting from these, as well as new versions of older technologies, in order to improve productivity and services.
3. Not much attention is being paid to these developments by IVHS programs.
4. Still, there is the possibility of considerable mutual interest between trucking and IVHS goals.

5. What the truckers do may or may not support these mutual interests. IVHS work may or may not support mutual interests.
  
6. So the goal is to understand position and communication technology trends in trucking from the point of view of IVHS interests.

What makes matters difficult is this: It is very difficult to monitor and interpret changes by only a few firms in a large pool of firms. There is the option of waiting until a trend(s) is well established, at which time monitoring would be easy. But it may be costly to wait because predominant technologies may emerge that do not take advantage of the possible mutual interests of IVHS programs and the trucking industry.

If the decision is made not to wait, here are some options for attempting to monitor the current and emerging situation:

Surveys of the type undertaken in the current study could be repeated. Because at this time there are small numbers of new technology adopters, large samples should be taken. Also, because different types of carriers may have different technology adoption and use patterns, samples should be subdivided by type of carrier. The disadvantages are the large samples required and the difficulty of sampling from carriers not reporting to the ICC.

Instead of attempting to sample firms, it might be possible to piggy-back questions onto on-going surveys of drivers. A study published recently illustrates the use of information obtained by contacting drivers at rest stops and state points of entry (Federal Railroad and Maritime Administrations, **Double Stack Container Systems: Implications for U.S. Railroads and Ports**, 1990). Questions might be added to efforts to evaluate the HELP program. However, it may be difficult to infer what firms are doing from driver-obtained information. Also, it may be difficult to judge how well the population sampled is representative of the industry.

Consideration of the processes of technological change suggests other options. A good bit is known about the characteristics of innovators and innovative firms and about the diffusion of new technologies. Using this information as well as information available from the industry on the activities of firms, a panel of selected firms might be monitored. Disadvantages are requirements for intensive interviewing and difficulties in generalizing to the population of all firms.

There are some approaches that combine the last suggestion with more **traditional** and formal survey methods. Panels are often used for monitoring purposes, as well as to anticipate decisions when new products are offered. Again, there is the disadvantage of resource intensiveness and uncertainties about what the population of all firms would do.