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Exploration of GPS to Enhance the Safe Transport of Hazardous Materials

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13. ABSTRACT (Maximum 200 words)

This report (1) documents a set of requirements for the performance of location systems that utilize the Global Positioning System (GPS),(2) identifies potential uses of GPS in hazardous materials transport, (3) develops service descriptions for the identified uses, and (4) conducts a detailed benefit/cost analysis of three case applications based on the service descriptions.

The potential uses for GPS and related technologies in hazardous materials transport that were identified were (1) monitoring and tracking hazardous materials shipments, (2) projecting routes for hazardous materials transports, and (3) aiding in the emergency response to hazardous material transport incidents.

While it was found that there are gains to be made by reducing the impacts of hazardous materials incidents, it was noted that the gains to be made through improved fleet management and operations are the driving force behind the adoption and application of GPS and related technologies by industry. Compared to the gains from improved fleet management and operations, hazmat-related gains are expected to be relatively minor.

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PREFACE

This report explores the use of the Global Positioning System (GPS) and related technologies to enhance the safe transport of hazardous materials by truck and rail. Annually in the U.S., thousands of transportation incidents occur that involve the release or threat of release of hazardous materials. New or existing technologies, such as GPS, may be able to play a role in augmenting the safe transport of hazardous materials, or may help expedite more effective response to incidents.

This report was prepared by the Volpe National Transportation Systems Center (Volpe Center), Research and Special Programs Administration (RSPA), U.S. Department of Transportation (U.S. DOT). Dr. James V. Carroll of Volpe's Center for Navigation was the Project Engineer, and Dennis L. Goeddel of Volpe's Operations Assessment Division performed the benefit/cost analyses.

This report was prepared for the Office of Hazardous Materials Safety, RSPA, U.S. DOT.

METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in) = 2.5 centimeters (cm)
1 foot (ft) = 30 centimeters (cm)
1 yard (yd) = 0.9 meter (m)
1 mile (mi) = 1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2) = 6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2) = 0.09 square meter (m^2)
1 square yard (sq yd, yd^2) = 0.8 square meter (m^2)
1 square mile (sq mi, mi^2) = 2.6 square kilometers (km^2)
1 acre = 0.4 hectare (ha) = 4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz) = 28 grams (gm)
1 pound (lb) = .45 kilogram (kg)
1 short ton = 2,000 pounds (lb) = 0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp) = 5 milliliters (ml)
1 tablespoon (tbsp) = 15 milliliters (ml)
1 fluid ounce (fl oz) = 30 milliliters (ml)
1 cup (c) = 0.24 liter (l)
1 pint (pt) = 0.47 liter (l)
1 quart (qt) = 0.96 liter (l)
1 gallon (gal) = 3.8 liters (l)
1 cubic foot (cu ft, ft^3) = 0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3) = 0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

°C=5/9(°F - 32)

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm) = 0.04 inch (in)
1 centimeter (cm) = 0.4 inch (in)
1 meter (m) = 3.3 feet (ft)
1 meter (m) = 1.1 yards (yd)
1 kilometer (km) = 0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2) = 0.16 square inch (sq in, in^2)
1 square meter (m^2) = 1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2) = 0.4 square mile (sq mi, mi^2)
10,000 square meters (m^2) = 1 hectare (ha) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gm) = 0.036 ounce (oz)
1 kilogram (kg) = 2.2 pounds (lb)
1 tonne (t) = 1,000 kilograms (kg) = 1.1 short tons

VOLUME (APPROXIMATE)

1 milliliter (ml) = 0.03 fluid ounce (fl oz)
1 liter (l) = 2.1 pints (pt)
1 liter (l) = 1.06 quarts (qt)
1 liter (l) = 0.26 gallon (gal)
1 cubic meter (m^3) = 36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3) = 1.3 cubic yards (cu yd, yd^3)

TEMPERATURE (EXACT)

°F=9/5(°C) + 32

QUICK INCH-CENTIMETER LENGTH CONVERSION

INCHES	0	1	2	3	4	5

CENTIMETERS	0	1	2	3	4	5	6	7	8	9	10	11	12	13

QUICK FAHRENHEIT-CELSIUS TEMPERATURE CONVERSION

°F	-40°	-22°	-4°	14°	32°	50°	68°	86°	104°	122°	140°	158°	176°	194°	212°
°C	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°

For more exact and or other conversion factors, see NIST Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50. SD Catalog No. C13 10286.

Updated 8/1/96

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EXECUTIVE SUMMARY

PURPOSE. The purpose of this report is to document a set of requirements for the performance of position location and communication systems that utilize the Global Positioning System (GPS)[1], identify potential uses of GPS/DGPS in hazardous materials transport, develop service descriptions for the identified uses, and conduct a detailed benefit/cost analysis of three case applications based on the service descriptions.

BACKGROUND. The transport of hazardous materials is a concern of many citizens, as well as government agencies. It is estimated that more than 500,000 shipments of hazardous materials are made daily using the four major transportation modes (highway, rail, waterway, and air). Estimates made by the National Academy of Sciences[2] suggest that there are about 10,000 to 20,000 truck and 1,000 to 1,500 rail transportation incidents that occur each year that involve the release or threat of a release of hazardous materials. New or existing technologies may be able to play a role in augmenting the safe transport of hazardous materials, or may help expedite more effective response to incidents.

The primary objectives of safety improvements in the transport of hazardous materials are enhanced protection for people, the environment, and property. Other important objectives are to reduce impedances to the smooth flow of commerce and travel, and to develop additional safety capabilities. GPS/DGPS and related technologies (satellite communications and fleet tracking/management systems) have the potential to help achieve these objectives.

STUDY RESULTS. Service Descriptions. The analysis detailed in this report led to the description and benefit/cost analysis of the following three potential service applications using GPS/DGPS and related technologies:

- Monitoring and tracking hazardous material shipments.
- Projecting routes for hazardous materials transport.
- Aiding in the emergency response to hazardous material transport incidents.

Costs and Benefits. For the cost/benefit analysis, three case applications (two highway and one rail) involving the transport of hazardous materials were considered. In each of the case applications, the costs and benefits of GPS and its supporting technologies were analyzed.

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1 GPS is a satellite-based navigation aid whose transmitted signals are available to civilian and military users nearly anywhere on earth. GPS and a related system, differential GPS (DGPS), represent a technology which may benefit greatly the response to a hazardous materials incident, or the shipment of these materials. More complete descriptions of GPS and DGPS can be found in references [1] and [2].

2 [NAS] Transportation Research Board, *Hazardous Materials Shipment Information for Emergency Response*, Special Report 239, National Academy Press, 1993.

The primary system costs identified with the application of GPS and related technologies to track and monitor hazardous materials movements included costs for in-vehicle fleet equipment and fleet communications, and for fleet dispatch center equipment and fleet management operations.

The analysis also identified a range of system benefits associated with the application of GPS and related technologies. The primary areas where benefits would accrue include:

- Reduced costs associated with responding to hazmat incidents.
- Reduced hazmat incident-related injuries.
- Reduced hazmat incident-related fatalities.
- Reduced hazmat incident-related property damage.
- Reduced hazmat incident-related evacuations.
- Improved fleet management and operations of trucking/rail carriers.

Table ES.1 and Figure ES.1 present a comparative summary of the overall benefits and costs of the case applications considered in this analysis.

While there are gains to be made by reducing the impacts of hazardous materials incidents, it should be emphasized that the gains to be made through improved fleet management and operations are the driving force behind the adoption and application of GPS and related technologies by industry. As can be seen in Table ES.1, compared to the gains from improved fleet management and operations, hazmat-related gains are expected to be relatively minor.

FINDINGS. The principal findings of this study were:

- **Recent Growth of GPS and Satellite-Based Installation.** GPS and satellite-based vehicle tracking and communications system installations have grown significantly over the past decade, especially within the trucking industry. These installed systems can be used to support hazmat applications and benefits.
- **Costs.** The application of GPS and satellite based tracking/communications and fleet management systems within the rail and trucking industries require significant cost outlays for fleet equipment and fleet communications. System capital costs for in-vehicle equipment and recurring costs for fleet communications dominate the overall costs of these system applications.
- **Total System Benefits.** Current applications of these systems, especially within the trucking industry, appear to produce benefits to carriers in areas of improved operations, reduced operating costs, improved fleet utilization, and improved safety monitoring (e.g., verification of compliance with federal hours-of-service regulations). Savings in carrier transport costs, ranging from 0%-2%, were assumed for the case applications considered in this analysis.

To break even, rail and trucking carriers would only need operating efficiencies that would reduce carrier transport costs by 0.5%-1.0% to recover the capital and recurring costs of the application of these technologies over a twenty-year period.

- **Hazmat Benefits.** The application of GPS and satellite-based tracking/communications and fleet management systems within the rail and trucking industries can provide benefits in the form of reduced impacts from hazmat incidents. Primary among these are benefits derived from savings in hazmat incident emergency response costs and reduced impacts of hazmat incident-related injuries, fatalities, property damages, and site evacuations. For the rail and trucking applications considered, the benefits derived from reduced impacts associated with hazmat incidents ranged from $32.0 million to $63.0 million (discounted, 1995 dollars) over a twenty-year analysis period.

- **Benefit-Cost Ratios--Hazmat.** All case applications considered have positive ratios of total benefits to total costs. The benefits derived from reduced impacts associated with hazmat incidents alone are substantially less than overall system costs. Each case application requires savings in fleet operations to recover the costs of the application of GPS and satellite-based tracking/communications and fleet management systems.

Table ES.1 Comparative Summary of Benefits and Costs

	Case # 1 Large Rail Application	Case # 2 Large Trucking Application	Case # 3 Medium Trucking Application
	Millions of discounted 1995 dollars (for the period 1995-2014)		
System Costs			
Capital Costs	$136.1	$438.5	$93.4
Operating Costs	$232.6	$893.0	$280.7
Total System Costs	$368.7	$1,331.5	$374.1
System Benefits			
Reduced Impacts from Hazmat Incidents	$32.0	$63.0	$37.8
Improved Operations of Hazmat Carrier	$1,273.5	$2,677.0	$572.5
Total System Benefits	$1,305.5	$2,740.0	$610.3
Benefit/Cost Ratio	3.54	2.06	1.63

- **Benefit-Cost Ratios--Total System.** The rail application provides the highest level of system benefits to total system costs. Both trucking case applications have positive ratios of benefits to costs. Because there are significantly more large- and medium-sized trucking firms than there are Class 1 railroads, the trucking applications have significantly lower costs per carrier than the rail application does.

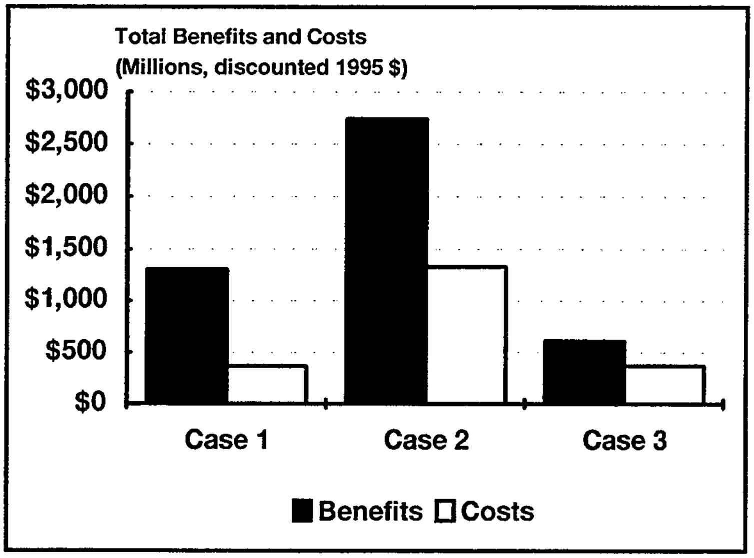

Figure ES.1 Comparative Summary of Benefits and Costs

RAPIDLY CHANGING TECHNOLOGIES. The technologies discussed in this report have made impressive strides in recent years. Furthermore, the trucking industry, a major focus of the report, has continued its installation of commercially available satellite-tracking systems. As a consequence of improving technologies and their expanding use by industry, some of the material in this report has been superseded or rendered moot by recent developments, or will be in the near future. Nevertheless, this report continues to be both timely and relevant. This report can be of considerable help to those in the transportation industry who (1) are interested in the technologies to better understand them and their potential uses, (2) are considering adopting the technologies to better understand their options, and (3) have adopted the technologies to better understand how those technologies can be of use in helping to ensure safe transport of hazardous materials.

CONCLUSION. The U.S. Department of Transportation has no plans to require or recommend the deployment of GPS/DGPS or related technologies by the transporters of hazardous materials because projected safety benefits alone are too small to justify such a requirement or recommendation. In many instances, information and operating efficiency gains are enough to prompt carriers to invest in these technologies, and it is expected that industry will expand their use as long as investment benefits exceed costs of deployment.

1. INTRODUCTION

The transport of hazardous materials is a concern of all citizens and agencies. It is estimated that over 500,000 shipments of hazardous materials are made daily using the four major transportation modes (highway, rail, waterway, and air). Some estimates suggest that there are about 10,000 to 20,000 truck and between 1,000 and 1,500 rail transportation incidents that occur each year which involve the release or threat of a release of hazardous materials.

Most of these incidents involve small releases of hazardous materials, result in little or no consequence, and do not require an emergency response action. Following a recent analysis by DOT, of the 12,815 incidents reported to DOT during 1993, 402, or about three percent of the total, could be considered to have a consequence serious enough to warrant a significant emergency response ([3]; see also Footnote 2 in the Executive Summary.). These incidents involved one or more of the following consequences: a fatality, major injury, general public evacuation, closure of a major artery, train derailment, or truck accident (overturn, collision, etc.).

Hazardous materials have the potential for great loss of life and property, as well as significant and long term environmental damage, if improperly or carelessly transported. Federal regulations governing the transport of hazardous materials now include the determination of permissible routes, evacuation plans for areas sufficiently near these routes, and notification of appropriate agencies for protection and escort of vehicles transporting selected classes of materials. It is expected that continuous monitoring, tracking, and even guidance will be required in the near future.

The Department of Transportation (DOT) has a natural interest in providing both the physical and regulatory infrastructure to ensure the safe and economic transport of hazardous materials. One of the ways this interest manifests itself lies in analyzing the potential incorporation of new technologies that may augment the safety of transporting these materials, or that may expedite effective response to incidents.

1.1 PURPOSE OF DOCUMENT

The purpose of this report is to document a set of requirements for the performance of location systems that utilize the Global Positioning System (GPS), identify potential uses of GPS/DGPS in hazardous materials transport, develop service descriptions for the identified uses, and conduct a detailed benefit/cost analysis of three case applications based on the service descriptions.

1.2 APPROACH

The approach involved performing the following project tasks:

1. Define GPS and DGPS Hazardous Materials Transportation Requirements.
2. Provide an Array of Current and Potential Civilian Uses of GPS and DGPS and Identify Potential Applications in the Field of Hazardous Materials Transportation.

3. Develop Service Descriptions for the Three Potential Applications Ranked Highest and Discuss IVHS (ITS[3]) Interfaces Where Applicable.
4. Conduct Cost Benefit Analyses of the Potential Applications

The results of each of these tasks are presented in Chapters 2 through 5 of this report.

[3] Since project initiation, the Intelligent Vehicle Highway System program has been renamed to Intelligent Transport Systems (ITS).

2. GPS HAZMAT TRACKING - SYSTEM REQUIREMENTS

2.1 DEVELOPMENT OF REQUIREMENTS

Requirements are defined as necessary attributes for a system prior to efforts to develop a design for it [4]. Requirements are developed by following a procedure similar to the following:

1. Collect available information on user needs. This information usually is found in published reports, presentations, and conversations with key people in government and industry.
2. Verify and validate the requirements. This also can be accomplished by more detailed interaction with key resources, in the form of phone conversations, sending out questionnaires, etc.
3. Update and revise the requirements as needed, based on the validation effort.

The methodology for quantifying requirements can follow two paths [5]:

- Risk Analysis (probabilistic)
- Worst Case Analysis

Risk analysis or risk assessment involves estimating frequencies and consequences of undesirable events, then evaluating the associated risk in quantitative terms. This is of necessity a probabilistic method, which means the risk probability values have uncertainties associated with them. Worst case analysis involves setting parameter values (e.g., speed) which are determined to be safe for all known situations involving the particular mode of travel, cargo, etc. Worst case analysis is very conservative, and despite this, may overlook some cases. Implementation for an effective system usually is more expensive.

Requirements for any system such as GPS are driven by user needs. When responding to a hazardous materials incident, accurate location of the incident is part of the overall need for information about the incident. Information needs are driven in this case by the decisions to be made regarding: location, determining whether or not hazardous materials are present, general type of hazard, protective equipment needed, specific identities of hazardous materials, and information about the surroundings.

The major need regarding *response to a hazardous materials incident* that can be addressed by (D)GPS is to reduce the response time. This can be accomplished by many factors, for example, by strategic placement of properly trained and equipped response teams, but sufficiently precise knowledge of the incident location is critical. This is especially true when poor weather or traffic congestion add to the uncertainty.

Tracking vehicles that *transport* hazardous materials is now economically feasible because of the full coverage provided by GPS. In contrast to hazardous materials incident response situations, the major transport need addressable by GPS/DGPS is for accurate location of the vehicle. This need addresses many issues such as continual knowledge of the carrier location, efficient shipping operation, and scheduling, but it also addresses safe transport of hazardous materials, thereby playing an indirect but important role in avoiding an incident.

The specific requirements for a GPS or DGPS system used in hazardous materials transport depend on the needs of particular users. Different categories of hazmat transport will, in general, have different sets of requirements. In addition, even where requirements sets are very similar, the priorities within each set may be very different for different categories. These requirements can be categorized into several classes, each of which has different specific requirements. The major classifications are as follows (see Table 2.1):

Table 2.1 Requirements Categories

I. Nature of the Location Function
- a.) Planning and tracking hazardous material shipments
- b.) Response to a hazardous materials incident
  - (i) First response
  - (ii) Follow-up responses

II. Transportation Modes
- a.) Highway
- b.) Rail
- c.) Waterway and Harbor
- d.) Air

III. Population, Traffic Density
- a.) Rural
- b.) Urban/suburban

IV. Radioactivity
- a.) Not radioactive
- b.) Radioactive

2.2 GPS HAZARDOUS MATERIALS TRANSPORTATION REQUIREMENTS

In the results that follow, values for the various requirements are presented in a series of tables. The tables were constructed to cover each of the Requirements Categories II, III, and IV in Table 2.1. Wherever the distinction is meaningful, the Requirements Category I elements are presented *within* a table.

2.2.1 Primary Requirements

The user needs identified in Chapter 3 drive the following requirements for a navigation or location system:

accuracy
integrity (time to alarm)
coverage area
data (sampling)

These primary requirements, in turn, drive secondary requirements including reliability, cost, power, size, weight and ease of use. Definitions for the primary requirements may be found in the Federal Radionavigation Plan [6]. Numerical values are sought for the primary requirements in each of the Requirements Categories listed in Table 2.1.

2.2.2 Secondary Requirements

Secondary requirements are defined in this document as those that pertain to a particular system or situation or are derived from the primary requirements. Secondary requirements for (D)GPS systems used in the transport of hazardous materials include:

cost	weather
power	time of day
size	season
weight	water level (e.g., tide)
ease of use	terrain
environmental factors	condition of road, railway, etc.
reliability	population factors, location

It can be seen that not all of the secondary requirements apply to every category in Table 2.1. For example, level of the tide does not usually influence response procedures for a highway incident.

2.2.3 Requirements Factors

The following paragraphs discuss factors that are relevant to quantifying the requirements. In all cases, potential benefits of using DGPS as opposed to GPS were considered. Although its location accuracy is from ten to a hundred times better than GPS, the extra cost and complexity of DGPS usually does not justify its use. Further details on the comparison of GPS and DGPS are discussed later.

Requirements Factors - Land Use (Categories IIa and IIb). The civil use of GPS and DGPS has experienced the greatest growth in land uses. In this report, land uses include the highway and rail modes. Land uses also include mapping and surveying as well as vehicle location and tracking. Although mapping and surveying appear to be unlikely factors in the transport of hazardous materials (hazmat), precisely surveyed and calibrated accident locations can be entered into a database for later analysis and prevention planning. A relatively new analysis tool, called Geographic Information System (GIS), exploits the technology advances in data processing, graphics, and databases. A GIS may be thought of as a spatially-referenced database, and is an ideal medium for maintaining accident location inventories. GIS is commonly used for selecting routes for hazmat transport that satisfy a particular criteria, such as selecting the shortest or quickest route for which no residence is within a specified distance from the road.

Other uses for GPS in this application include: tracking hazmat carriers; monitoring hazardous material containers; automated dispatch of fire, police, or paramedics; and transit system emergency response. The railroads have established their own tracking systems, and there is no comprehensive mandate to utilize GPS. However, at least two railroads, Burlington Northern and Union Pacific, have installed GPS-based tracking systems. Their particular needs include distinguishing among the parallel tracks a train might use, which would require a DGPS capability. The rail mode includes rail transit systems.

Requirements Factors - Waterway and Harbor Use (Category IIc). The U.S. Coast Guard (USCG) is responsible for the regulation of maritime traffic in U.S. waterways. They have initiated a major program, Vessel Traffic Services, which will upgrade the communication, surveillance, and tracking functions in the ports and waterways. The USCG states emphatically that incorporating DGPS will significantly improve waterway and harbor safety; further, that the safety benefits derived from using DGPS are substantial, and that satellite navigation capability soon will be required on certain classes of vessels. A comprehensive communication system, the Electronic Chart Display and Information System (ECDIS) is being designed for the Vessel Traffic Centers. This system will have the capacity to handle the added surveillance and information requirements imposed by VTS. The integration of DGPS and ECDIS is expected to provide emergency response units with more accurate information for responding to, tracking, and containing hazardous materials or oil spills.

Requirements Factors - Air Use (Category IId). Satellite navigation, in particular GPS navigation, has possibly represented the greatest enhancement to air navigation since radionavigation was introduced 50 years ago. When GPS is fully integrated, along with Automatic Dependent Surveillance and data links, into the National Airspace System, industry analysts estimate that the airlines will derive an annual economic benefit of billions of dollars. Much of this benefit is derived from more efficient route selection and a greater controlled traffic density, which would be possible with worldwide GPS navigation.

Only a small portion of the volume of hazardous materials shipments are made by air, so that this mode will not receive detailed analysis in this project. In addition, the unique nature of civil air travel necessitates very strict requirements for navigation and tracking systems, without meaningful distinction on the type of cargo carried. Transporting hazardous materials by air does not add more stringent tracking requirements to those governing normal operations. For this reason, radionavigation requirements already in place are generally considered to be adequate for hazardous materials transport (Federal Radionavigation Plan [6]).

2.3 AUTHORITY FOR THE REQUIREMENTS

The requirements and their values presented in this document were gathered and assimilated from several authoritative sources. These include discussions and material from government agencies such as FEMA and RSPA, from local authorities such as the Fairfax County Fire Department, and from several reports, which are cited in the References. Several requirements still are not validated or quantified with precision because the technology is so new that field performance testing is not complete.

The navigation and positioning requirements for the highway transport of hazardous materials are derived from fleet management needs for ITS (Tables 2.3 and 2.4).

2.4 TRANSPORT OF RADIOACTIVE MATERIALS

Radioactive material and waste transportation is governed by various Acts, including the Hazardous Materials Transportation Uniform Safety Act (HMTUSA) of 1990. This act requires that DOT determine standards for route selection and modes of transport for radioactive materials.

Historically, shippers make modal choices for transport, and carriers make routing choices. Highway, rail, and waterways are the available modal choices. Flexibility and options in route selection are, of course, greatest for highway transport. However, shippers seldom cite safety as the driving factor in their modal choice.

Only DOD and certain chemical companies review carrier safety records before selecting a carrier. In general, routing adjustments are made only for a select few hazardous materials. Hazardous materials are not typically differentiated from non-hazardous materials when making routing decisions.

Risk factors routing guidelines. The main factors are:

- Expected, per-mile population exposure (population risk)
- Expected, per-mile property value exposure (property risk)

Secondary factors include emergency response capability. Some suggested factors in route selection:

travel times, delays (e.g., road construction)
time of day
operating speed
traffic density
traffic, curiosity congestion
route length
surveillance coverage
hazmat traffic density
difficult sections - terrain, visibility
weather, climate conditions
hazmat incident response proximity, capability

communication
response times
available manpower

2.5 AVL REQUIREMENTS TABLES

Transportation requirements for the land, air, and marine mode applications are summarized in Tables 2.2 through 2.7. These tables summarize location requirements for hazmat transport in the major transportation modes. Many of the requirements are not firmly set, since the particular application has not been fully tested and implemented. The less certain a requirement is, or the more applications it has, the broader is its range of values.

In these tables, the mode applications are listed in a column, and the location system (GPS or DGPS) characteristics are listed horizontally. The requirements for a specific mode application will in general vary, but should fall within the appropriate ranges.

General; Table 2.2: Standard GPS accuracy may be adequate for most highway (ITS) applications involving hazardous materials transport. Certain operational areas may be subjected to blockage of GPS signals (for example, high buildings, forested areas). These areas would require augmentation of GPS with another system such as dead reckoning (DR), which would be costly.

On March 29, 1996, the White House issued a Presidential Decision Directive on the use of GPS. Key points in this Directive are that continued access to the basic GPS service for peaceful civil, commercial, and scientific use was reaffirmed, and that planning would begin to turn off GPS Selective Availability (SA) within the decade. SA is the GPS feature by which access to the full GPS location precision is restricted to U. S. and allied military users. Turning off SA would therefore result in all users - civil and military - having access to the full GPS location precision.

The full impact of this Directive on the hazardous materials shipping applications discussed in this report cannot be determined in detail yet. However, it seems clear that applications which now use GPS will benefit from much improved accuracy for basically no added cost, although the economic or operational benefit of this added accuracy is difficult to quantify at this time. Applications which use the augmented GPS service, DGPS, are likely to revert to the simpler and less expensive basic GPS service when SA is turned off. The actual direction taken will be the result of a benefit/cost analysis of the specific application.

Tables 2.3 and 2.4: Integrity requirements for land uses of (D)GPS are not well defined as yet. Resolution of final system architecture issues is needed, and several systems are still under study.

A primary means for monitoring the transportation of hazardous materials on land is through vehicle tracking services and systems. The navigation and positioning requirements for hazardous materials transport - as opposed to incident response - correspond to the Fleet Management (AVL/AVI) needs of shipping and carrier users shown in Table 2.4. AVL stands for Automatic Vehicle Location, and AVI for Automatic Vehicle Identification.

Vehicle control is listed in the table, but has only a very limited near-term application. There is a conceivable use for DGPS, but the technologies for a system that meets operational requirements, particularly reliability, are experimental.

If distinguishing train location on parallel tracks is important, DGPS may be required for those areas where the tracks are sufficiently close to require DGPS for resolution - for example, terminal areas or freight car storage areas.

Table 2.5: The major railroad industry group is the Association of American Railroads (AAR). Incidents at railroad crossings would be classified as railroad incidents only if railroad equipment is involved.

Table 2.6: A primary means for monitoring the transportation of hazardous materials in ships is through vessel tracking services and systems. For inland waterways such as rivers, accurate location capability for handling hazardous materials is needed, and the need is critical. Following an incident, all available transportation modes with any potential of reaching the site must be evaluated for the fastest possible response.

Table 2.7: DGPS would be required to supply the necessary tracking accuracy in runway and taxiing operations.

Table 2.2 Summary of Federal Transport Requirements

Mode Application		Accuracy (2 drms[4])		Time to Alarm		Availability		Coverage Area		Sample Rate	
		RANGE	MEAN	RANGE	MEAN	RANGE	MEAN	RANGE	MEAN	RANGE	MEAN
Land	Highway (ITS)	1-100 meters	20 meters	1-15 seconds	15 seconds	99.7%	99.7%	Nation- to World-Wide	Nation-wide	1 second	1 second
	Railroad	1-30 meters	10 meters	1-5 seconds	5 seconds	99.7 - 100%	99.7%	Nation-wide	Nation-wide	0.1 - 1 second	1 second
Marine	Navigation (Harbors)	8 - 20 meters	10 meters	Depends on Mission		99.5 - 99.7%	99.7%	Nation- to World-Wide	Nation-wide	1 - 5 seconds	1 second
Air	Navigation	1 km hor. & vert.[5] to h: 4.1 m v: .365 m	depends on phase of flight	2 - 10 seconds	depends on phase of flight	99.977 - 99.992%	N/A	National Airspace System		None Specified	

[4] When two-dimensional accuracies are involved, the 2 drms (distance root mean squared) is used. Two drms is twice the radial error drms. The radial error is defined as the rms value of the distances from the true location point of position fixes in a series of measurements.

[5] This range of accuracies reflects the differences between en route and precision approach flight phases. "h" and "v" mean horizontal and vertical, respectively.

Table 2.3 Highway Transportation Requirements - Incident Prevention

Mode of Application	Accuracy (2drms)	Time to Alarm	Availability	Coverage Area	Sampling Rate
Collision Avoidance - Hazardous Situation	5 meters	1 - 15 seconds	99.7%	Critical Locations	1 second
Fleet Management - Hazmat (AVL/AVI)	25 - 1500 meters	1 - 15 seconds	99.7%	Nationwide	1 second

Table 2.4 Highway Hazmat Transportation Requirements

Mode Application	Accuracy (2 drms)	Time to Alarm	Availability	Coverage Area	Sample Rate
Mayday/Incident Alert	5 - 30 meters	1-15 seconds	99.7%	Nationwide	1 second
Fleet Management (AVL/AVI)	25 - 1500 meters	1 - 15 seconds	99.7%	Nationwide	1 second
Emergency Response (APTS/CVO)	75 - 100 meters	1 - 15 seconds	99.7%	Nationwide	10 seconds
Vehicle Command and Control (APTS)	30 - 50 meters	1 - 15 seconds	99.7%	Nationwide	1 second
Collision Avoidance-Control	1 meter	1 - 15 seconds	99.7%	Critical Locations	0.1 second
Collision Avoidance-Hazardous Situation	5 meters	1 - 15 seconds	99.7%	Critical Locations	1 second
Accident Data Collection	30 meters	1-15 seconds	99.7%	Nationwide	1 second

Table 2.5 Railroad Hazmat Transportation Requirements

Mode Application	Accuracy (2 drms)	Time to Alarm	Availability	Coverage Area	Sample Rate
Position/Location	10-30 meters	5 seconds	99.7%	Nationwide	1 second
Speed Determination	±1 km/hr up to 5% of speed	-	-	Nationwide	0.1 second to 1 second
Train Control	1 meter	less than 5 seconds	100%	Nationwide	0.1 second to 1 second
Railroad Survey	10 centimeters	N/A	N/A	Nationwide	N/A
Collision Avoidance	1 meter	less than 5 seconds	100%	Nationwide	0.1 second

Table 2.6 Marine Hazmat Transportation Requirements

Mode Application	Accuracy (2 drms)	Time to Alarm	Availability	Coverage Area	Sample Rate
Harbor/Harbor Approach Large Ships and Tows	8 - 20 meters	6 - 10 seconds	99.7%	U.S. Harbors and Approaches	6 - 10 seconds
Harbor/Harbor Approach Smaller Ships	8 - 20 meters	6 - 10 seconds	99.7%	U.S. Harbors and Approaches	1 second
Harbor/Harbor Approach Resource Exploration	1 - 3 meters	5 seconds	99.7%	U.S. Harbors and Approaches	2 seconds
Coastal - All Ships	460 meters	Not Specified	99.7%	U.S. Coastal Waters	2 seconds
Coastal - Recreation Boats and Other Smaller Vessels	460 - 3700 meters	Not Specified	99.7%	U.S. Coastal Waters	5 minutes
Ocean - Safety of Navigation	3700 - 7400 meters	Not Specified	99.7%	Worldwide	15 minutes or less
Ocean - All Craft	1800 - 3700 meters	Not Specified	99.7%	Worldwide	2 hours maximum

Table 2.7 Aviation Hazmat Transportation Requirements

Mode Application	Accuracy (2 drms)	Time to Alarm	Availability	Coverage Area	Sample Rate
En Route Oceanic	Not Specified	Less than 10 seconds	99.977%	27.5 - 40,000 ft within NAS	Not Specified
En Route Domestic	1000 meters	Less than 10 seconds	99.977%	500 - 60,000 ft within NAS	Not Specified
Terminal	500 meters	Not Specified	Not Specified	500 - 18,000 ft within NAS	Not Specified
Helicopter	500 meters	Not Specified	Not Specified	Not Specified	Not Specified
Ground and taxi	3 - 10 meters	Not Specified	Not Specified	Airport Surface	Not Specified
Approach and Landing:					
Nonprecision	100 meters	10 seconds	99.977%	250 - 3000 ft above ground level areas covered by approach maneuvers	Not Specified
Category I Approach	horiz.: 9 meters vertical: 3 meters	6 seconds	99.99%		
Category II Approach	h: 4.5 meters v: 1.2 meters	2 seconds	99.99%		
Category III Approach	h: 4.1 meters v: 0.365 meters	2 seconds	99.99%		

3. POTENTIAL USES OF GPS/DGPS IN HAZARDOUS MATERIALS TRANSPORT

3.1 INTRODUCTION

Objectives. The primary objectives of safety improvements in the transport of hazardous materials are enhanced protection for people, the environment, and property. Other objectives are to promote the flow of commerce and travel through increased efficiency, and to develop additional safety capabilities. These objectives apply to the application of GPS/DGPS technology for safety improvement.

The broad objectives are expanded and grouped into three categories:

1. **Protection**
   » Protect people
   » Protect property
   » Protect the environment

2. **Efficiency**
   » Anticipate problems
   » Identify incident locations
   » Respond promptly
   » Respond adequately
   » Resolve the incident quickly
   » Expedite traffic movement
   » Expend minimum resources

3. **Development**
   » Plan operations
   » Maintain and improve capabilities
   » Train personnel

Functions. There are eight evident functions that GPS/DGPS will support in meeting the objectives for hazardous materials transport safety. Prior to a hazardous materials incident, the use of GPS/DGPS will enhance safety by:

(1) showing the locations of hazardous materials transport vehicles in transit

(2) aiding in prediction, planning, or control of routes used by the vehicles; and,

(3) assisting any necessary rendezvous with hazmat vehicles by enforcement officials.

After a hazardous materials incident, GPS/DGPS will enhance safety by:

(4) defining the location of the incident

(5) indicating the locations of emergency responders

(6) showing the actual movement vector of hazardous materials after release

(7) furnishing the DGPS-calibrated locations of sensitive sites that may require protection, and
(8) aiding the cleanup of hazardous materials that leaked while in transit.

Each of the functions noted can apply to the transport of hazardous materials by the various modes used (i.e., highway, waterway, railroad, and air).

3.2 METHODS

There are two kinds of position reports that can be provided from vehicles. *Static* positions will be from non-moving vehicles and *dynamic* positions from those in motion. Of the eight functions named in Section 3.1, static position reports will meet only three (i.e., incident site location, emergency responder location, and approximate locations of sensitive sites that need protection), and these three functions are important only after an incident has occurred. Dynamic reports will meet all eight of the functions.

Static Position Reports. Static GPS/DGPS position information can be reported from a transport vehicle or emergency responder by voice communication over existing radio equipment, by cellular telephone service, or by any other available means of communication. The report can be made to the local emergency management organization by responders or to a company communications center by the vehicle operator. With only static position information, emergency managers will know the location of an incident and then can match that information with stored position data on nearby sites that require protection. Early position information from an incident provided by the transport vehicle can assist responders in locating that incident. The accuracy of the position will be best if reported either from the vehicle involved in the incident or from a responder physically at the disabled vehicle. If the responder must avoid approaching the actual site of an incident because of hazard [3], then the position accuracy will be degraded by the responder's offset position. Three of the eight functions identified in Section 3.1 will be supported by static position reporting.

Dynamic position reporting will be more complex and costly than the static concept, because location data must be transmitted automatically at regular intervals, which requires added communications links. However, dynamic reporting will support additional functions and has more benefits. With dynamic position reporting, vehicles can provide GPS/DGPS position periodically as they move. The reporting vehicles can be hazardous materials vehicles, emergency responders, or both. Reports can be made to designated local or area emergency centers. Commercial vehicles also can report to company management. All eight functions can be met by the use of dynamic position reporting. Dynamic position information will provide the most benefits. It also is apparent that simple, static position information will provide very useful benefits.

3.2.1 Safety Functions and GPS/DGPS Position Reporting

Functions. Eight functions that can enhance the safety of hazardous material transport were identified in Section 3.1. An expanded description of each function is provided below to clarify the potential benefits of each and the objective(s) that it meets:

(1) Plotting the locations of hazardous material vehicles while in transit

Vehicle Tracking. The function will be similar to aircraft tracking by air traffic control in the National Airspace System. Each designated transporter of a hazardous material will report position periodically as it moves along a route. The data from hazardous materials vehicles moving within an area of jurisdiction will be processed and used by public authorities to:

(a) plan response to accidents,
(b) aid in route planning and control,
(c) aid in rendezvous with vehicles, and
(d) designate an incident location.

The objectives met by the vehicle tracking will be "Protection" because the needs to guard people and the environment can be anticipated, and "Efficiency" in location and response to an incident. An additional benefit can be use of the position data by companies to assist in fleet management.

(2) Aiding in prediction or planning of routes used by hazmat transporters

Route Planning. Initial data collected after a dynamic tracking system begins operation will identify the routes preferred by hazardous materials transporters. With the data, local planners can make contingency plans to ease the potential effects of incidents along the routes, or to restrict use of the routes. Such plans can include seasonal concerns such as school operations, use of recreational areas, and special events that may involve large groups of people. Short and long term changes in routes that result from such occurrences as highway construction, rail accidents, and weather effects can be anticipated. The objective most supported will be "Development" because of the aid to planning.

(3) Assisting any necessary rendezvous with vehicles by enforcement officials

Rendezvous. In the case of especially hazardous materials, security, or safety reasons, it may be necessary for enforcement officials to intercept or escort a specific vehicle. Accomplishment of a rendezvous will depend on the vehicle tracking and route prediction capabilities described earlier. The objective met will be "Efficiency" in the anticipation of potential problems.

(4) Defining the location of a hazardous materials incident

Hazmat Transport Vehicles. In most instances, a vehicle involved in an incident will stop. If vehicles are equipped to provide position information, then an incident location can be known before emergency responders appear at the scene. The halt of a hazardous materials carrier vehicle along a route will not indicate, necessarily, an incident, but the information can be used for initial alert prior to actual response by emergency personnel. The use of unexpected changes in vehicle movements to anticipate emergencies will become more accurate and beneficial as the experience and the expertise of tracking system personnel grows.

Position Measurement and Guidance. If only emergency responder vehicles are equipped with position reporting systems, then the exact position of an incident will not be known until they arrive. As noted earlier, the accuracy of incident location will depend upon how close the responder can get to the hazardous material vehicle. If two or more responder vehicles are at the site but cannot approach closely, the position information can be improved by magnetic bearing readings to the incident site from the responder vehicles. The accurate position of the incident can be calculated with the responder geodetic positions and the bearing readings. Position information can be used to guide additional ground and airborne responders to the site with the area navigation capability of GPS/DGPS. Area navigation will provide steering guidance that will permit movement from the an initial position to another known position (e.g., from the fire station to an accident site). The guidance can be a map display for a boat or land vehicle, or left-right guidance for an aircraft. "Efficiency" will be the objective met in the accurate identification of an incident location.

(5) Indicating the locations of emergency responders

Emergency Vehicle Management. With a dynamic tracking system, the locations of emergency response vehicles on the road will be known. Managers then can direct appropriate emergency vehicles toward an incident. Directions can be given to circumvent traffic blockages and guidance given to find incidents at remote sites. In addition, evacuation routes to hospitals, or other safe sites, can be created in real time. Political boundaries also can be monitored to ensure that the appropriate responders manage the situation at the incident site. Proper and well managed response to an incident will meet the "Efficiency" objective.

(6) Showing the actual movement vector of hazardous materials after release

Hazardous Material Movement. The movement vector of a released hazardous material will be the direction and speed of the material. The vector can be predicted from prevailing winds, which may be different than actual winds at the site. A material plume or flow can be tracked accurately with a dynamic GPS/DGPS positioning system.

Position information on the moving material can be furnished by vehicles moving with the plume, or by automatic position reporting equipment moving with the material. The objective met will be "Protection" because of the immediate, potential affect on people and the environment in the area of the incident.

(7) Furnishing the DGPS calibrated locations of sensitive sites that may require protection

Sensitive Sites Identification. Planning for the protection of sensitive sites will involve extensive data collection and establishment of a way to use the data quickly. Sensitive sites can be those that have the potential for heightened risks to people, the environment, or property. The locations of hospitals, schools, nursing homes, housing developments, shopping centers, and stadiums would be candidates that fall within the sensitive category. Sensitive environmental sites along routes used by hazardous materials transporters are candidates also. In a 1993 Transportation Research Board report [3] on hazardous material shipment problems, the subject of the cost resulting from environmental damage and cleanup was discussed. The report said:

> Poor emergency response information that results in slow, inappropriate, or overly cautious response could result in greater pollution and other environmental damage due to a release of hazardous substances into the air, ground, or water. In these instances, information problems can lead to higher cleanup and remediation costs, including those associated with spill removal (e.g., from soil and water), clearance of contaminated wreckage, and repair of damaged tracks and roadways.

Each intersection between a stream, or wetland, and a highway or a railroad will have the potential for environmental harm if a material spill occurs nearby. With available charts from the U.S. Geological Survey and most state, county, or commercial street maps, the sensitive sites can be approximately located. After location on a chart, each site can be calibrated accurately by a visit from a vehicle equipped with a DGPS receiver. After calibration, the latitude and longitude can be entered into a computer data base for immediate comparison with incident locations. If a pre-defined distance limit [7] between an incident and a sensitive site is violated, the appropriate emergency response procedure can be set in motion. The planning objective under "Development" will be met by the function.

(8) Aiding the cleanup of hazardous materials that leaked while in transit

Hazardous Material Leaks En Route. If a vehicle leaks material over a portion of a route, tracking system data from the point of leak discovery can be used to backtrack the route. With knowledge of the route followed, the vehicle's schedule, stops and pauses along the route, and data on the material, emergency responders can be guided in their searches. Both the "Protection" and "Efficiency" objectives will be met by the function.

3.3 FACTORS IN IDENTIFYING CIVIL APPLICATIONS

Clearly, the practical application in hazmat-related areas of GPS/DGPS technology within the United States lies primarily in the benefits that can be gained for the investment required. Reasonable objectives that can be accomplished with the technology were described briefly in preceding sections. Before decisions can be made with confidence, however, it will be necessary to consider cost and technical questions about the use of GPS/DGPS. As with any radionavigation system, users must receive acceptable navigation signals and then process the data taken from those signals into position measurements. After the vehicle positions are measured, that information will be communicated to a communications center for final use. At the communications center it will be necessary to have enough information from various sources to combine into a complete product that will aid in meeting the objectives

3.3.1 Reception of GPS and DGPS Signals

Signal Strength. The GPS signals available for use by the civil community are those of the "Standard Positioning Service." The signals from each satellite are on the same radio-frequency carrier (i.e., 1,575.42 megahertz). Navigation information from each satellite is in the form of a fixed message format. The message is encoded at the satellite and transmitted as modulation of the 1,575.42 MHz radio frequency carrier signal. A receiver sorts signals from various satellites and processes them to regain the encoded information. The information is used by the receiver to measure the assumed range to each satellite and then to compute the position of the vehicle on the surface of the theoretical earth. Because of the laws of physics, the satellite signal will lose most of its power as it travels in its present orbit of approximately 10,900 nautical miles from an overhead satellite to a receiver. When the GPS signal arrives at the antenna of any vehicle, it is extremely weak.

Reception and Interference. The low amplitude signals received from GPS satellites may on occasion affect the successful use of these signals in land vehicles. There will be little system tolerance for any blockage in the path between the satellites and the receiver antenna. Because the GPS satellites are in inclined orbits they will move in apparent arcs across the visible sky. Generally, satellites will be viewed in a southerly direction and frequently near the horizon. Any buildings, terrain, vehicles, or devices on vehicles that block satellite signal paths may have a detrimental affect on results. Passage of the signals through foliage (e.g., to vehicles under leafing trees) can reduce the signal strength to an unusable level [8]. Since all GPS signals use the same radio frequency, any signal near 1,575.42 MHz may interfere severely with receiver operations and prevent adequate processing of the satellite signals.

Despite these cautions, it must be emphasized that GPS is proving to be a highly useful location and navigation system both in military and civilian applications. Any area within an emergency response district that experiences GPS tracking difficulties can be identified in advance, and appropriately handled in hazmat response planning and training.

GPS Management. The GPS satellite constellation is managed by the Department of Defense and this may have an operational impact on civil applications of the system. Information transmitted by each satellite will be updated daily from the Air Force Consolidated Space Operations Center at Falcon AFB in Colorado Springs, Colorado. If not updated, the satellite information will degrade over several days and become unusable. Incorrect data updates will result in immediate position errors. A backup facility at Onizuka AFB near Sunnyvale, California will monitor GPS satellite information but cannot update satellite data.

System Failure Consideration. Disastrous failure at the Colorado facility, or individual satellite failures, will affect performance. Replacement of a failed satellite probably will take several months although many failures are predictable. If more than one satellite fails during a common period, then gaps in signal coverage will result, especially for ground-level users who cannot make best use of available satellites visible low on the horizon. Any change in satellite orbits for national security purposes may impact civil users of the system.

3.3.2 System Architectures

System Elements. There can be five major elements in the architecture of an operational GPS/DGPS system. The elements are:

1. Global Positioning System (GPS) (i.e., satellites, receivers, control)
2. Communications Center
3. Digital communication link
4. Voice communication link
5. Vehicles (i.e., emergency response and/or cargo vehicles)

Global Positioning System (GPS). Briefly, GPS is a satellite-based positioning system which can provide accurate and reliable position data for an expanding variety of civilian and military applications. Users equipped with GPS receivers can determine their location to within an accuracy of 100 meters or better 95% of the time almost anywhere on earth.

Differential GPS enhances GPS accuracy to about 5 meters by combining the standard GPS signal with an error correction signal which is broadcast from a base station. In order to use the correction data, a digital data link must be established between the base station and the GPS data source. DGPS therefore can be more complex and costly than GPS alone. The base station should be within about 100 miles of the area planned for DGPS usage; in particular, it can be part of the emergency response communications center.

Communications Center. A communications center will be a central facility to which all vehicle reports will be sent and where emergency managers will be located. A communications center can serve a local area such as a county or city, a broader area over a state or several states, or the nation as a whole. Technical functions of a local communications center probably will be more complex than at centers for wider geographic areas. The reason for greater complexity in the local facility involves the calculation, encoding, and use of DGPS corrections. It will be unlikely that a multi-state or national communications center will be responsible for the provision or use of differential corrections in vehicles.

Two alternative sets of activities will be possible at a local communications center for the use of DGPS.

Activity Set No. 1

1. Reception of GPS signals from satellites in view
2. Computation of differential GPS correction values
3. Reception by digital data link of GPS pseudorange[6] data from emergency vehicles
4. Extraction of GPS pseudorange data from vehicle messages
5. Application of differential corrections to GPS data received from vehicles
6. Computation of the DGPS positions of vehicles
7. Assembly of all pertinent data for presentation
8. Presentation of pertinent data in context with vehicle position information
9. Voice communication to vehicles

Activity Set No. 2

1. Reception of GPS signals from satellites in view
2. Computation of differential GPS correction values
3. Encoding of DGPS corrections for transmission to vehicles
4. Transmission of DGPS corrections on a digital data link to vehicles
5. Reception of DGPS vehicle positions via digital data link from vehicles
6. Extraction of DGPS position information from vehicle messages
7. Assembly of all pertinent data for presentation
8. Presentation of data in context with vehicle position information
9. Voice communication to vehicles

Wide area architectures, which are DGPS designs capable of providing correction data over "wide" areas, can use differential GPS corrections from a number of sources. These include the Wide Area Augmentation System (WAAS) that is being deployed by the

[6] A *pseudorange* is the distance from the user (receiver) to a GPS satellite, plus an unknown user clock offset distance. The clock offset distance results from the user and satellite clocks not being in exact agreement. When four satellite signals are tracked simultaneuosly, it is possible to compute position and offset distance. If ths user clock offset is known, three satellite signals suffice to compute a position.

FAA, the U.S. Coast Guard radio beacon signals that are modulated with DGPS data in coastal and inland river areas, or commercially provided corrections on FM broadcast signals. Local area systems also can use the various sources of corrections noted, but for best performance and maximum control, the differential GPS corrections will be determined by the local system.

Activity Set No. 2 will be the less desirable method because it requires one additional communication activity - transmission of DGPS corrections on a digital data link to vehicles. There will be no pressing need for a DGPS position to be computed in emergency vehicles rather than in a communications center.

Digital communication link. Digital data links are used to transmit digital data between data processing components. In GPS hazmat tracking applications, a digital link could be used to broadcast dynamic GPS/DGPS position reports from moving vehicles. Another use is to broadcast DGPS correction data to where it can be combined with the basic GPS position measurement. The actual data link can be physical, such as a phone line, or it can be a VHF or microwave link. If position reporting is desired on a regular basis, a digital link is a necessity.

Voice communication link. Voice links are in common use today in most emergency response organizations. Two-way radio, CB radio, cellular phones, and similar devices are examples of common and practical voice links. A basic hazmat response system must have at least a voice link, so that static position measurements can be transmitted by voice from the incident site to the communications center. A voice-only link such as two-way radio probably would be impractical for hazmat transport applications, because of the near-continual need for location updates.

Vehicles. Vehicle equipment for participation in a GPS or DGPS positioning system can be of several levels of complexity and cost. The least requirement will be a GPS receiver with a display of latitude and longitude that can be read by personnel on the vehicle. This option is very inexpensive for vehicles that already have a voice link. The next level will be a unit that transmits satellite range measurements to the communications center. The third level will involve reception of differential GPS corrections for DGPS position computation on the vehicle, and then transmission of that position to the communications center. In the second and third levels a digital radio link will be needed, which adds somewhat to overall system cost. In all cases a voice link between the communications center and vehicles in the field will be essential. It may be possible to carry voice and digital information simultaneously on the same radio link. This would save some of the expense.

3.3.3 System Selection, Acquisition, and Installation

Institutional Considerations. Institutional factors involved in each decision to use GPS/DGPS technology are illustrated in Table 3.1 with a typical list of actions needed to establish any new system.

Table 3.1 Institutional Factors

1. Recognition of a requirement that can be fulfilled by GPS/DGPS technology
2. Preparation of a proposal with benefits and optional solutions
3. Development of cost and schedule estimates, and a benefit-to-cost ratio analysis
4. Development of proposed organizational structure, authority, and responsibility
5. Presentation to organizational entities that must approve the proposal
6. Presentation in public, commercial, and organizational forums, as necessary
7. Budget item preparation, submission, and approval
8. Legal or regulatory enactments needed for any "mandated" participation
9. Competitive acquisition of equipment and facilities
10. Organizational establishment
11. Equipment installation
12. Personnel assignment and training
13. Initiation of service
14. Day-to-day operation and maintenance of the system

Impact of Institutional Factors. The list of factors in Table 3.1 may vary among situations but, from start to implementation, almost all must be handled for every GPS/DGPS system established. If items number 6 and 8 in Table 3.1 can be avoided, implementation will be expedited. Broader scope proposals will have difficulty if they involve mandatory participation by commercial organizations, enactment of laws, or rules changes by government regulatory agencies. Implementations that cross political boundaries also may cause delays if detailed agreements and coordinated budgets are required.

Implementation Considerations. The selection of civil applications should be done with full consideration of factors in Table 3.1. Situations that demand quick establishment should be kept within the smallest political and budgetary boundaries possible. Furthermore, such situations should not require mandatory participation by anyone outside the emergency response organization, and there should be no major legal implications involved in the use of the system.

3.4 INTELLIGENT TRANSPORTATION SYSTEMS (ITS) IMPLEMENTATION

Integration with ITS. The application of GPS/DGPS technology for the improvement of hazardous materials transportation should be integrated with the extensive Intelligent Transport Systems (ITS) implementation in order to gain the greatest benefits at the lowest possible cost. During the period of this study, some ITS projects were completed and others were in progress. The final architecture of the ITS was not defined. In part because of this, definitive requirements for the use of GPS/DGPS in hazardous material transport and incident response have not been fully developed yet.

ITS/GPS Projects. A number of ITS projects were established to use GPS for vehicle locations (e.g., "California Smart Traveler," "Dallas Smart Bus Evaluation," "MTA (Baltimore) Smart Bus," and "RTD (Denver) Smart Bus"). Communication protocols and the availability of radio frequencies were considered. The "Capital" operational test in the Washington, D.C., area used the existing cellular telephone infrastructure for vehicle surveillance and communication. Transponders were installed on trucks for identification and for other data in the "Advantage I-75" and "Help/Crescent" projects. Radio frequency concerns in regard to availability were the subject of a continuing study "ITS Radio Frequency Spectrum Planning," and electromagnetic compatibility was the subject of the study "Electromagnetic Compatibility Testing for ITS."

Institutional Issues. A variety of institutional areas were studied, and were under study, in preparation for ITS implementation. Institutional issues were examined that could impede or prevent achievement of ITS goals for commercial vehicles. Regional conferences were held to identify environmental benefits from ITS; to discuss federal, state, and local cooperation; to consider policy issues; and, to facilitate greater understanding among policy-makers, program administrators, and interested private organizations.

ITS Architecture. ITS system architecture was under study by four industry teams and, after refinement and evaluation, the final architecture will be selected in 1996 from among the candidates. Ultimate deployment of the many components of the ITS will be, primarily, a local process. The DOT is funding deployment planning studies to assist local agencies in identification of needs and in development of plans to meet those needs. The goal of the DOT is the development of deployment plans by the end of 1997 for the 75 largest U.S. metropolitan areas and 30 of the major intercity corridors connecting the metropolitan areas.

Design Flexibility. The impact of ITS implementation on the use of GPS for improvement of hazardous materials transportation will be one of awareness of the overall plan with little restriction on specifics. Any system designed for hazardous material safety should consider that digital message formats may change in the future, different communication methods may be required, and data displays may change to an agreed standard. If the interface elements of any GPS/DGPS system are kept flexible, the ultimate connection to ITS will be done readily.

3.5 POTENTIAL APPLICATIONS BY SERVICE AREA

3.5.1 Functional Ratings

Service Areas. There will be three major service areas in which the application of GPS/DGPS technology can be most beneficial for the improvement of hazardous materials transportation safety. The service areas are:

1. Monitor the geographic position of hazardous material shipments within the United States.

2. Provide information for projected hazardous material transport routes and adherence to routes.

3. Aid in the emergency response to hazardous material transport incidents by modes (i.e., road, water, rail, and air)

Ratings by Service Area. In Section 3.2, the potential use of static and dynamic position data was discussed in relation to the sources of the position reports (i.e., the emergency responder vehicle, the hazardous materials transport vehicle, or the hazardous material). The static and dynamic position information can be separated further into "GPS" and "DGPS" positions and rated versus the three service areas for each major transportation mode. To rate the value of each method by service area, an identical table was used for each mode and the estimate of functional value was indicated using a scale from "0" to "10;" with "10" being the most valuable application.

The functional values that appear in Tables 3.2 - 3.7 were selected based on discussions with hazmat responders and industry experts, and on institutional knowledge and experience. The estimate of functional value is *subjective* with a rationale provided as appropriate.

Highway Applications. The static DGPS rating is higher than static GPS in the Monitor Position column in Table 3.2 because DGPS possibly could be used for identification of the side of a highway on which a vehicle was stopped for an emergency. A basic GPS derived position has an accuracy of 100 meters or better, 95% of the time and can be used to identify a point on a road. A DGPS position can identify the correct side of a

Table 3.2 Functional Ratings: Road or Highway Applications

Method	Monitor Position	Route Adherence	Aid Emergency Response
Static GPS	2	2	4
Static DGPS	4	3	5
Dynamic GPS	8	8	8
Dynamic DGPS	10	10	10

wide road, such as an interstate highway. The value of the correct-side-of-the-road capability probably will be meaningful only when interstate or other multi-lane highways with uncrossable center barriers are considered. Emergency response to the correct side of a highway can increase effectiveness of response. The rationale did not apply to dynamic GPS and DGPS because the side of the highway can be determined from the travel direction of the vehicle.

Table 3.3 Functional Ratings: Waterways Applications

Method	Monitor Position	Route Adherence	Aid Emergency Response
Static GPS	4	4	5
Static DGPS	5	5	6
Dynamic GPS	8	8	8
Dynamic DGPS	10	10	10

Waterway Applications. The scores for static GPS and DGPS were slightly higher in the waterways application in comparison to road applications. There will be fewer waterways than highways used to transport hazardous cargoes. In the "monitor position" and "route adherence" areas, static position information probably will give a better indication of the prior route followed for a vessel than for a truck on a highway.

Table 3.4 Functional Ratings: Rail Applications

Method	Monitor Position	Route Adherence	Aid Emergency Response
Static GPS	4	4	5
Static DGPS	5	5	6
Dynamic GPS	8	8	8
Dynamic DGPS	10	10	10

Rail Applications. The value of DGPS will emerge as the management of trains evolves from "Train Position Tracking" to "Train Control." A Department of Commerce report [9] on a national approach to the provision of DGPS described the functional application in train operations. Train Position Tracking requires knowledge of the position of a train in relation to a block of track. Train Control refers to the dynamic supervision of multiple trains on a known track structure which may include parallel tracks and multiple switches. Parallel tracks may be spaced as close as 3.8 meters, center-to-center. Collision avoidance is an aspect of Train Control.

Table 3.5 Functional Ratings: Air Applications

Method	Monitor Position	Route Adherence	Aid Emergency Response
Static GPS	4	0	5
Static DGPS	5	0	6
Dynamic GPS	8	0	8
Dynamic DGPS	10	0	10

Air Applications. Although technically possible, it will be unlikely that dynamic GPS or DGPS will be used widely for aircraft tracking. Almost all aircraft are equipped to use the air traffic control radar beacon system (ATCRBS) for tracking the movement of aircraft in the U.S. and internationally. Static position reports of GPS or DGPS position can be of value on airport surfaces, or if an aircraft crashes. One potential use of GPS/DGPS reporting could be by helicopters that operate entirely within a local area.

3.5.2 Complexity Ratings

Complexity Ratings. In Tables 3.2 through 3.5, relative functional ratings were given for the static and dynamic position information versus the three service areas. An important consideration, in addition to the functional, will be the relative complexity of each method for each service area. Complexity ratings can be separated into technical complexity and implementation complexity. Technical complexity will be concerned with the number of technical elements, described in Section 3.3.2, necessary to construct the desired system. Implementation complexity involves all of the 14 processes listed in Section 3.3.3. Table 3.6 shows technical complexity ratings with a "10" for the highest relative complexity on a scale from "0" to "10". Table 3.7 shows implementation complexity ratings.

Table 3.6 Relative Technical Complexity Ratings

Method	Monitor Position	Route Adherence	Aid Emergency Response
Static GPS	2	2	1
Static DGPS	4	4	4
Dynamic GPS	6	6	7
Dynamic DGPS	8	8	10

Technical Complexity. Technical functions of a local communications center for emergency response vehicles, as noted earlier, probably will be more complex than at centers for wider geographic areas. The greater complexity in the local facility will involve the calculation, encoding, and transmission, or application, of differential GPS corrections. A multi-state or national communications center probably will not be responsible for direct provision of differential corrections for use in en route vehicles.

Table 3.7 Relative Implementation Complexity Ratings

Method	Monitor Position	Route Adherence	Aid Emergency Response
Static GPS	3	3	1
Static DGPS	5	5	4
Dynamic GPS	8	8	6
Dynamic DGPS	10	10	8

Implementation Complexity. Implementation complexity ratings reflect the expected difficulty in the processes that must be followed to establish a new system. The least complex installation will be simple GPS position reporting from emergency response vehicles. The most complex will be dynamic reporting of DGPS positions of cargo vehicles as they move along routes. The emergency vehicle situation for dynamic reporting will be less complex than the cargo vehicles, again, because of the local situation and the ability to limit the number of processes that must be observed for implementation.

3.5.3 Summary of Ratings

When the function ratings from Section 3.5.1 and the complexity ratings from Section 3.5.2 were considered together, *in a subjective manner*, the highest combined rating was for the use of static GPS position information by emergency responders. The high rating was achieved because of two good features -- useful benefits and lack of complexity. There was little to choose between the two dynamic applications (i.e., GPS and DGPS) with the GPS ratings slightly higher than DGPS because of slightly lower complexity.

3.5.4 Examples of Applications

There is a variety of examples in which GPS or DGPS can be used to enhance safety in the transportation of hazardous materials. Table 3.8 contains examples of applications.

Additional Applications. There will be potential applications of DGPS that may improve safety in the transport of hazardous materials but that do not involve position reports for tracking. One application may be the use of DGPS derived positions entirely within a vehicle on a map-like display of the vehicle position relative to fixed objects. Such a display can complement radar presentations on boats. In the event of radar failure, a captain or pilot still will know the position of the vessel relative to bridges, piers, or embankments. Another possible application of vehicle-derived DGPS positions can be to maintain required inter-vehicle separation distances for safety purposes. With short-distance digital radio links, the DGPS position of each vehicle of a group can be broadcast to other members of the group. Upon receipt of each position, a vehicle can compute the distance to each member of the group and keep the required distances fore and aft.

3.5.5 Three Favorable Applications

In view of the ratings in Tables 3.2 through Table 3.7, three suggested applications can be made that will have benefits and can be implemented. The three suggested applications are:

1. Static GPS positions from emergency response vehicles of a single organization.

The installation of off-the-shelf GPS receivers in emergency response vehicles of a single organization for voice reports will provide the quickest benefits with minimum complexity.

Table 3.8 Examples of Applications

Method	Monitor Position	Route Adherence	Aid Emergency Response
Static GPS	N/A	N/A	Aid in hazardous material incident location identification. ——— Equip emergency response vehicles with GPS receivers and lat/lon display for voice reporting of position.
Static DGPS	Aid in identification of the correct side of the road of an incident. ——— Equip hazardous materials transporters with DGPS receivers and communication capability. Establish a communications center to receive the messages.	N/A	Aid in location of obscured environmental sites. ——— Equip emergency response vehicles with GPS receivers that report range values by digital link to a communications center for DGPS position computation and voice direction to sensitive sites.
Dynamic GPS	Provide for tracking of hazardous materials vehicles as they pass through successive jurisdictional areas. ——— Equip hazardous materials vehicles with GPS receivers and digital radio links for position reporting when polled, or by random transmission. Establish position tracking facilities by appropriate governments.	Provide route-made-good and planned route information of hazardous materials vehicles. ——— Equip hazardous materials vehicles with GPS receivers and digital radio links for position reporting when polled, or by random transmission. Establish route tracking facilities by appropriate governments. Include individual planned route and permitted route information.	Assist management observation and control of emergency response vehicle deployment to an incident. ——— Equip emergency response vehicles with GPS receiver and digital communications. Establish a communications center for reception and display of vehicle location data on appropriate maps.
Dynamic DGPS	Provide for tracking of hazardous materials vehicles as they pass through successive jurisdictional areas. ——— Equip hazardous materials vehicles with DGPS receivers and digital radio links for DGPS position reporting when polled. Establish position tracking facilities by appropriate governments. Correct side-of-road position identification will be possible.	Provide route-made-good and planned route information of hazardous materials vehicles. ——— Equip hazardous materials vehicles with DGPS receivers and digital radio links for position reporting when polled. Establish route tracking facilities by appropriate governments. Include individual planned route and permitted route information. Correct side-of-road information will be possible.	Assist management observation and control of emergency response vehicle deployment to an incident and location of sensitive sites. ——— Equip emergency response vehicles with GPS receiver and digital communications. Establish a communications center for reception of GPS data, computation of DGPS positions and display of vehicle location data on appropriate maps.

2. Dynamic DGPS positions from emergency response vehicles of a single organization.

The concept will provide the best position information with the least technical and implementation complexity. A single path data link from the vehicles to the communications center should be used if possible. Position computation in the center will reduce the potential for error by elimination of one communication event for each position determination.

3. Dynamic GPS positions for commercial hazardous materials vehicles, and dynamic DGPS positions for emergency response vehicles within a restricted area.

Provision of GPS positions of hazardous material transport vehicles moving through an area will provide route information and reasonable incident positions. Emergency response vehicles equipped to provide DGPS positions in the same area will gain improved tracking and dispatch efficiency and will provide accurate information for incident location and protection of sensitive sites.

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4. SERVICE DESCRIPTIONS

4.1 INTRODUCTION

A range of potential applications of GPS technology in hazardous materials transportation was named in Chapter 3. From the range of applications, three were selected as those with a potential either to promote economic, efficient, and safe transport of hazardous materials, or to expedite response to a hazardous material transport incident. Each of the three candidate applications will be expanded as service descriptions in terms of operational concept, service users, technical feasibility, performance criteria, business and government organizational impacts, schedules, public and private roles, interfaces with other systems, and benefits. An example application also will be presented with each service description.

4.2 DESCRIPTIONS

4.2.1 First Service Description: MONITOR AND/OR TRACK HAZMAT SHIPMENTS

4.2.1.1 Operational Concept

Concept. The concept involves tracking the positions of commercial hazardous material carrier vehicles anywhere within a defined area. All vehicles tracked will be shown on graphic displays in commercial and government operations centers. Emergency managers will have access to all information needed to support the most thorough and efficient response to a hazardous materials incident.

Under the concept, commercial carriers of hazardous materials will provide vehicle positions as GPS-derived latitude and longitude when they operate within a designated geographic area (e.g., a state or a metropolitan area), or along a designated route. Information will be provided via a digital radio message on a designated radio frequency. The message will include position, vehicle identity, and any other information required (e.g., cargo identity).[7] In application, progress by hazardous materials carriers along designated routes can be monitored. For example, "key trains" that contain significant amounts of hazardous materials can be observed in relation to established "key routes" per Association of American Railroads Circular No. OT-55-B.

Area-Wide Interconnection. With the wide geographic area involved in the concept, operations centers will not be isolated with only local information. Interconnection will be necessary with other operations centers that will provide pertinent information in regard to approaching traffic of concern.

4.2.1.2 Service Users

In general, the primary motivation for installing and operating AVL systems in the trucking industry is to give operators or carriers more fleet control. Reducing accidents and environmental damage generally are considered to be beneficial by-products which would not, by themselves, justify the investment. Chapter 5 covers this issue in more detail.

The main users will be commercial dispatchers and area traffic managers who may have regulatory obligations regarding special hazmat classes. Vehicle operators have a potential benefit through direction to safer, less circuitous, or less congested (hence, cost effective) routes.

4.2.1.3 Technical Feasibility

4.2.1.3.1 Commercial Carrier Vehicles

Equipment. To provide required information, each carrier vehicle will need (1) a GPS receiver with an antenna, an operator display, and a digital interface, (2) a control computer with interfaces for GPS and other data, and a device for manual or automated data entry, and (3) a radio receiver and transmitter with an interface for digital information transfer with the control computer. A diagram of the carrier vehicle equipment is shown in Figure 4.1. The GPS coordinates should be displayed to the operator of the carrier vehicle for added value from the system. When operated in areas not equipped to use the digital radio messages, the vehicle operator will be able to read the position by voice to any emergency manager, anywhere.

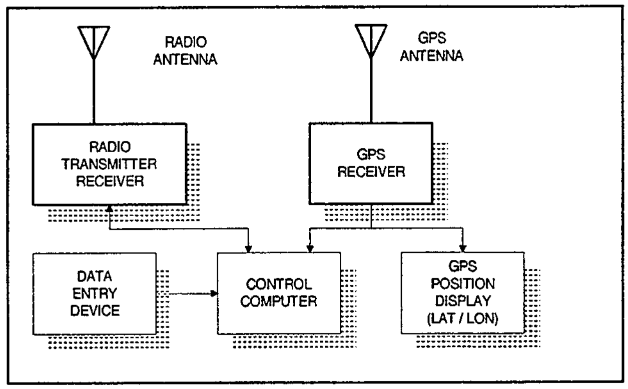

Figure 4.1 Carrier Equipment

Equipment Installation. If the carrier vehicle GPS equipment package, including the GPS antenna, requires a permanent installation, then it probably should be mounted on an unchanging part of the total vehicle (i.e., the tractor of a truck or the engine of a freight train). Suitable electrical power and a secure location for the electronic equipment will be needed. The GPS receiver antenna must be mounted on top of the vehicle to preclude blockage of the line-of-sight to all available satellites. GPS signals received from satellites will be very low in amplitude. In contrast, the radio signals transmitted to report position will be very high in amplitude. Consideration should be given to mounting the GPS and radio transmitting antennas at some distance apart to prevent damage to the GPS receiver. A more complex approach to protection of the GPS receiver can be blocking the receiver front-end electronically when the transmitter is active. If the equipment will be a self-powered, portable package including radio communication, then it will be mounted where most useful. For example, a portable package can be placed on the central car in a group of train cars that contain hazardous materials.

Communication. Use of existing radio equipment in commercial carrier vehicles may be feasible. It may be necessary to modify the existing radio transmitter to accept position reports from the GPS package. The reception of digital messages from the operations center to all vehicles also may be necessary if a vehicle polling concept is used. In any case, the radio frequencies to be used must be established. At the frequency bandwidths allocated for radio communications, the radio waves generally cannot reflect well off the upper atmosphere, or pass through solid objects such as buildings. Since the frequencies therefore may impose a range limited to line-of-sight, an array of repeater units may be needed to permit signal reception from anywhere in the designated geographic area. Terrain and buildings in the area will dictate any line-of-sight restriction that must be overcome. The use of satellite communication will be possible but expensive; it will have severe blockage problems in high terrain, and limited availability in the northern tier of states where communication satellites appear low on the horizon.

4.2.1.3.2 Operations Center

It will be necessary to have an operations center equipment suite as illustrated in Figure 4.2. All of the equipment will be available from commercial sources. Local operations centers will need a means to acquire data from nearby operations centers. Several dedicated telephone lines, modems, and commercial software can provide the inter-center communication necessary. A basic element in communication between centers will be data format compatibility. Standards should be established before equipment and software are procured (i.e., similar to RTCA or RTCM minimum standards).

4.2.1.4 Performance Criteria

4.2.1.4.1 Commercial Carrier Vehicles

Message Reliability. The hazardous materials carrier vehicles (i.e., trucks) will report their position in latitude and longitude via a digital radio link. Successful performance will require that the reported position information be current and accurate. The rate of position reports can vary widely depending on application. The interval between position reports can be used by the vehicle equipment mathematically to smooth computed GPS-based positions and to forecast the next position report from heading and speed computations. By smoothing information, the problem of reporting erroneous positions because of incorrect GPS measurements will be reduced. In addition, a smoothing capability may avoid the need to implement DGPS for some applications. A standard data format for vehicle reports should be established before many vehicles are equipped with off-the-shelf, and possibly incompatible, systems. If the vehicles transmit data in a variety of formats, each operations center along the routes will be required to accept and transform the data into a usable form.

Hazardous Material Location and Position Report Agreement. To be useful, a vehicle position report must be tied firmly to the actual position of the hazardous material cargo. The subject arose in comments on a study of a concept required by the Hazardous Materials Transportation Uniform Safety Act of 1990. Under the concept, every carrier of a hazardous material would transmit to a central facility a record of vehicle contents in a prescribed format [3]. A permanently installed GPS position reporting equipment package would be mounted on an unchanging part of the total vehicle to ensure best operation. A method will be needed to make certain that every hazardous cargo is moved only by a truck tractor that is equipped to report positions while in transit. If cargo identity is to be part of the vehicle message along with position, then en route vehicle changes will require message changes.

Minimum Performance Standard. A document should be developed that states minimum technical and performance standards to inform companies considering participation about position-reporting equipment that will be acceptable to business and government. Such a document will be similar to the Minimum Performance Standards issued by the RTCA and RTCM groups associated with air and marine equipment, respectively. The boundaries, or "terms of reference," for a standard will be prepared and issued before development of the standard begins. Primary responsibility for development of the terms of reference and for establishment of a group to write the minimum standard will lie within the DOT. Extensive industry participation in development of a minimum standard should be encouraged.

4.2.1.4.2 Operations Center

Equipment. An operations center will need to have an equipment suite as illustrated in Figure 4.2. It typically will be operated by a carrier or a government organization. All of the equipment required in the operations center will be available from commercial sources. If the basic GPS option is selected, a GPS receiver and associated equipment is not needed in the operations center.

Software. If DGPS is used, it may be necessary to develop software to apply the differential GPS correction values to vehicle measurements in the operations center computer. Software for calculation of geodetic coordinates from GPS pseudoranges[7] was developed in the past and can be used. A method to calculate distances and directions from vehicle positions to sensitive sites must be developed, but it will be relatively simple because a flat earth representation can be used for the short distances involved. For basic and differential GPS, software also will be needed to process message traffic from the vehicles. If a vehicle polling method is used for each position transmission, then the operations center computer will control the polling sequence. If vehicle transmission assignments are made by time designation, or by some other method, then the center computer will require software that can accommodate the message arrivals with correct vehicle identifications. Customization of graphic display software may be necessary to meet the needs of operations center staff and emergency managers.

[7] See the footnote in Section 3.3.2, p. 26, for a definition of *pseudorange*.

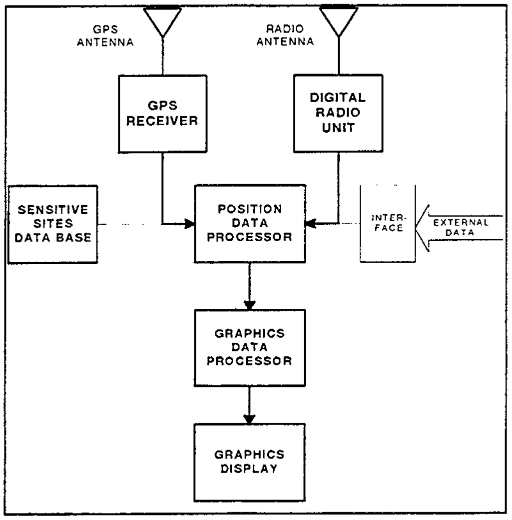

Figure 4.2 Operations Center

Data Interchange. The equipment suite may require a function to process the two-way flow of data between centers. Information from adjacent areas need not be as timely as that from the primary area of interest. The establishment of data communication criteria can be optimized without an overriding concern for the immediacy of external information.

Polling. Requests for position reports, or active polling, will require close coordination so that vehicles are not asked for reports at a rate beyond what is necessary. The polling rate should be as low as possible and be based on the operational need for updated position reports. Active polling should not be the first design choice because of the additional cost factors.

4.2.1.5 Organizational and Other System Impacts

4.2.1.5.1 Commercial Participation

Major Impacts. The most significant organizational impact in the concept will be the need for commercial hazardous materials carrier vehicles to carry a position reporting device when operating within a defined area, possibly an entire route extending hundreds of miles.

Participation Options. There are at least three ways to achieve the goal of GPS position reporting by commercial vehicles: (1) require the installation of equipment at the owner's expense, (2) require that each designated vehicle carry a government provided, portable tracking package, (3) seek voluntary participation and installation of specified equipment. The first two options are unlikely to be implemented in the near future. The third option will be the least rigorous of the three and could have the least participation until potential economic benefits to using GPS are realized. Effectiveness might be increased with some benefit for voluntary participants over non-participants.

4.2.1.5.2 Government Responsibilities

Use of Data. Questions might arise in relation to the use of the vehicle tracking data. For example, can successive position reports be used to measure the speed of a vehicle for enforcement of speed laws? Will information gathered by government organizations be provided to companies for tracking their own vehicles, or competitor's vehicles?

4.2.1.6 Time Frame for Implementation

Start Date. Again, it was assumed that off-the-shelf equipment and software will be used to the extent possible. This will reduce delays in initiating the acquisition process. A minimum standard still will be needed for the participating companies to use in purchase of equipment. The following schedule for industry implementation as indicated in Table 4.1 will be typical:

Table 4.1 Schedule for Implementation - Monitor/Track Hazmat Shipments

	Action	Time Required
1	Decision to implement the GPS position system	Start
2	Overall system design	3.0 months
3	Prepare minimum standard	2.0 months
4	Prepare specification & acquisition documents	2.0 months
5	Procure system	2.0 months
6	Install system and train personnel	3.0 months
7	Declare system operational	End
	Total time:	**12.0 months**

4.2.1.7 Public and Private Sector Roles in Implementation

The concept includes both public and private sector roles in implementation. Private companies will volunteer to carry equipment on their vehicles. Emergency services, including database access services, will be equipped with a new capability at public expense. Appropriate government agencies also will have a role as a clearinghouse for tracking and communications technologies, as well as being a repository for data.

4.2.1.8 Interface with the ITS

The commercial vehicle tracking function with GPS information will be part of the ITS under several projects. Any system procured can assure compatibility with the final ITS configuration by flexibility in data provided to outside devices. The greatest concern probably will be message format, content, and rate.

4.2.1.9 Benefits

Benefits from GPS position reports from commercial carriers of hazardous materials will be:

1. Efficiency. Efficiency in hazmat transport will improve from the early knowledge of the carrier vehicle location and from the ability to direct vehicles to alternate routes, or to respond to changes in the transport schedule or itinerary.

2. Safety. Safety will improve with the location of hazardous cargoes in relation to potential threats to safety (e.g., weather, accidents, traffic blockage).

3. Appropriateness. Appropriateness of any incident response will improve from real-time knowledge of the locations and capabilities of all responding emergency vehicles under the direction of an operations center and from a better knowledge of the hazardous material from the carrier reports. An important benefit will be the reduction in over-response to an incident.

4. Jurisdiction. Location information will be used to ensure that any incident is within the jurisdiction of the appropriate monitoring or responding authority.

These benefits will make the hazardous materials transport more economical and efficient.

4.2.1.10 Example Application

Advantage I-75. A potential application for GPS/DGPS in hazmat highway transport is the *Advantage I-75* program. *Advantage I-75* is a partnership of public and private interests along the Interstate I-75 corridor, including connections to Canada (Highway 401). Interstate I-75 extends from Detroit to Miami, and traverses a varied commercial and industrial area in which great volumes of hazardous materials are shipped regularly via all four transportation modes. The partnership goal is to enhance safety, increase efficiency, and reduce congestion for users of I-75. The project hopes to exploit mature ITS (IVHS) technologies that are economically attractive to potential participants in the highway environment. The project began in 1990 in Lexington, KY. Underlying project principles include small-scale projects (with incremental expansion), emphasis on implementation, use of proven, off-the-shelf technology, decentralized control, use of existing statutes and regulations, and public/private cooperation.

The 2,000 mile I-75/Highway 401 corridor now supports truck volumes of 4,500 per day. Highway 401 carries over 320,000 vehicles of all kinds daily in the Toronto area - the highest volume in North America. Trucks represent from 20 to 35 per cent of daily traffic along the corridor, hauling goods with an annual value of over $7 billion.

Weigh Stations. The need for administrators and enforcement authorities to monitor freight transits has led to the installation of a series of weigh stations along corridors such as I-75. The large volume of trucking along this corridor has severely strained the weigh station resources, resulting in costly delays (which can approach an hour per station), more air pollution from deceleration and acceleration, and potentially dangerous merging and diverging at entry/exit ramps to the weigh stations. A study conducted at the University of South Florida concluded that if all I-75 weigh stations could be replaced with mainline bypasses, the savings would total $260 million annually. A key element of Advantage I-75 is the development of a system which will allow properly instrumented and documented trucks to travel any segment along I-75 without having to make stops at several inspection stations along the way. The tracking capability provided by GPS can reduce to one the number of such stops along a trip segment.

The concept is as follows: at the beginning of a trip on the I-75 corridor, the truck stops at an inspection station and provides information on the date, time, location, weight, and number of axles. These data can be stored on the truck, and retrieved automatically while in motion en route. When developing weigh-in-motion technology is implemented, even the initial inspection stop could be eliminated for properly equipped vehicles. A simple two-way communication system can be used that would allow authorities to call in a truck in need of en route inspection.

GPS/DGPS Potential. A potential role for GPS in *Advantage I-75* is to utilize the automatic vehicle identification (AVI) equipment on participating trucks to report GPS position information. This information can be used primarily by the carrier company for activities such as route scheduling, monitoring the progress of the vehicle, etc. Regulatory authorities could use GPS to ensure that the truck did not conduct transactions since its initial "weigh-in" stop.

4.2.2 Second Service Description: Project Hazardous Materials Routes

4.2.2.1 Operational Concept

Concept. GPS position information from vehicles carrying hazardous materials will be used to: (1) aid in strategic route planning, (2) make possible tactical route decisions, and (3) ensure adherence to route restrictions. The goals of route planning and route employment are improved safety, reduction of costs, and adherence to schedules. Strategic planning by industry and government to achieve the goals will involve a combination of historical data, existing conditions, and long-term changes. Tactical route decisions will be based, in part, on vehicle and crew status, route conditions, short-term disruptions, unexpected lading changes, and weather. Past and present data on vehicle identity, cargo, position, time, and date will be essential. States and cities that establish required routes for certain cargoes will be able to observe and enforce compliance.

Use of Position Data. The position information needed will be basic GPS latitude and longitude with an accuracy of 100 meters, 95% of the time. Data will be used immediately on real-time graphic displays by tactical managers. Historical data will be stored for use by strategic planners.

4.2.2.2 Service Users

The consumers of the information will be company traffic managers and government traffic control organizations.

4.2.2.3 Technical Feasibility

There is little technical concern that GPS position reports can be delivered from en route vehicles to commercial or government operations centers.

4.2.2.3.1 Commercial Carrier Vehicles

Equipage of commercial carrier vehicles will be the same as described in Section 4.2.1.3.1.

4.2.2.3.2 Operations Center

Operations centers will be equipped as described in Section 4.2.1.3.2

4.2.2.4 Performance Criteria

Performance criteria for commercial carrier vehicles and operations centers will be identical to those described in Sections 4.2.1.4.1 and 4.2.1.4.2, respectively.

4.2.2.5 Organizational and Other System Impacts

4.2.2.5.1 Commercial Participation

Commercial participation will be voluntary. Use of the concept for strategic route planning and tactical route management will entail the installation of GPS equipment on commercial vehicles that carry hazardous materials. Such an installation will necessitate planning, budgeting, procurement, installation, and maintenance of the GPS devices, and training in their use and repair. Also, companies will need a central data display and data archiving facility for use by traffic managers and planners.

4.2.2.5.2 Government Responsibilities

Government organizations that participate will be concerned with safety in planned routes through their area of responsibility and in adherence to those routes. Each government entity will need an operations center to receive, display, and store data. Some interaction between the operations center and government safety officials probably will be required when vehicles are detected to be off planned or designated routes.

4.2.2.6 Time Frame for Implementation

The same assumptions are made as those made in Section 4.2.1.6 (i.e., commercial off-the-shelf equipment will be used). The following schedule for industry implementation as indicated in Table 4.2 will be typical:

Table 4.2 Schedule for Implementation - Project Hazmat Routes

	Action	Time Required
1	Decision to implement the GPS position system	Start
2	Overall system design	3.0 months
3	Prepare minimum standard	2.0 months
4	Prepare specification & acquisition documents	2.0 months
5	Procure the system	2.0 months
6	Install system and train personnel	3.0 months
7	Declare operational status	End
	Total time:	**12.0 months**

4.2.2.7 Public and Private Sector Roles in Implementation

The greatest burden will be on commercial carriers in implementation of the concept. Installation of GPS equipment in vehicles, establishment of operations centers, and the creation of staff positions for route planning and tactical management will be the responsibilities of participating companies. Public participation will involve approval of planned routes and assurance that vehicles adhere to routes and schedules.

4.2.2.8 Interface with the ITS

The interface with ITS will be the same as described in Section 4.2.1.8.

4.2.2.9 Benefits

Benefits derived from using DGPS for projecting routes for commercial hazardous materials carriers will be:

1. Cost. Cost savings will be realized through the efficient use of personnel and vehicles along planned routes, and selection of the most fuel efficient routes.

2. Schedule Efficiency. Schedule enhancement will result from more accurate departure and arrival times and accounting for needed lading changes en route.

3. Safety. Safety will improve because strategic route planning will incorporate consideration of infrastructure conditions, population centers, long-term weather conditions, and traffic density. Tactical route management will account for current weather conditions, accidents, road or rail repairs, and actual adherence to defined routes.

These benefits will make the hazardous materials transport more economical and efficient.

4.2.2.10 Example Application

HELP/Crescent. The Heavy Vehicle Electronic License Plate Program (HELP) project is a multi-state, multi-national research effort to design and test a heavy vehicle (truck) monitoring system using the AVI, Automated Vehicle Classification (AVC), and weigh-in-motion (WIM) technologies. The goal of *HELP/Crescent* is to demonstrate the technologies along a crescent-shaped corridor of interstate highways extending down the U.S. West Coast from British Columbia, and east to Texas. The focus of *HELP/Crescent* is commercial vehicles. Information obtained by the system would be used by carriers for tracking activity levels and to support financial and strategic planning; and by states to support tax administration, safety monitoring, and enforcement. These activities already exist, but *HELP/Crescent* can reduce greatly the inefficiencies of existing systems by using current technology in developing an integrated system to identify, weigh, and classify heavy vehicles at selected locations. The concept can be extended to specific hazmat applications and data requirements.

The primary *HELP/Crescent* partners are the Federal Highway Administration, the Arizona Department of Transportation, state governments along the HELP/Crescent corridor, and members representing motor carriers, including the California Trucking Association, the New Mexico Trucking Association, and the Western Highway Institute. The project ultimately should enhance efficiency and productivity in the trucking industry, and for the states, improve efficiency and provide a reduction in administrative burden. Operational field testing is under way along the entire corridor. Thirty-three reporting sites are functioning along the Crescent corridor and include mainline data collection sites, weigh stations, and ports-of-entry.

GPS/DGPS Potential. A potential role for GPS in *HELP/Crescent* is to utilize the AVI and AVC equipment on participating trucks to report GPS position information. This information can be used primarily by the carrier company to facilitate route scheduling, as well as to monitor the progress of the vehicle. This information will be of use in the timely development of projected routes designed to accommodate actual road conditions efficiently. Regulatory authorities could use GPS to ensure that trucks do not conduct transactions after their initial "weigh-in" stops.

4.2.3 Third Service Description: Aid Emergency Response to Hazmat Incidents

4.2.3.1 Operational Concept

Concept. GPS position coordinates can be reported to an operations center by digital link. The digital link will require less attention by the responders. As each emergency vehicle moves toward an incident site its position will be reported to the operations center, where it will be "visible" on a digital map display. Emergency response vehicles operated by a single organization (e.g., a county or city) will be equipped with a GPS receiver, a digital radio link, and a means to control the message traffic. In some hazmat incident response situations, DGPS may be a more cost effective system. An effective system would compute the DGPS position of each responding vehicle at the operations center.

DGPS Method. The GPS receiver on each emergency response vehicle will measure the pseudorange value[8] to each satellite in view. The vehicle transmitter, periodically, will send a digital message to the operations center. The message will contain the identification of the vehicle and the value of each measured GPS pseudorange, along with satellite identifications. At the operations center a GPS receiver simultaneously will measure satellite pseudorange values. A computer at the operations center will calculate the error in each measured satellite pseudorange (i.e., differential GPS corrections) and store those values. The error is based on the measured pseudoranges and precise (surveyed) knowledge of the operations center's location. When a vehicle message is received, the operations center computer will apply the stored corrections to the vehicle

[8] The pseudorange value is the raw data measured by the GPS receiver.

values and calculate the accurate differential GPS position of the vehicle in latitude and longitude.

Use of DGPS Position Data. The coordinates of the vehicle will never be available in the vehicle itself; they will be used only in the operations center. With the method described, the center will know the positions of all equipped emergency response vehicles to an accuracy of 5 to 10 meters with a 95% probability. The vehicles can be in motion or stationary. Vehicle locations will be shown on a computer-driven, graphic display. Accurate vehicle positions will aid in the location of nearby sensitive sites calibrated previously with the same DGPS method and stored in an operations center database (Section 3.2.1 (7)). With emergency vehicle locations and knowledge of routes in the vicinity, the operations center will have the information needed to direct vehicle movements for the most effective control of hazardous materials incidents.

4.2.3.2 Service Users

The user of the information will be emergency managers at the operations center. There will be little, if any, benefit to emergency responders on the scene to have knowledge on the latitude and longitude of the incident.

4.2.3.3 Technical Feasibility

The limitation in the use of differential GPS corrections to emergency vehicles operated by a single governmental entity will make possible the most accurate DGPS method. Local use will preclude the possible dilution of correction accuracy. In DGPS applications, accuracy decreases as distance increases from the source of differential correction values, although the satisfactory use of DGPS over a range of several hundred miles has been demonstrated. Also, there will be less risk of lost data than in a conventional DGPS where correction values are transmitted for position computations in the vehicle.

4.2.3.3.1 Emergency Response Vehicles

Installation. Vehicle installations will require: (1) a GPS receiver with an antenna and a digital interface, (2) a control computer with interfaces for GPS and other data, and a device for manual data entry, (3) a radio transmitter with an interface for digital information from the computer. The GPS receiver antenna must be mounted in a location on the top of the vehicle and clear of obstructions. The sensitive GPS receiver should be protected during vehicle radio transmissions. Housing in an electronically and mechanically protective enclosure, and suitable electrical power should be provided for the GPS unit and the computer.

Radio Equipment. It may be possible to use existing voice communication equipment in emergency vehicles, but modifications may be required to handle digital data from the GPS unit. The communication protocol used may require a two-way data interchange between the vehicle and the operations center. If two-way data communication is required, then a radio receiver in each vehicle will be necessary with digital demodulation capabilities and an interface for connection to the GPS package. A benefit/cost study may be important to compare modification of old radio equipment versus procurement of new equipment. If a different radio frequency band must be used for position report messages, then some new equipment will be needed throughout. Access to new radio frequency carriers for position message traffic should be approved before the communication equipment is specified.

4.2.3.3.2 Operations Center

Individual operations center installations essentially will be the same as that described in Section 4.2.1.4.2.

Off-the-Shelf Systems. Commercially available systems already exist that measure and display the locations of vehicles with GPS/DGPS data. Such systems may meet the requirements of an individual organization. Before an available system is procured it will be prudent to determine whether it can be compatible with other systems. In a situation where monitored vehicles could be moving through adjacent jurisdictions, each operations center in the area must be able to receive and use the same data format from the vehicles. Especially important in compatibility will be data message formats, data rate, polling methods, radio frequencies, digital modulation of the radio frequency carrier, and display resolution.

4.2.3.4 Performance Criteria

4.2.3.4.1 Emergency Response Vehicles

Communication Reliability. The GPS receiver and control computer must be rugged enough to withstand the environment of an emergency vehicle (i.e., shock mounted). The concept will permit near real-time tracking of the positions of all vehicles. To accomplish such tracking it will be necessary to have a reliable communication link. Reliable communication will be necessary for two reasons: (a) for the transmission of vehicle-based position information to the operations center, and (b) for vehicles to receive position requests from the center, if a polling concept is used. Reliable communication with moving vehicles may be difficult to achieve in other than flat terrain.

Position Determination Reliability. Since the concept requires current, vehicle-based position information when polled, it will be necessary for the GPS receiver to maintain continuous reception of satellite signals. For difficult antenna location problems it may be possible to augment the GPS information with magnetic heading and odometer information, or to add a Loran-C receiver to the installation. With the additional information, the operations center computer can predict position by dead reckoning methods to fill gaps in GPS signal reception, or use the Loran-C derived position.

4.2.3.4.2 Operations Center

Equipment Performance. The operations center GPS receiver installation (DGPS option) should be duplicated for reliability because the entire concept is based on the use of differential corrections derived from receiver data. It may be necessary for the receiver to have a more sophisticated antenna than those on the vehicles. A better antenna system will permit reception of satellite signals close to the horizon. With signals from low angle satellites, the operations center will be able to check satellite message quality before any position data are received from vehicles for the same satellites. The antenna also may be required to reject nearby interference sources.

Computer Functions. DGPS information processing functions in the operations center will be varied and simultaneous. The first function must process all data from the center GPS receiver(s) and from the vehicles, calculate differential corrections, compute each vehicle position in latitude and longitude, and provide polling requests. The second function, which also applies to basic GPS, must provide all graphic display support. The third function (GPS and DGPS) must hold the sensitive site database and calculate distances and direction to those sites for guidance to emergency responders.

Communication Performance. All communication facilities, other than those on vehicles, will be considered as part of the operations center capability. A digital radio capability must be established suited to the area of operation. If terrain blocking is a problem, the installation of repeater stations may be necessary. There may be a positive benefit/cost ratio in the use of commercial cellular telephone service by vehicles as an alternative to the installation of radio repeater stations. In either case, careful planning and tests will be necessary to ensure that vehicle-to-center data communications will be adequate.

Display Performance. Information displayed in the operations center for use by emergency managers must meet their needs to gain the full benefits of the system. It is probable that the managers will have strategic and tactical requirements that the displayed information can support. Strategic requirements will involve the overall planning and conduct of large-scale operations of the organization. Tactical requirements will include expedient actions for the achievement of immediate goals. Graphic displays that will accept a variety of types and scales of information must be planned to meet management requirements. The most typical display will be an array of icons that represent different types of vehicles moving on a road map of the local area. Other display levels will have locations of sensitive sites, locations of fire hydrants and water sources, planned roadblock locations and detour routes, and evacuation routes.

4.2.3.5 Organizational and Other System Impacts

Decision and Specification. The initial organizational impact will be the decision to procure GPS receivers for emergency response vehicles and the development of methods for use of the resultant information. The technical arm of the organization will prepare the specification for procurement of receivers with the required physical, electrical, and performance features. The technical group also will choose mounting locations for the GPS receiver, the display, and the antenna in each type of vehicle concerned, and it must prepare engineering documents and drawings. Long-term maintenance of the GPS equipment will be planned and appropriate training arranged for technical personnel. The operational group will determine how they will receive and record the voice information from vehicles, and how the information will be used to the fullest benefit. Any equipment needed at the operations center also will be specified for procurement.

Procurement The second impact will be procurement of the GPS equipment. If the procurement is competitive with proposals submitted by several vendors, a team with appropriate technical expertise will be needed to evaluate the proposals and recommend a source. After contract award, and before delivery, the organization technical group can begin preparation for installations and the operational group can develop procedures. Initial trials of the vehicle/operational combination can be conducted prior to full operation.

Message Format. In the dynamic, digital reporting concept, the full content of messages must be established before any equipment is specified (e.g., RTCM or NMEA formats). In addition to the geodetic coordinates of each vehicle, the operations center may need other useful data such as fuel level, stores and equipment available, personnel onboard, or meteorological data (e.g., wind direction, temperature, humidity). Everything that may ever be wanted in vehicle messages should be identified before the communication system and message formats are specified. Consideration of the full content of vehicle messages will, in turn, impose a requirement on operations center equipment and software to receive, process, store, display or use the message data. Beyond the single organization needs, the compatibility of message formats with systems in adjacent jurisdictions should be considered.

Equipment Test and Installation. The equipment procured from the specifications may be quite complex and will require a thorough, pre-delivery acceptance test by the organization. Detailed acceptance tests normally will be developed by the provider of the system and adopted by the procuring organization after review and approval. Vehicle installations must be designed on an individual class basis (e.g., fire truck, ambulance, car, etc.) because of the importance of GPS antenna location and the need to protect electronic units from mechanical or electrical harm. Operations center installations may require a separate room for the equipment and displays, and have cable access to the building roof for GPS and communication antennas. An extensive calibration project will be essential before the system can become operational. Known survey benchmarks can be used to measure the accuracy provided by the GPS system on the emergency vehicles and then with applied differential corrections in the operations center. Areas of GPS or communication signal loss or interference should be determined for later use during operations. Personnel who will operate and maintain the system must be trained and tested.

System Operation. After completion of all installations, system calibration, and personnel training, the system can be declared operational. The organization must provide day-to-day staffing of the facility in the operations center and develop maintenance policies for vehicle and center equipment.

4.2.3.6 Time Frame for Implementation

The same assumptions are made as those made in Section 4.2.1.6 (i.e., commercial off-the-shelf equipment will be used to the extent possible and adequate funds must be available). The operations center facility may require customization of software, or some new software, to accommodate the peculiar local situation (e.g., road maps, special strategic and tactical information needs, etc.). Preparation of the specifications will require significant time to ensure the completeness and compatibility of message formats, displays desired, and radio frequencies to be used. Acquisition will be a large effort that will include extensive acceptance testing. After the equipment is delivered and installed there will be a calibration and test period before operational status is declared. All of the factors cited will bring a time requirement to the implementation. The following schedule for industry and government working together as indicated in Table 4.3 will be typical:

Table 4.3 Schedule for Implementation - Emergency Hazmat Response

	Action	Time Required
1	Decision to implement the GPS position system	Start
2	Overall system design	4.0 months
3	Prepare specification & acquisition documents	4.0 months
4	Procure the system	7.0 months
5	Install system and train personnel	4.0 months
6	Declare operational status	End
	Total time:	**19.0 months**

4.2.3.7 Public and Private Sector Roles in Deployment

Only the public sector will be involved in deployment of the dynamic DGPS position reporting system. There will be no requirement for any actions by operators of commercial transportation systems.

4.2.3.8 Interface with the ITS

The emergency vehicle position data developed at the operations center can be used in the ITS. In a typical application, a collection of emergency vehicles near an incident will trigger ITS activity to reroute traffic around any roadway blockage. The interface necessary to deliver the data to the ITS is not defined, but the vehicle tracking system design should include the consideration for that future application. The most significant

ITS considerations probably will be message format, content, and rate. If some flexibility for delivery of data to the ITS is incorporated into the design, then future interconnection should not be a significant problem.

4.2.3.9 Benefits

Benefits from the DGPS position reports of emergency vehicles will be:

1. Safety. Safety will improve because of the location of a hazardous materials incident being available at an operations center for use in planning the protection of nearby people and property, as well as the *accurate* location of environmentally sensitive sites.

2. Efficiency. Efficiency of response will improve because of the ability to direct vehicles rapidly to the incident.

3. Appropriateness. Appropriateness of the response will improve because the operations center will have real-time knowledge of the locations and capabilities of all responding emergency vehicles under their direction.

4. Jurisdiction. Location information will be used to ensure that the on-site authority at an incident is within the appropriate jurisdiction.

4.2.3.10 Example Application

Operation Respond. A potential application for GPS/DGPS in hazmat rail transport incidents, *Operation Respond* is an information system developed by the Federal Railway Administration and a Houston, TX area industry consortium. The program, begun in 1992 with the primary goal of providing a 911 protocol for first responders to an incident, is now in the demonstration phase. Effective incident response can be realized when first responders have timely access to key information about hazardous materials involved in an incident.

The Port Terminal Railroad Association (PTRA) of Houston, a switching company representing participating railroads, is the major partner with the Federal Railroad Administration (FRA). Houston was chosen as the test site because of the large volume of dangerous petrochemicals which are transported into and out of the area. The PTRA operates switching facilities for Santa Fe, Amtrack, Union Pacific, Burlington Northern, Southern Pacific, and Houston Belt and Terminal. Over 200,000 hazardous material rail shipments were made in the Houston area in 1993, according to the PTRA. Of this number, 13 incidents were reported and addressed successfully by *Operation Respond*. *Operation Respond* is scheduled to be established at sites in New York, Louisiana, Texas, and Canada in the near future. Also, planning is underway at USDOT to extend the concept to the trucking industry.

Computer Link. The heart of *Operation Respond* is a computer link which connects 911 dispatch centers, fire, and police to a rail database. The database contains information about the contents of a rail car, and instructions on handling them. The computer terminals which link to the PTRA database are situated at 911 centers. First responders are instructed to call 911 and give the dispatcher the USDOT identification number of the rail car. The dispatcher then interrogates the database for the needed response information.

GPS/DGPS Potential. The toxicity and volume of the petrochemicals transported by rail, truck, and boat in the Houston area justifies the selection of *Operation Respond* as having potential for benefiting from GPS. There likely will be no practical use for DGPS which would justify the extra expense of that system. Potential need for GPS is based on the need to locate accurately the site of the incident. When location information is available to the dispatcher, a more effective allocation of response resources is possible.

5. EVALUATION OF BENEFITS AND COSTS OF GPS TECHNOLOGIES TO ENHANCE THE SAFE TRANSPORT OF HAZARDOUS MATERIALS

5.1 INTRODUCTION

Previous analyses conducted under this study have examined the requirements, technical feasibility, performance criteria, organizational, and other system requirements associated with the application of GPS/DGPS and related technologies to promote the safe transportation of hazardous materials. From a range of applications considered, three potential service descriptions were identified in Chapter 4 based on promoting the economic, efficient, and safe transport of hazardous materials, or on expediting the emergency response to a hazardous materials transport incident. These service descriptions were defined relative to three hazardous materials transport objectives:

- Monitor and/or track hazardous material shipments
- Project routes for hazardous materials transport
- Aid in the emergency response to hazardous material transport incidents

This analysis examines the relative costs and benefits on the application of GPS and related technologies (satellite communications and fleet tracking/management systems) for the safe and efficient transport of hazardous materials. Three case applications, involving highway (trucking) and rail transport of hazardous materials, were considered. This analysis addresses current industry practices and technologies available as a basis for identifying the most cost efficient means of applying GPS to support the safe transport of hazardous materials.

The framework, assumptions and results of this analysis are presented within the following subsections. Section 5.2 presents a summary description of the transport of hazardous materials in the trucking and rail industries. Section 5.3 presents a description of the current characteristics and applications of satellite/cellular communications and GPS vehicle tracking systems. The analysis framework, including a definition of the case applications considered and the study assumptions, are presented in Section 5.4. Sections 5.5 and 5.6 define, respectively, the system costs and postulated system benefits, relating to the cases under analysis. The final section, 5.7, summarizes the study results for the cases considered.

5.2 TRANSPORTATION OF HAZARDOUS MATERIALS

5.2.1 Movement of Hazardous Materials by Truck

The transportation of hazardous materials is a large and growing segment of the U.S. transportation industry. The U.S. Congressional Office of Technology Assessment, back in 1986, estimated in a report on Hazmat [10] that over 1.5 billion tons of hazardous materials were transported by land, air, and sea in the United States in 1982. Of this total, more than half (927 million tons) were transported by a fleet of 476,000 trucks.

Estimates on the number and volume of shipments of hazardous materials is limited by the sampling accuracy and availability of data within existing databases. The most recent and informative data,[9] that characterizes the shipments of hazardous materials by the trucking industry, is available within the 5-year "Census of Transportation" surveys,[10] conducted by the U.S. Department of Commerce [11]. The recently published 1992 Census of Transportation - Truck Inventory and Use Data (TIUS), which provides data on the physical and operational characteristics of the U.S. truck population,[11] was used as the primary source of data for estimates of the volume of truck shipments of hazardous materials and as a basis for estimating truck accident/incident rates of Hazmat shipments.[12]

The 1992 TIUS estimated a total 59.2 million trucks in the U.S., a 33% increase in the number of trucks (44.6 million) in 1987. The total truck-miles driven in 1992 was estimated at 786.3 billion miles, a 48.5% increase in the total truck-miles (529.3 billion) driven in 1987.

The 1992 TIUS contains estimates on the number of trucks registered[13] and the total truck-miles driven in the transport of hazardous materials. The TIUS also includes data on the characteristics of truck Hazmat shipments (i.e., number of trucks/truck-miles by Hazmat commodity type, 1-way trip range of Hazmat trucks/truck-miles, and the types of trucks used in Hazmat transport). As shown in Table 5.1, the total number of trucks registered and used in the transport of hazardous materials is 1.15 million, nearly 2% of the total US truck population. The total 1992 truck-miles driven in the transport of hazardous materials was approximately 11.6 billion miles.

Table 5.1 TIUS Estimates of 1992 Hazmat Trucks/Truck-Miles

1992 TIUS Data	Trucks (Thousands)	Truck-Miles (Millions)
Total U.S. population of trucks	59,200.8	766,273.9
U.S. trucks transporting Hazmat	1,151.6	11,586.0
% of U.S. trucks transporting Hazmat	1.9%	1.5%

9 The Truck Inventory and Use Survey (TIUS) was used, based on recommendations made by personnel of the Bureau of Transportation Statistics and the American Trucking Association, as the primary source of data on hazardous materials shipments by the trucking industry.

10 Most recent Truck Inventory and Use Survey (TIUS) data is available for years: 1982, 1987 and 1992.

11 The 1992 TIUS data is based on a probability sample of over 150,000 private and commercial trucks registered (or licensed) in each State during 1992. This survey is used to measure the operating characteristics of the estimated total population of approximately 60 million trucks in the U.S.

12 Hazmat incident data, reported to the U.S. DOT/RSPA, was used in this study and related to the overall volume of truck Hazmat shipments.

13 The TIUS estimates the total population of trucks based on State vehicle registrations. Since registration practices for commercial vehicles varies among the States (due to different or staggered registration dates), the TIUS adjusts the registrations for reporting on a 1992 calendar-year basis. Only truck power units are included in the TIUS registered truck counts.

By comparison, the total number of trucks transporting hazardous materials in 1987 was estimated (by the 1987 TIUS inventory) at 340.1 thousand, with a total truck-mileage of 14,523.1 million miles.

The U.S. chemical industry [12] estimates that approximately 65% of the truck shipments of petrochemicals, are shipped by "truckloads for hire" carriers, 5% by "less-than-truckload for hire" carriers, and the remaining 30% by private carriers (i.e., petroleum and chemical companies). Over the past decade, the trucking industry has made significant gains into the market share of railroads in the transportation of petroleum, chemicals, and allied products. Trucks are used more in the transport of intermediate-range bulk shipments and short-range, small-volume packaged products.

Table 5.2 presents the estimated number of trucks and truck-miles carrying hazardous materials, as reported in the 1992 TIUS truck inventory. As shown, the primary hazardous materials shipped by truck are flammable and combustible liquids (Hazard Class 3), corrosive materials (Hazard Class 8), and flammable gas and solids (Hazard Classes 2.1 and 4).

Table 5.2 TIUS Estimates of 1992 Hazmat Trucks/Truck-Miles (by Hazmat Class)

1992 Hazardous Materials Shipments by Truck				
Hazard Class	**Trucks (Thousands)**	**% of total**	**Truck Miles (Millions)**	**% of total**
1.1 - 1.6 Explosives	92.2	8.0%	482.2	4.2%
2.1 Flammable Gas	103.9	9.0%	1,560.7	13.5%
2.2 Non-Flammable Gas	74.7	6.5%	692.3	6.0%
2.3 Poison Gas	28.9	2.5%	161.3	1.4%
3 Flammable/Combustible Liquid	292.3	25.4%	3,718.3	32.1%
4 Flammable Solid	132.2	11.5%	574.8	5.0%
5.1 Oxidizer	114.2	9.9%	777.3	6.7%
5.2 Organic Peroxide	30.6	2.7%	154.5	1.3%
6.1 Poison B	82.6	7.2%	357.3	3.1%
7 Radioactive material	22.6	2.0%	106.4	0.9%
8 Corrosive Material	129.3	11.2%	1,475.6	12.7%
9 Miscellaneous	39.4	3.4%	375.7	3.2%
not reported	8.7	0.8%	1,149.6	9.9%
Total	**1,151.6**	**100.0%**	**11,586.0**	**100.0%**
Source: US Dept. Commerce / 1992 Truck Inventory and Use Data				

The TIUS data, showing the number of trucks and truck-miles by range of operation (one-way range) in the transport of hazardous materials, was used to develop an estimate of the total number of 1992 Hazmat shipments by truck.[14] This estimate of total Hazmat truck shipments was used in this study to establish estimated volumes of truck shipments (for the cases under analysis) and to establish truck Hazmat accident/incident rates on a per truck shipment basis.

[14] The TIUS data does not provide estimates of the annual number of truck shipments of hazardous materials by trucks. Data, showing the distribution of trucks and truck-miles one-way range of operations, is available and can be used to develop an estimate of total annual truck shipments of hazardous materials.

Figure 5.1 illustrates the distribution of truck-miles carrying hazardous materials by range (one-way range) of operation. As shown, the truck-miles of hazardous materials transported less than 50 miles (3,109 million) was 27% of the total 1992 Hazmat truck-miles (11,586 million), nearly equal to the estimated truck-mile shipments in excess of 500 miles (one-way range). The total 1992 truck miles of hazardous materials transported within a one-way range of less than 200 miles was 6,134 million-miles (53%) as compared to 47% (5,453 million-miles) for Hazmat trips greater than 200 miles (one-way).

Forty-two percent of trucks carrying Hazmat (484.7 thousand trucks) operate within a one-way trip range of less than 50 miles; while a total of 545 thousand trucks (47%) have one-way trip lengths greater than 100 miles.

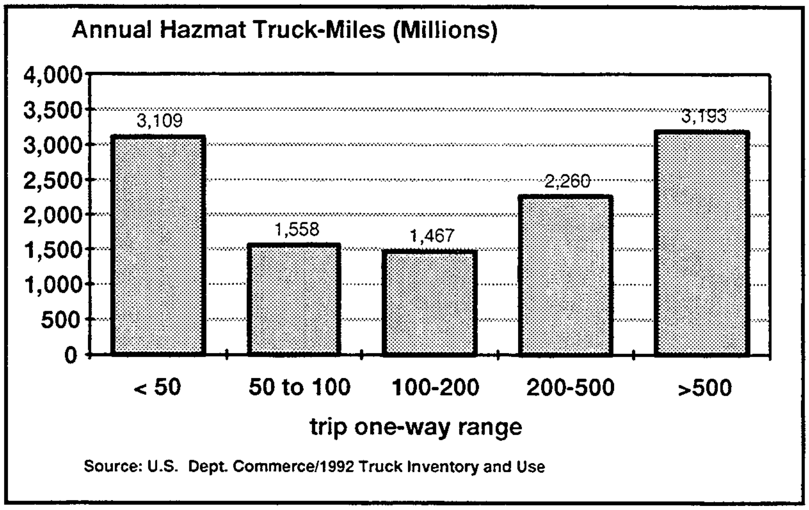

Figure 5.1 TIUS 1992 Hazmat Truck-Miles

Based on the TIUS data identifying the estimated volume of trucks and truck-miles carrying hazardous materials by range of operation, it is estimated[15] that the total number of truck shipments of hazardous materials in 1992 is approximately 94.2 million. Table 5.3 summarizes the estimates on the volume of Hazmat truck shipments used in this analysis.

[15]The volume of Hazmat shipments by truck in 1992 was estimated by taking the distribution of annual Hazmat truck-miles (shown in Figure 5.1) by one-trip range to calculate a weighted average (one-way) trip length per Hazmat shipment. The volume of Hazmat shipments (in 1992) was then calculated by taking total Hazmat truck-miles divided by weighted average trip length per Hazmat shipment. This value of Hazmat shipments was used to establish a projected volume of Hazmat shipments for 1995 and a prorated share of Hazmat truck shipments for each of the trucking cases considered in this analysis.

Table 5.3 Estimated 1992 Truck Shipments of Hazmat

Total US Estimated Truck Shipments of Hazmat	(in thousands)	94,168.2
Total US Trucks with Hazmat	(in thousands)	1.151.6
Total US Hazmat Truck-miles	(in millions)	11,586.0
Average miles per Hazmat truck shipment		123
Average annual Hazmat shipments per truck		82

5.2.2 Movement of Hazardous Materials by Rail

Railroads account for approximately 25% [12] of the total tonnage of chemicals and chemical allied products (approximately 136 million tons) transported in 1993. Rail is the common mode of transport for the shipment of commodity chemicals such as chlorine, alkalies, bulk petrochemicals and industrial inorganic chemicals.

Data on the shipments of hazardous materials by rail are generally available from databases maintained by individual railroads and data compiled by the Association of American Railroads (AAR). The AAR maintains a comprehensive database, TRAIN-II, on the movement of approximately 90% of the rail traffic in the U.S.[16]

A summary of the AAR's TRAIN-II database [13] on Hazmat car originations shows that the volume of rail car shipments has remained relatively constant over the 1988-1993 time period (the latest available data from the AAR). The total rail car originations of hazardous materials over this period is presented in Table 5.4.

Table 5.4 Rail Carload Originations of Hazmat (1988-1993)

Year	Hazmat Car Originations	Year	Hazmat Car Originations
1988	1,153,926	1991	1,359,373
1989	1,523,774	1992	1,361,817
1990	1,404,203	1993	1,497,464
Source: Association of American Railroads			

The largest number of rail car originations of hazardous materials is freight rate/freight forwarder traffic. These are loads of hazardous materials that are shipped under special contract rates or intermodal traffic (trailer or container on a rail flat-car), which may contain more than one type of hazardous material. In 1993, a total of 380,581 carloads of freight rate/freight forwarding hazardous materials shipments were transported by U.S. railroads.

Table 5.5 illustrates the distribution of rail car shipments of hazardous materials, by Hazmat class, exclusive of the rail freight rate/freight forwarding Hazmat car shipments.

[16] All of the major Class-I freight railroads and many of the short-line and regional railroads report their waybill information, car interchanges, and car locations into the AAR TRAIN-II system.

As shown, the primary hazardous materials shipped by rail are the flammable and combustible liquids (Hazard Class 3), corrosive materials (Hazard Class 8), and flammable/non-flammable gases (Hazard Classes 2.1 and 2.2).

Table 5.5 1993 Rail Hazmat Shipments (by Hazmat Class)

1993 Hazardous Materials Shipments by Rail		
Hazard Class	**Rail Car Shipments**	**% of all Shipments**
1.1 - 1.6 Explosives	6,566	0.6%
2.1 Flammable Gas	196,812	18.1%
2.2 Non-Flammable Gas	68,096	6.3%
2.3 Poison Gas	56,722	5.2%
3 Flammable/Combustible Liquid	302,967	27.9%
4 Flammable Solid	7,409	0.7%
5.1 Oxidizer	42,022	3.9%
5.2 Organic Peroxide	94	0.0%
6.1 Poison B	31,253	2.9%
7 Radioactive Material	217	0.0%
8 Corrosive Material	249,725	23.0%
9 Miscellaneous	124,720	11.5%
Total	1,086,603	100.0%

Source: Association of American Railroads
Note: Number of Car Shipments does not include Freight Rate or Shipper Traffic

5.3 SATELLITE/CELLULAR COMMUNICATIONS AND VEHICLE TRACKING SYSTEMS

5.3.1 Existing Systems And Applications

Over the past five to seven years, there has been a significant growth in the application of satellite/cellular communications and satellite vehicle tracking systems within the transportation industry. Estimates from industry trade journals[17] and individual suppliers of these technologies indicate that the current number of fleet installations approaches 200,000 vehicles (primarily in the trucking industry) and over 500 transportation firms.

The market for providing satellite/cellular communications and fleet tracking/management systems is highly competitive. Currently, there are primarily five to eight major suppliers that provide satellite communications and fleet management services to the transportation industry. For this analysis, product information was obtained and communications were held with five of these suppliers to identify the capabilities, costs, and industry applications of these systems. These suppliers, and their satellite/cellular communication and fleet tracking/management systems, were:

- Qualcomm, San Diego, CA - OmniTRACS® [14] satellite communications and vehicle tracking and fleet management system.

[17] Sources: "Inside IVHS" and "Transport Topics."

- American Mobile Satellite Corp., Reston, VA - SKYCELL® [15] satellite communications and vehicle tracking/fleet management system.
- Rockwell Highway Transport Electronics, Cedar Rapids, IA - TripMaster® and FleetMaster® [16] satellite communications and vehicle tracking/fleet management systems.
- Highway Master, Dallas, TX - Highway Master® [17] cellular communications and vehicle tracking/fleet management system.
- North American Collection & Location by Satellite, Inc. Landover, MD - RailTrax® [18] satellite-based 'passive' vehicle tracking system.

Discussions were also held with a number of transportation (trucking) firms and governmental transportation agencies (Department of Energy, Sandia National Laboratory and the DOD Naval Ordnance Center) that utilize these systems for both general freight and hazardous materials transport. Data obtained from these sources served, in the analysis, as the basis for determining the system costs and potential benefits of these systems within the transportation industry. Appendix A presents summary descriptions of the DOE Sandia STARBASE system and the DOD Defense Transportation and Tracking System (DTTS) satellite communication/vehicle tracking systems used in the transportation of hazardous materials.

5.3.2 Characteristics of Current Systems

The major elements of all of these systems include the following (see Figure 5.2):

- A communications satellite or cellular communications network to provide data (and/or voice communications) from a fleet dispatch center (via communications center) to/from vehicle fleet.
- A data communication center that provides transmissions of data messages to a communications satellite to/from vehicles and transportation dispatch centers.
- In-vehicle equipment capable of transmitting/receiving data messages. These units normally include a GPS receiver that receives and determines vehicle position fixes from the GPS system for encoding into vehicle data communications.
- Transportation dispatch center processing equipment and fleet tracking and management software for handling fleet dispatch, communications, and fleet management operations.

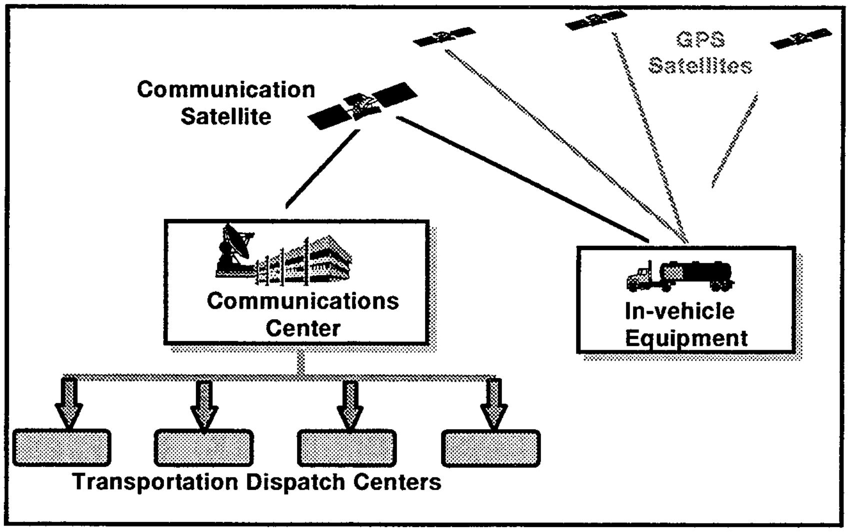

Figure 5.2 Satellite Communication/Vehicle Tracking System

Most of the existing systems provide satellite communications, using communication channels leased from providers of satellite communication services. The satellites are geosynchronous or low-earth orbiting and have relatively good coverage of North and Central America.

Vehicle positioning and tracking is accomplished either through satellite ranging (off of the communications satellite) or through GPS position fixes received by the vehicle through an in-vehicle GPS receiver and encoded in the vehicle-to-dispatch center data messages. Accuracy of vehicle position fixes are in the range of 100-300 meters (GPS and satellite ranging).

All of these systems[18] provide data communications (and/or voice, in some cases) between the equipped vehicles and carrier dispatch centers through data messaging. Vehicle polling is normally at a frequency of once per hour. All of these systems offer dispatch center fleet management systems, with a range of features for monitoring/tracking vehicles, scheduling shipments, and maintaining fuel and driver records.

[18] With the exception of RailTrax, a 'passive vehicle positioning/reporting system,' that reports rail car position based on satellite ranging off of a low-earth orbit satellite. Because of satellite coverage, position reports are usually made at a frequency of 4-6 position fixes per day.

Table 5.6 summarizes the major characteristics of the systems.

Table 5.6 Characteristics of Existing Satellite Vehicle Tracking/Fleet Management Systems

System Attribute	Description
System components	• Communications satellite or cellular communications network • Centralized satellite communications center • Vehicle communications unit • Transportation dispatch communications and fleet management system
Vehicle components	• On-board communications transmitter/receiver • Communications antenna • GPS/DGPS receiver (built-in unit) /antenna • On-board vehicle sensors (specialized applications) • Emergency (panic) button/alarm
Methods of vehicle tracking	• Satellite ranging • GPS/DGPS positioning • LORAN-C
Types of vehicle communications	• Voice • Data messaging • Voice and data messaging
Vehicle positioning accuracy	• 100-300 meters (using GPS or satellite ranging) • Increased accuracy with DGPS
Vehicle polling rate	• Usually once per hour • Immediate vehicle message under emergency situations
In-vehicle equipment costs	• $2,000 to $4,000 per vehicle unit including GPS receiver and unit installation on vehicle. • Life of in-vehicle equipment - 5 years
Vehicle - dispatch center communication costs	• $80 to $120 per month, per vehicle (depending on polling rate and volume of data transmissions) for satellite communications. • $100 to $180 per month, per vehicle (depending on polling rate and volume of voice/data transmissions) for cellular communications.
Dispatch center equipment	• Dispatch display/data processing equipment (computer workstations) • Fleet management software • Dispatch data communications equipment
Dispatch center equipment costs	• $10,000 to $50,000 depending on the size of installation and the processing features of fleet management system. • Life of dispatch center equipment and software - 10 years

5.4 STUDY FRAMEWORK

5.4.1 Hazardous Materials Service Description Objectives

From a range of potential service applications considered, preliminary analyses, conducted under this study, identified three primary service description objectives to promote the economic, efficient, and safe transport of hazardous materials, or to expedite the emergency response to a hazardous materials transport incident. They are

- Monitor and track hazardous material shipments.
- Project routes for hazardous materials transport.
- Aid in the emergency response to hazardous material transport incidents.

Potential benefits that could be derived with the application of GPS and related technologies (satellite communications and fleet tracking/management systems) for these Hazmat service description objectives were considered with respect to rail and highway (trucking) case applications.

Table 5.7 presents a summary of the potential benefits for each of the three Hazmat service description objectives while Section 5.4.2 defines the rail and highway (trucking) case applications under analysis.

Table 5.7 Potential Hazmat Service Description Benefits (Rail and Highway Cases)

Hazmat Service Description Objectives	Case 1 Rail Application	Cases 2 and 3 Highway (Trucking) Applications
Monitor and track Hazmat shipments	• Accurate positioning of Hazmat shipments. • Improved information on location of Hazmat incidents.	• Accurate positioning of Hazmat shipments. • Strategic control of Hazmat shipments. • Improved information on location of Hazmat incidents.
Project routes for Hazmat transport	• Improved scheduling and dispatching of Hazmat shipments. • Strategic route planning of Hazmat shipments.	• Improved scheduling/dispatching of Hazmat shipments. • Strategic route planning of Hazmat shipments. • Monitor adherence to routing/travel time guidelines. • Tactical (real-time) routing of Hazmat shipments to avoid highway traffic delays (weather, construction, congestion).
Aid in the emergency response to Hazmat incidents	• Identification of exact location of Hazmat incidents. • Improved response time to Hazmat incidents. • Improved efficiency in responding to Hazmat incidents.	• Identification of exact location of Hazmat incidents. • Improved response time to Hazmat incidents. • Improved efficiency in responding to Hazmat incidents.

5.4.2 Case Applications

This analysis considered three case applications, representative of the potential applications associated with the transport of hazardous materials within the trucking and rail industries. They are

- a large rail application, involving a composite of seven Class-I railroad operations within the U.S.
- a large highway (trucking) application, involving a composite of 668 specialized commodity carriers within the trucking industry.
- a small-medium highway (trucking) application, involving a composite of 100 petro-chemical commodity carriers within the trucking industry.

5.4.2.1 Case #1: Rail Application (Composite of 7 Class-I Railroads)

This case examines the application of GPS and related technologies for a composite of seven Class-I U.S. railroads. The total operations of these rail lines represent approximately 80% of both the total carload originations and rail Hazmat carload originations of Class-I railroads in the U.S. Table 5.8 presents a profile of the total operations (1993)[19] of these rail lines based on financial and operating data provided to the AAR [19].

Table 5.8 Case 1: Large Rail Application

Case Application: Large Rail Composite of 7 Class 1 Rail Systems (1993 Operations)	Units	Total (all Rail Lines)	Average (per Rail Line)
Miles of road operated		107,985	15,426
Freight cars in service		504,072	72,010
Locomotives in service		16,063	2,295
Operating Revenue	millions	$26,183.4	$3,740.5
Operating Expenses	millions	$22,237.8	$3,176.8
Net Operating Income	millions	$2,188.9	$312.7
Carloads originated - Total		19,129,153	2,732,736
Carloads originated - Chemical Products		1,364,662	194,952
Carloads originated - Petro Products		299,997	42,857
Tons Originated	millions	1,235.5	176.5
Ton-miles	millions	1,013,360	144,766
Train Miles		372,448,984	53,206,998
average haul/carload	miles		588
tons/carload			65
Revenue per carload originated	$-per carload		$1,368
Cost per carload originated	$-per carload		$1,163
Projected 1995 Hazmat Shipments		**1,200,000**	

[19] These data on the operations of the Class-I railroads represents the most current data available from the Association of American Railroads (AAR).

As shown, the total annual 1993 revenue operations of these rail lines approaches $26.2 billion, with the average annual revenue per rail line of $3.7 billion. This case considers equipping a total fleet of 16,063 locomotives with in-vehicle tracking/communications equipment for the monitoring of rail hazardous materials carload shipments.[20] The average haul of the rail shipments was 588 miles, with an average cost per shipment of $1,163 (per carload originated).

This case analysis assumes a 1995 (base year) traffic movement of 1.2 million carload shipments of hazardous materials (an average of 171.4 thousand carloads per rail line) and an assumed growth in the volume of Hazmat rail car shipments of 1% per year, over the twenty-year time horizon of this analysis (1995-2014). The assumed volume (1.2 million) of rail carload shipments of Hazmat was based on a prorated share of carload originations of petrochemical products for the seven Class-I railroads (considered in this case) to the total petrohemical carload originations of all Class-I railroads. The assumed growth rate of Hazmat rail shipments (1% per year) is a conservative estimate, considering that over the six-year period (1988-1993) Hazmat rail car originations increased at an average annual rate of 5% and over the past three years (1991-1993) at an average rate of 3% per year.

5.4.2.2 Case #2: Large Trucking Application (Specialized Goods Movement)

This case considers the application of GPS and related technologies in the transport of hazardous materials within a large highway (trucking) application, involving a composite of 668 trucking firms that transport materials classified[21] as 'specialized goods'. These carriers are generally long-haul trucking firms, carrying full-truck load shipments of average hauls in excess of 200 miles. Table 5.9 presents a profile of the total 1993 operations of these carriers, based on the most recent carrier financial and operating data available [20].

As shown, total 1993 revenue operations of these firms were $12.2 billion, with an average annual revenue of $18.3 million per carrier. In 1993, these carriers transported over 451 millions tons at an average haul of 279 miles and an average shipment cost of $1.45 per truck-mile.

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[20] This case assumes/utilizes a Class-I rail industry average of 62 rail cars per train-consist and 5 Hazmat rail cars per train consist. The number of rail cars per train consist for Class-I railroads was based on data provided by the AAR. The assumed number of Hazmat cars per train consist was based on the ratio of carloads originated for petrochemical products to total rail carload originations.

[21] These 'carriers of specialized commodities' represent trucking firms that are involved in the long-haul transport of commodities such as petroleum and chemical products, film and associated commodities, and dangerous/hazardous materials. They represent approximately 10%-15% of the overall trucking industry (full truck load and less-than-truck load') carriers.

Table 5.9 Case 2: Large Trucking Application

Case Application: Large Trucking Composite of 668 Specialized Trucking Carriers (1993 Operations)	Units	Total (all Trucking Firms)	Average (per Trucking Firm)
Gross Freight Revenues	thousands-$	$12,228,549	$18,306
Total Operating Expenses	thousands-$	$11,729,985	$17,560
Net Carrier Income	thousands-$	$296,663	$444
Operating Ratio		95.9%	95.9%
Net Profit Margin		2.4%	2.4%
# Tractors		48,543	73
# Trailers		138,426	207
Total Hwy.-miles Operated	thousands	8,089,946	12,111
Tons Transported	thousands	451,088	675
Ton-Miles	thousands	125,654,196	188,105
Revenue/Mile	dollars		$1.51
Average Load	tons		15.53
Average Haul	miles		278.56
Operating cost per mile	dollars/mile		$1.45
Projected 1995 Hazmat Shipments		**4,000,000**	

This case considers equipping a total fleet of 48,543 tractors with in-vehicle tracking and communications equipment for the monitoring of hazardous material shipments of these carriers. Each carrier is assumed to have a fleet of 73 tractors equipped with communications equipment. This case analysis assumes a 1995 (base year) traffic movement of 4.0 million truck-load shipments of hazardous materials and an assumed growth in the volume of Hazmat shipments of 1% per year, over the twenty-year time horizon of this analysis (1995-2014). This volume of shipments was developed based on the 1993 TIUS estimated Hazmat shipment data (see Section 2.1).[22] It represents approximately 24% of the total annual long-haul volume of Hazmat shipments (estimated at 16.4 million) transported by the truck in the U.S. The estimated 1995 base-year volume of Hazmat shipments (4.0 million), assumed in this case, represents an annual (1995) volume of around 5,988 shipments per carrier (82 Hazmat shipments per year per equipped tractor).

5.4.2.3 Case #3: Small-Medium Trucking Application (Petrochemical Movement)

This case considers the application of GPS and related technologies in the transport of hazardous materials within a small-medium trucking application, involving a composite of 110 trucking firms that transport petroleum and chemical products. These carriers are generally short-haul trucking firms, carrying full truck-load shipments, with average hauls of less than 200 miles. Table 5.10 presents a profile of the total 1993 operations of these carriers, based on the most recent carrier financial and operating data available [20].

[22] This analysis estimated a total volume of 94.2 million annual (1992) Hazmat shipments by truck, based on the 1992 TIUS data. Of this total volume, it was estimated that 17% of these shipments (16.4 million) were long-haul shipments (greater than 150 miles per one-way haul) and the remaining 83% of the shipments (77.7 million) were short-haul shipments (less than 150 miles per 1-way haul).

As shown, total 1993 revenue operations of these firms were $2.6 billion, with an average annual revenue of $23.9 million per carrier. In 1993, these carriers transported over 134 millions tons[23] of petroleum and chemical products, at an average haul of 171 miles and an average shipment cost of $1.71 per truck-mile.

This case considers equipping a total fleet of 10,497 tractors with in-vehicle tracking and communications equipment for the monitoring of hazardous material shipments of these carriers. Each carrier is assumed to have a fleet of 95 tractors equipped with communications equipment. This case analysis assumes a 1995 (base year) traffic movement of 2.4 million truck-load shipments of hazardous materials and an assumed growth in the volume of Hazmat shipments of 1% per year, over the twenty-year time horizon of this analysis (1995-2014). This volume of shipments was developed based on the 1993 TIUS estimated Hazmat shipment data (described in Section 5.2.1).

The estimated 1995 base-year volume of Hazmat shipments (2.4 million) represents approximately 3% of the total annual short-haul volume of Hazmat shipments (estimated at 77.7 million) and 2.5% of the total annual Hazmat shipments transported by the truck in the U.S. The estimated 1995 base-year volume of Hazmat shipments (2.4 million), assumed in this case, represents an annual (1995) volume of around 21,800 Hazmat shipments per carrier (230 Hazmat shipments per year per equipped tractor).

Table 5.10 Case 3: Small - Medium Trucking Application

Case Application: Small-Medium Trucking Composite of 110 Petro Product Trucking Carriers (1993 Operations)	**Units**	**Total (all Trucking Firms)**	**Average (per Trucking Firm)**
Gross Freight Revenues	thousands-$	$2,637,723	$23,979
Total Operating Expenses	thousands-$	$2,508,580	$22,805
Net Carrier Income	thousands-$	$90,811	$826
Operating Ratio		95.1%	95.1%
Net Profit Margin		3.4%	3.4%
# Tractors		10,497	95
# Trailers		31,176	283
Total Hwy.-miles Operated	thousands	1,464,452	13,313
Tons Transported	thousands	134,780	1,225
Ton-Miles	thousands	23,081,334	209,830
Revenue/Mile	dollars		$1.80
Average Load	tons		15.76
Average Haul	miles		171.25
Operating cost per mile	dollars/mile		$1.71
Projected 1995 Hazmat Shipments		**2,400,000**	

[23] This volume of shipment represents total tons transported by these firms. The bulk of these shipments are classified as shipments of petroleum and chemical products.

5.4.3 Study Assumptions

The primary assumptions and guidelines used in this study were:

- OMB guidelines [21] for the performance of benefit/cost analyses of Federal programs were followed.
- Departmental guidelines [22, 23] were followed and 1995 data on the value of a 'fatality averted' and 'injury averted' were used in determining the impacts of hazardous materials incidents. These guidelines[24] establish monetary values, based on "collective willingness of society to pay for reduced risks of fatalities and injuries," to be used in the evaluation of DOT regulations and investments to improve transportation safety.
- The study considered a twenty-year time horizon (1995-2014) in the evaluation of overall system benefits and costs. A twenty-year time horizon was selected to cover the normal life-cycle of major capital acquisitions considered in the analysis and as a nominal period for the realization of expected benefits as a result of these capital investments.
- All costs and benefits are reported in constant and discounted 1995 dollars.
- The OMB recommended discount rate of 7% as used.

5.5 SYSTEM COSTS

The primary system costs identified with the application of GPS and related technologies (satellite communications and fleet tracking/management systems) to track and monitor the movement of hazardous materials within the trucking and rail industries would include costs for:

- in-vehicle fleet equipment and fleet communications
- fleet dispatch center equipment and fleet management operations.

5.5.1 Fleet Equipment and Fleet Communications Costs

In-vehicle fleet data communications equipment for transmitting and receiving digital data messages from a transportation dispatch/operations center, through satellite communications, is a proven technology that has been used, primarily by the trucking industry, since 1987. Current estimates indicate the application of this technology has been installed and is operational in trucking fleets (estimated over 200,000 trucks equipped) in over 500 transportation firms.

[24] The referenced guidelines provide a detailed description of the rationale and guidance for assessing the value of reduced risks in avoiding injuries and fatalities associated with transportation accidents.

Cost estimates (shown in Table 5.11) were developed based on discussions with current suppliers[25] of this equipment, providers of satellite communications services, and several trucking firms[26] that utilize satellite communications and vehicle tracking systems. Capital costs for in-vehicle equipment range from $2,000 to $4,000 per vehicle, depending on the types of data communication options/features desired (i.e., emergency panic alarm) and the number of units procured for fleet installation. This analysis assumed a per vehicle unit cost of $3,500, including costs of in-vehicle installation, emergency panic alarm, and the cost of a built-in GPS receiver.[27] This cost does not include any costs for the installation of remote sensors (i.e., truck cab and trailer vehicle intrusion, temperature or environmental sensors. etc.), that are available on several of these systems. A capital equipment life of five years was assumed[28] for the in-vehicle communications equipment.

Fleet communication costs, for vehicle positioning and data messaging from the vehicle to transportation dispatch centers, through satellite communications and a satellite communications center, range from $80 - $120 per month, per equipped vehicle. These costs are based on having only data messaging (non-voice) capability[29] between the equipped vehicle fleet and firm dispatch centers. These costs also assume having vehicle positioning information (from satellite ranging or GPS position fixes) encoded in the data transmissions based on a vehicle polling rate of once per hour (except under emergency situations).[30] This analysis assumed a monthly cost of $100 per equipped vehicle for the cases under analysis.

5.5.2 Fleet Dispatch Center Costs

Each of the identified satellite communication/fleet management systems provide for system installation equipment and software for monitoring/tracking vehicle position and managing vehicle dispatch communications. The costs of fleet dispatch/fleet management systems vary widely,[31] based primarily on the services and features offered

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[25] The major providers of satellite communications and vehicle tracking/fleet management systems were identified in Section 3. Discussions and information obtained from all of these sources were used to develop these cost estimates.

[26] Discussions were held with a number of trucking transportation firms including Schneider Transportation, J.B Hunt, Roberts Express, Chemical Leaman, Boyle Transportation, and Clean Harbors Environmental concerning their use of satellite communication and fleet management systems. Information from these discussions was used in the development of the system cost estimates of this section and as the basis for identifying operational and fleet management benefits in Section 5.6.6.

[27] Current estimates are that a built-in GPS receiver/antenna costs approximately $250-$350 per in-vehicle unit.

[28] The assumed life of in-vehicle communications equipment was established based on discussion with equipment suppliers and product lease/warranty literature.

[29] Costs for vehicle communications (voice and/or data), using cellular communications were higher, ranging from $100-$180 per month per equipped vehicle.

[30] Both suppliers and transportation firms tend to agree that the frequency of a 'once per hour' per vehicle polling rate is sufficient for their normal dispatch and fleet management operations.

[31] The costs of fleet management/fleet communication systems do not vary widely across available systems as much as the types of services/features provided.

Table 5.11 Fleet Equipment and Communications Costs

Costs in 1995 Constant Dollars	Case 1: Large Rail Application	Case 2: Large Truck Application	Case 3: Medium Truck Application
In-vehicle Feet Equipment Cost (per truck/locomotive)	$3,500	$3,500	$3,500
Assumed Life of Equipment	5 years	5 years	5 years
Fleet Communications Cost (per month per vehicle)	$100	$100	$100

for fleet management (i.e., fuel tax recording, fuel/mileage performance, driver time logging, etc.). Estimated costs for these systems range from as low as $10,000 for low-end systems and small fleet deployments to as high as $50,000 for more extensive fleet applications.

This analysis assumed a capital cost[32] of $30,000 for equipment and fleet management software for all of the cases under analysis (see Table 5.12). For the trucking cases considered, this is representative for companies deploying fleets of 100-150 equipped tractors. For the rail case, the same capital cost was assumed (even though the size of the equipped fleet is significantly higher) based on the assumption that this cost is for 'system modifications' to existing rail dispatch/fleet management systems.[33] The assumed dispatch center capital costs include costs for equipment, fleet management/dispatch communications software, and geographical mapping and databases (i.e., locations and information on available commercial/contract hazardous materials emergency response services, police/fire, medical services, etc.) at the carrier dispatch center.[34] A capital equipment useful life of 10 years was assumed on this equipment and software.

Dispatch operating costs, for the monitoring/tracking of hazardous materials shipments and for providing coordination of Hazmat emergency response services (not including any costs for Hazmat emergency response) at the local transportation carrier dispatch center were estimated on a per hazardous materials shipment basis. This analysis assumed that an expanded Hazmat dispatch operations would exist, at each carrier dispatch center, to plan routes, schedule shipments, monitor/track Hazmat shipments, and coordinate Hazmat emergency response activities with available 911 (enhanced 911) and/or 'carrier contract' emergency response services. This analysis assumed a cost of $5 per Hazmat shipment to cover the costs of expanded Hazmat dispatch operations within trucking and rail firms.

[32] This cost assumption was based on information and discussions with fleet management/fleet communication system suppliers and various trucking firms that have these systems installed.

[33] Almost (if not all) Class-I rail systems use Automated Car Identification (ACI) and waybill processing systems for reporting into the AAR's TRAIN-II system as one source of information of tracking cars and commodity shipments.

[34] This analysis assumed one centralized dispatch center per carrier operation in each of the case applications.

Table 5.12 Fleet Dispatch Center Costs

Costs in 1995 Constant Dollars	Case 1: Large Rail Application	Case 2: Large Truck Application	Case 3: Medium Truck Application
Dispatch Center Capital Cost (per dispatch center)	$30,000	$30,000	$30,000
Assumed Life of Equipment	10 years	10 years	10 years
Dispatch Center Operating Costs (per Hazmat Car/Truck shipment)	$5	$5	$5

5.6 SYSTEM BENEFITS

This analysis identified a range of system benefits associated with the application of GPS and related technologies (satellite communications and fleet tracking/management systems) to track and monitor hazardous material shipments and to improve overall fleet operations of trucking and rail carriers. The primary areas where benefits would be accrued include:

- reduced emergency response and reduced emergency response costs to Hazmat incidents.
- reduced impacts in Hazmat-incident related injuries.
- reduced impacts in Hazmat-incident related fatalities.
- reduced impacts in Hazmat-incident related property damages.
- reduced impacts in Hazmat-incident related evacuations.
- improved fleet management and operations of trucking/rail carriers.

5.6.1 Reduced Emergency Response Time and Cost

In a report to Congress [24] dealing with a statutory mandate to improve hazardous materials identification systems, the DOT reported that the vast majority of hazardous materials shipments in the U.S. are packaged properly, meet stringent transportation requirements, and arrive at their destination safely. This Congressional report cited an analysis, conducted by the DOT, that found that only 4% (396 incidents) of the total (9,320) incidents reported to the DOT in 1992 could be considered to have a consequence[35] serious enough to warrant a significant emergency response. In a study [3] dealing with the information requirements and the feasibility of a centralized reporting system for improving the emergency response to hazardous material incidents, the National Academy of Sciences (NAS) found that less than 1% of all truck incidents (around 100-200 per year) and less than 0.5% of all rail incidents (around 4-6 per year) would have a "consequential" outcome. Far less frequently, serious accidents do occur that require significant emergency response actions.

[35] These incidents involved one or more of the following consequences: a fatality, a major injury, an general public evacuation, closure of a major artery, a truck accident or train derailment.

Figure 5.3 illustrates the trend in Hazmat incidents reported to DOT/RSPA over the past ten years. As shown, highway (trucking) accounts for nearly 83% of all Hazmat incidents reported, rail approximately 12%, with the remaining being air and marine incidents. Current data [25] shows a significant increase in the number of reported incidents over the past five years (primarily in highway/trucking). In 1994, a total 16,076 incidents were reported, representing an 81% increase in the number of incidents reported in 1990 (8,882).

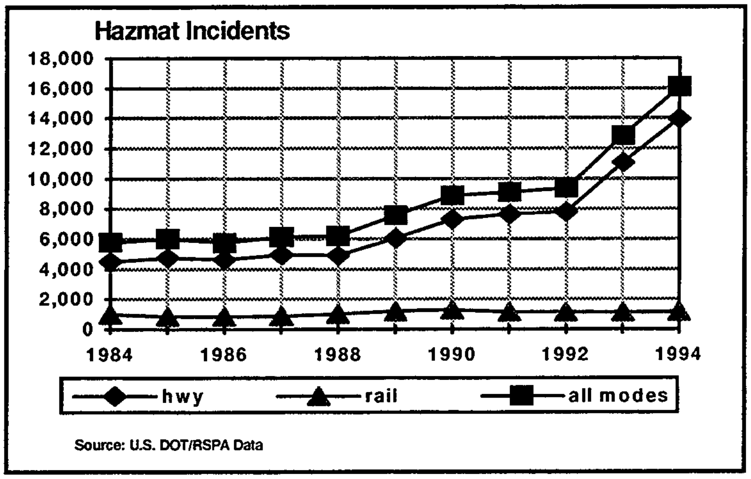

Figure 5.3 Hazmat Incidents

Using Hazmat incident data from DOT/RSPA, the volume of Hazmat shipments by rail (source AAR data), and the estimated volume of shipments by trucking (1992 TIUS data), incident rate estimates were developed for the rail and trucking modes. These estimates, shown in Table 5.13, indicate the incident rate for trucking is around 15 incidents per 100,000 Hazmat shipments, while rail incidents occur at a rate of 82 incidents per 100,000 Hazmat shipments.

Table 5.13 Hazmat Emergency Response Data and Assumptions

Hazmat Emergency Response Data and Assumptions	Case 1: Large Rail Application	Case 2: Large Truck Application	Case 3: Medium Truck Application
Number of Hazmat Incidents per 100,000 Hazmat Shipments	81.8	14.9	14.9
Average Hazmat Response Time	60 minutes	60 minutes	60 minutes
Average Cost of Incident Response ($/minute)	$25/minute	$25/minute	$25/minute
% reduction in response time/cost	5 %	5 %	5 %

Data on representative times that emergency response teams take to respond to Hazmat incidents (see Table 5.14) was based on the work and analyses conducted in 1994 by Rogers [26]. His analysis of Hazmat incidents, consisting of over 232 decisions (62 decisions to warn the public, 101 protective action decisions, and 62 all-clear decisions), characterized the decisions and actions taken by emergency responders (and community officials) to warn the public, take protective action, and issue an all-clear as follows:

Table 5.14 Hazmat Emergency Response Times

Activity	Timing
Decision to Warn Public	Range: less than a minute to 16 hours Average Time: 79 minutes
Protective Action Decision	Range: none to 24 hours Average Time: 1 hour and 45 minutes
All-Clear Decision	Range: less than a minute to 2 days Average Time: 7.5 hours
Source: Information on Rogers analysis reported in Texas Transportation Institute study for Houston Cooperative Emergency Planning Project. [27]	

This analysis utilized a value of 60 minutes (for all cases considered) as a base value to initiate emergency response. With the availability of vehicle positioning/monitoring and improved response communications from the vehicle to the carrier dispatch center to an emergency response team, this analysis assumed that a percentage reduction of 0% - 10% could be achieved in overall <u>initial</u> Hazmat response time. The results of the case analyses conducted reflect a 5% reduction in emergency response time.

Costs for emergency response vary based on the nature and severity of incidents and the number of available emergency response teams capable of responding to an incident. Information from CHEMTREC and various 'contract/commercial emergency response firms' indicate that these costs could range from $1,200 per hour to $3,600 per hour. This analysis utilized a base value of $1,500 per hour ($25/minute) as the cost of a Hazmat emergency response.

5.6.2 Reduced Impacts of Hazmat Injuries

Figure 5.4 presents data on the reported injuries as a result of Hazmat incidents. As shown, the number of injuries associated with Hazmat incidents increased significantly over the past five years. In 1994, a total of 576 injuries were reported, a 36% increase over the number of Hazmat-related injuries (423) reported in 1990. On average, highway (trucking) accounts for around 74% of the reported Hazmat injuries, while rail accounts for virtually all the remainder.

With improved monitoring and tracking of Hazmat shipments and improved communications between the incident vehicle, the carrier dispatch center, and 911 (enhanced 911) centers and emergency response teams, this analysis assumed that the impacts of Hazmat injuries could be reduced up to 10%. For the cases considered, a 5% reduction in Hazmat-related injury impacts was used. Table 5.15 presents the data and assumptions used in determining the benefits derived from reduced impacts (i.e., reduced severity of injuries with improved emergency response) of Hazmat incidents. The incidences of Hazmat-related injuries were determined based on the DOT/RSPA data on Hazmat injury incidents in relation to the number of rail or trucking Hazmat shipments.

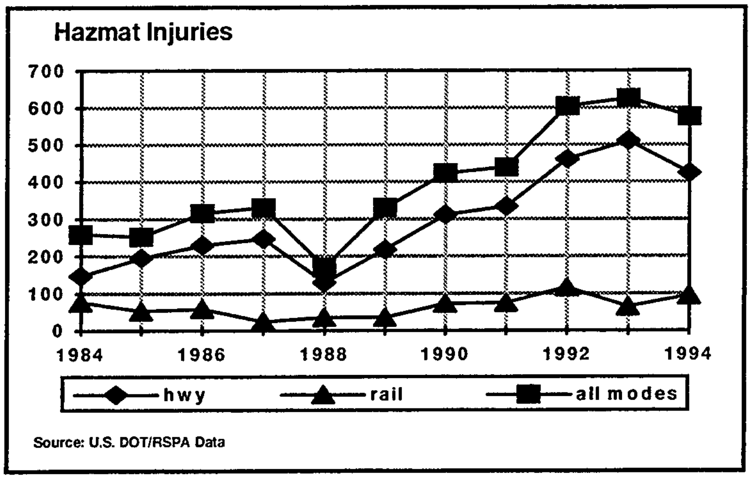

Figure 5.4 Hazmat Injuries

Table 5.15 Hazmat Incident Injury Averted Data and Assumptions

Hazmat Incident Injury Averted Data and Assumptions	Case 1: Large Rail Application	Case 2: Large Truck Application	Case 3: Medium Truck Application
Number of Hazmat Injuries per 100,000 Hazmat Shipments	5.35	0.63	0.63
Value of Hazmat Injury Averted (1995 dollars)	$100,000	$100,000	$100,000
% reduction in Hazmat Injuries	5 %	5 %	5 %

A weighted average value of $131,100 (1995 dollars) was used as the value of an injury averted (or the seriousness of an injury), based on U.S. DOT guidelines [22, 23]. According to these guidelines, a value of an 'injury averted' is determined relative to a value of a 'fatality averted' based on defined factors of injury severity. Table 5.16 summarizes the weighted average cost of an 'injury averted' (or reduced injury severity), based on the DOT guidelines and an assumed percentage distribution of incidents by injury severity class.

5.6.3 Reduced Impacts of Hazmat Fatalities

The incidence of fatalities related to Hazmat accidents/incidents is low. Data reported to DOT/RSPA on the impacts of Hazmat incidents indicate that over the past ten years (1984-1994), there were a total of 128 fatalities. Of this total, 126 were associated with highway (trucking) incidents and one was associated with rail incidents.

Table 5.16 Hazmat Injury Averted Weighted Average Cost

Value of fatality averted (1995 dollars): $2.7 million			
Injury Severity	**DOT Guideline Factor [Refs. 22,23]**	**Assumed Percentage[36] of Incidents (rail & truck)**	**Weighted Average Value 'Injury Averted' (Thousands, 1995 dollars)**
Minor	0.0020	30%	$1.6
Moderate	0.0155	40%	$16.7
Serious	0.0575	20%	$31.1
Severe	0.1875	8%	$40.5
Critical	0.7625	2%	$41.2
Fatal	1.0	considered in Section 5.6.3	
	Total	100%	$131.1

The incidence of fatalities related to Hazmat accidents/incidents is low. Data reported to DOT/RSPA on the impacts of Hazmat incidents indicate that over the past ten years (1984-1994), there were a total of 128 fatalities. Of this total, 126 were associated with highway (trucking) incidents and one was associated with rail incidents. Table 5.17 outlines the data and assumptions used in this analysis for the highway and rail cases considered. The incidences of Hazmat-related fatalities were determined based on the DOT/RSPA data on Hazmat fatal incidents in relation to the number of rail or trucking Hazmat shipments. The DOT guideline value for a 'fatality averted' ($2.7 million, 1995 dollars) was used in determining the impacts of reduced Hazmat fatalities.

Table 5.17 Hazmat Incident Fatality Averted Data and Assumptions

Hazmat Incident Fatality Averted Data and Assumptions	**Case 1: Large Rail Application**	**Case 2: Large Truck Application**	**Case 3: Medium Truck Application**
Number of Hazmat Fatalities per 100,000 Hazmat Shipments	0.05	0.03	0.03
Value of Hazmat Fatality Averted (1995 dollars)	$2.7 million	$2.7 million	$2.7 million
% reduction in Hazmat Fatalities	5 %	5 %	5 %

[36] The distribution of injuries, by injury class, shown in the table was assumed for this analysis.

5.6.4 Reduced Impacts of Hazmat Property Damages

Over the past ten years, property damages as a result of Hazmat incidents totaled over $204.8 million dollars. Figure 5.5 shows the trend in total property damages of Hazmat incidents for the 1984-1994 period. Data reported to DOT/RSPA on total Hazmat damages by mode (rail/trucking) was used and related to overall Hazmat incidents (rail/trucking) to determine the incidence of Hazmat property damage cases and the average property damage loss per incident.

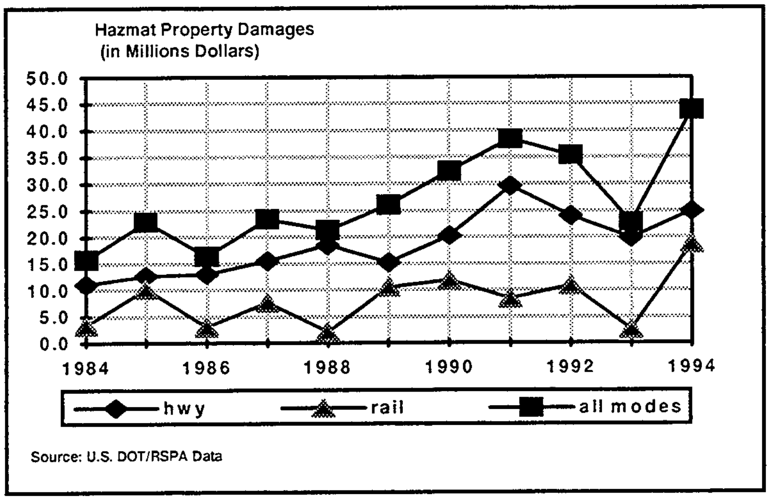

Figure 5.5 Hazmat Property Damages

Table 5.18 presents the data used in this analysis. As shown, on a per shipment basis, property damages for rail Hazmat incidents occur at a rate of about 67 cases per 100,000 rail Hazmat shipments, with an average property damage loss of $9,140 per rail incident. Highway (trucking) Hazmat property damage occurs at a rate of 12 times per 100,000 truck Hazmat shipments, with an average property damage loss of $3,173 per time.

This analysis assumed that with increased tracking/monitoring of Hazmat shipments, improved communications in reporting the immediate occurrence of Hazmat incidents, and with improved information and communications to marshal appropriate emergency response teams, the overall adverse impacts in the loss of personal property and to the environment could be significantly reduced. A conservative estimate of a 5% reduction in the overall adverse impacts associated with Hazmat incident property damage losses was assumed in this analysis.

Table 5.18 Hazmat Incident Property Damages Data and Assumptions

Hazmat Incident Property Damages Data and Assumptions	Case 1: Large Rail Application	Case 2: Large Truck Application	Case 3: Medium Truck Application
Number of Hazmat Property Damage Incidents per 100,000 Hazmat Shipments	66.54	12.09	12.09
Average Value of Hazmat Property Damage Case (1995 dollars)	$9,140	$3,173	$3,173
% reduction in Hazmat Property Damage Impacts	5 %	5 %	5 %

5.6.5 Reduced Impacts of Evacuations and Traffic Delays

The incidence of public evacuations and/or closures of major transportation arteries occur with both rail and highway (trucking) Hazmat incidents. The frequency of having major highway closures associated with trucking incidents is high, as evidenced by analyses conducted by the National Transportation Safety Board [28] and by the National Academy of Sciences [3] on highway Hazmat incidents. The NTSB study examined 40 Hazmat cases, 13 (33%) of which involved major highway closings with a total duration of 158 hours (an average of 12 hours per highway closing). The NAS study looked at 40 California Trucking Hazmat cases and found that 25% (10) of these cases involved highway closures, having a total duration of 91 hours (an average of 9 hours per highway closure).

These same studies also examined the number of evacuations and the number of persons evacuated for these trucking Hazmat incidents. The NTSB study found that, in the 40 cases examined, 5 cases (12%) required evacuations, with a total of 4,525 persons evacuated (an average of 538 persons per evacuation case). In the NAS study, 40 California cases examined showed a higher percentage of cases requiring evacuation, 30% (12 out of 40 cases) with a total of 760 persons evacuated.

Data on evacuations resulting from rail Hazmat incidents were available from the AAR [13] and the NTSB [29]. The AAR data shows that, on average, 2%-3% of all rail Hazmat incidents require evacuations. Between 1985-1989 (the period for which data was available), there were 142 evacuations involving 106,011 persons (an average of 746 persons were involved in each evacuation). The NTSB study of 45 rail Hazmat incidents occurring in 1988-1989 found that 32 (out of the 45 cases) required an evacuation, with a total of 17,223 persons evacuated.

This analysis used the data/assumptions[37] presented in Table 5.19 as the basis for measuring the adverse impacts of evacuations as a result of rail/trucking Hazmat incidents. As shown, the incidence of both rail and highway evacuations (on a per Hazmat shipment basis) is about 2 evacuations per 100,000 rail/truck Hazmat shipment. Representative data on the impact per person evacuated could not be found for this analysis. In the absence of any data, this analysis used a value of $1,000 per person evacuated per Hazmat evacuation incident for both the rail and trucking cases.

Table 5.19 Hazmat Incident Evacuation Data and Assumptions

Hazmat Incident Evacuations Data and Assumptions	Case 1: Large Rail Application	Case 2: Large Truck Application	Case 3: Medium Truck Application
Number of Hazmat Evacuation Incidents per 100,000 Hazmat Shipments	2.04	2.23	2.23
Number of Evacuees per Evacuation Incident	1,600	1,140	1,140
Average Cost per Evacuee	$1,000	$1,000	$1,000
% reduction in Hazmat Evacuation Impacts	5 %	5 %	5 %

5.6.6 Improved Operations for Hazmat Shippers/Carriers

The installation of a satellite-based vehicle tracking and communication system within the rail or trucking industry requires a significant cost outlay to cover the capital costs associated with the installation of in-vehicle equipment and on an annual, recurring basis to cover the costs of vehicle-to-dispatch center communications.

The need to improve overall logistics[38] to meet the current 'just-in-time' scheduling and delivery requirements of major manufacturing and supply industries has forced many transportation carriers in recent years to utilize advanced communication and fleet management systems to improve overall scheduling of shipments and increase fleet and driver performance. This is especially true in the trucking industry, where trucks are subject to more frequent changes in routing and scheduling, mechanical failures, accidents, traffic delays, and adverse road conditions. Carriers of dangerous cargoes and hazardous materials have found the requirement for monitoring/tracking and increased communications between dispatch centers and vehicles is essential considering the nature, value, and risks of the cargo being transported.

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[37] For both the rail and trucking modes, this analysis used a range (high-low) of the individual cases and data available in establishing an average number of persons evacuated per incident. The analysis only considered system evacuations (as opposed to both evacuations and major artery closures) since it was felt that both (evacuations and highway closings) are too highly interrelated.

[38] *Transport Topics*, 4/17/95, "Schneider Builds on Concept of Asset-Based Logistics." Schneider sees increasing demand for "just-in-time" delivery schedules. A survey of shippers indicated that, in 1990, 18% of products were shipped "just-in-time" and sees this figure increasing to 39% by the year 2000.

The primary benefits most often cited for the application of satellite-vehicle tracking and communication systems are

- increased fleet utilization and driver productivity
- improved adherence to delivery schedules
- better response to emergency situations
- overall improvement in customer satisfaction.

Information obtained from discussions with representatives of various trucking firms (see Footnote 12) and individual suppliers of these systems have identified specific improvements in carrier operations in the following areas

- time savings at stops (check calls) are reduced, thereby improving vehicle/driver "on-road time".
- reduced empty "deadhead" miles on the order of 2%-5% are realistic.
- reduced "out-of-route" miles. It is not uncommon in the trucking industry to have non-sanctioned mileage on the order of 6%-7%; vehicle monitoring reduces this mileage.
- reduced dispatch and administrative costs. Fleet management and communication systems force dispatchers into a load-planning role and generally allows dispatchers to handle larger fleets/drivers. Administrative costs for reporting fuel tax allocations, shipment billing, and reports on vehicle/driver performance are often reduced.

This analysis considered that overall carrier operations would be improved and would serve as an overall system benefit. Since satellite vehicle tracking and vehicle communications affect all carrier operations, this analysis assumed direct benefits would accrue to all carrier shipments (not just Hazmat carrier shipments). Table 5.20 identifies the data and assumptions associated with this benefit area. For trucking operations, savings ranging from 0%-5% in reduced carrier transport costs are representative within the industry. This analysis assumed a 2% reduction in carrier transport costs as a base value for this analysis. Within the rail industry, the opportunity for improving the routing and scheduling of rail carrier shipments and reducing the costs of the shipments, with the application of satellite-based communication and fleet management systems, would not be as high as the savings that would be achieved in the trucking industry. Within the trucking industry, the routing and scheduling of shipments is more dynamic and flexible, thus allowing for improved efficiencies in operations as compared to the rail operations. This analysis assumed a 0.5% reduction in carrier shipment cost for the rail case.

Table 5.20 Data/Assumptions Associated with Improved Carrier Operations

Improved Operations for Hazmat Carriers Data and Assumptions	Case 1: Large Rail Application	Case 2: Large Truck Application	Case 3: Medium Truck Application
Average Cost per Carrier Shipment	$1,163/car shipment	$1.45/truck-mile	$1.71/truck-mile
% Reduction in Cost Shipment	0.5%	2 %	2 %

5.7 STUDY RESULTS

5.7.1 Case #1: Large-Rail Application Results

Table 5.21 summarizes the total system costs, expressed in discounted[39] and constant 1995 dollars for the 1995-2014 time period, for the large rail application case. As shown, the total system cost for this case application is $368.7 million (discounted 1995 dollars), of which $136.1 million (37%) are for fleet and dispatch center capital costs and the remaining $232.6 million are for recurring fleet communication and dispatch operating costs. Total system costs for this application are dominated by costs for fleet in-vehicle equipment and fleet communications, representing over 96% ($355.7 million discounted 1995 dollars) of the total system cost, while costs for fleet dispatch center equipment and dispatch center Hazmat operations represent the remaining 4% ($13.0 million discounted 1995 dollars). The total system cost of this case application, in constant 1995 dollars, is $674.2 million, of which $225.3 million are for system capital costs and $449.9 million in operating costs over the 20-year analysis period.

Table 5.21 Case 1: System Costs

System Costs (Period:1995-2014 in Constant 1995 Dollars)	Capital Costs (Millions, 1995-$)	Operating Costs (Millions, 1995-$)	Total Costs (Millions, 1995-$)
Fleet	$224.88	$424.43	$649.31
Dispatch Center	$0.42	$24.49	$24.91
Total	$225.30	$448.92	$674.22
System Costs (Period:1995-2014 in Discounted 1995 Dollars)	**Capital Costs (Millions, 1995-$)**	**Operating Costs (Millions, 1995-$)**	**Total Costs (Millions, 1995-$)**
Fleet	$135.76	$219.96	$355.72
Dispatch Center	$0.30	$12.69	$12.99
Total	$136.05	$232.65	$368.70

[39] All study results are presented in constant and discounted, present value 1995 dollars and in equivalent annualized 1995 dollars. Present value costs and benefits are discounted over the 20-year (1995-2014) period at a 7% discount rate.

The total system benefits of this case application, as presented in Table 5.22, are $1,305.5 million (discounted 1995 dollars) or $2,519.0 million (constant 1995 dollars). As shown, 97% ($1,273.5 million discounted 1995 dollars) of the projected benefits for this case are benefits derived from improved carrier operations and fleet utilization efficiencies resulting from the application of GPS/satellite communication technologies and fleet management systems in rail operations. These benefits are based on savings on all carrier operations (not just Hazmat shipments), since it was assumed under this case that the total carrier fleet of locomotives would be equipped and monitored with GPS and satellite communications.

Table 5.22 Case 1: System Benefits

System Benefits	System Benefits Period 1995-2014 (Millions, Constant 1995 dollars)	System Benefits Period 1995-2014 (Millions, Discounted 1995 dollars)
Reduced Cost of Emergency Response	$1.6	$0.8
Reduced Impacts of Hazmat Injuries	$7.1	$3.7
Reduced Impacts of Hazmat Fatalities	$1.7	$0.9
Reduced Impacts of Hazmat Property Damages	$8.0	$4.2
Reduced Impacts of Hazmat Evacuations	$43.2	$22.4
Improved Operations of Hazmat Carrier	$2,457.3	$1,273.5
Total System Benefits	$2,519.0	$1,305.5

System benefits, as a result of savings in Hazmat incident-emergency response costs and reduced impacts of Hazmat incident-related injuries, fatalities, property damages, and site evacuations, totaled $32.0 million (discounted 1995 dollars) or 3% of the total system benefits of this case. These benefits are derived based on cost savings in response to over 21,600 Hazmat incidents, and reduced impacts on a projected 1,413 Hazmat incident-related injuries, 13 Hazmat incident-related fatalities, 17,580 Hazmat property damage incidents, and 540 Hazmat incident site evacuations over the 20-year analysis period. As shown in Table 5.22, the primary areas of Hazmat incident benefits are in reduced costs for Hazmat incident site evacuations of $22.4 million (discounted 1995 dollars), Hazmat incident property damages of $4.2 million (discounted 1995 dollars), and Hazmat incident-related injuries of $3.7 million (discounted 1995 dollars).

A summary of the total system benefits and costs of this case application is presented in Table 5.23. As shown, total system benefits exceed total system costs by over $936.8 million (discounted 1995 dollars), with an overall system benefit/cost ratio of 3.5. These results are based primarily on achieving efficiencies in carrier operations that would reduce carrier transport costs by 0.5%. As a break-even point for this case application, rail carriers would only have to achieve operating efficiencies that would reduce their transport costs by 0.15% to cover the system capital and operating costs of GPS/satellite communication and fleet management system over a twenty-year period.

Table 5.23 also identifies the annual costs and benefits (expressed in equivalent annualized 1995 dollars) per rail line for this case application. As shown on an annualized basis, total costs exceed $4.9 million per year with total benefits of $17.6 million per rail line.

Table 5.23 Case 1: Summary of Benefits and Costs

Benefit/Cost Summary	**Total Period 1995-2014 (Millions, Discounted 1995 dollars)**	**Annualized Per Rail Line (Thousands, Annualized 1995 dollars)**
System Costs		
Capital Costs	$136.1	$1,834.6
Operating Costs	$232.6	$3,137.2
Total System Costs	$368.7	$4,971.8
System Benefits		
Reduced Impacts to Hazmat Incidents	$32.0	$430.9
Improved Operations of Hazmat Carrier	$1,273.5	$17,172.9
Total System Benefits	$1,305.5	$17,603.8
Benefit/Cost Ratio	3.54	

5.7.2 Case #2: Large Trucking Application Results

For the large trucking case application, the total system costs, over a twenty-year (1995-2014) period, are presented in Table 5.24. The total system cost for this application is $1,331.5 million (discounted 1995 dollars), of which $438.5 million (33%) are for fleet and dispatch center capital costs and the remaining $893.3 million are for recurring fleet communication and dispatch center operating costs. In-vehicle fleet equipment and fleet communication costs represent over 80% ($1,075 million discounted 1995 dollars) of the total system costs of this application, while costs for fleet dispatch center equipment and dispatch center Hazmat operations account for the remaining 20% ($256.5 million discounted 1995 dollars). The total system cost of this case application, in constant 1995 dollars, is $2,442.7 million, of which $719.7 million is for system capital costs and $1,723.0 million is for operating costs over the twenty-year analysis period.

Table 5.24 Case 2: System Costs

System Costs (Period:1995-2014 in Constant 1995 Dollars)	Capital Costs (Millions, 1995-$)	Operating Costs (Millions, 1995-$)	Total Costs (Millions, 1995-$)
Fleet	$679.6	$1,282.6	$1,962.2
Dispatch Center	$40.1	$440.4	$480.5
Total	$719.7	$1,723.0	$2,442.7
System Costs (Period:1995-2014 in Discounted 1995 Dollars)	**Capital Costs (Millions, 1995-$)**	**Operating Costs (Millions, 1995-$)**	**Total Costs (Millions, 1995-$)**
Fleet	$410.3	$664.7	$1,075.0
Dispatch Center	$28.2	$228.2	$256.5
Total	$438.5	$893.0	$1,331.5

The total system benefits of this case application, presented in Table 5.25, total $2,740.0 million (discounted 1995 dollars) or $5,287.1 million (constant 1995 dollars). Of the total projected benefits for this case, 97% ($2,677.0 million discounted 1995 dollars) are derived from improved carrier operations and fleet utilization efficiencies, as a result of the application of GPS/satellite communication technologies and fleet management systems within the trucking operations. These benefits are based on savings on all carrier operations (not just Hazmat shipments), since it was assumed under this case that the total carrier fleet would be equipped and monitored with GPS and satellite communications.

Table 5.25 Case 2: System Benefits

System Benefits	System Benefits Period 1995-2014 (Millions, Constant 1995 dollars)	System Benefits Period 1995-2014 (Millions, Discounted 1995 dollars)
Reduced Cost of Emergency Response	$1.0	$0.5
Reduced Impacts of Hazmat Injuries	$2.8	$1.4
Reduced Impacts of Hazmat Fatalities	$4.1	$2.1
Reduced Impacts of Hazmat Property Damages	$1.7	$0.9
Reduced Impacts of Hazmat Evacuations	$112.0	$58.0
Improved Operations of Hazmat Carrier	$5,165.6	$2,677.0
Total System Benefits	$5,287.1	$2,740.0

System benefits, as a result of savings in Hazmat incident emergency response costs and reduced impacts of Hazmat incident-related injuries, fatalities, property damages, and site evacuations, totaled $63.0 million (discounted 1995 dollars) or 2% of the total system benefits of this case. These benefits are derived based on cost savings in response to over 13,000 Hazmat incidents, and reduced impacts on a projected 560 Hazmat incident-related injuries, 31 Hazmat incident-related fatalities, 10,600 Hazmat property damage incidents, and 1,960 Hazmat incident site evacuations over the 20-year analysis period. As shown in Table 5.25, the primary areas of Hazmat incident benefits are in reduced costs for Hazmat incident site evacuations, which are expected to total $58.0 million (discounted 1995 dollars), Hazmat incident fatalities averted, which are expected to total

$2.1 million (discounted 1995 dollars), and Hazmat incident-related injuries averted, which are expected to total $1.4 million (discounted 1995 dollars).

Table 5.26 summarizes the total system benefits and costs and the annualized cost and benefits, per trucking firm, for this case application. As shown, total system benefits exceed total system costs by over $1,408.5 million (discounted 1995 dollars), with an overall system benefit/cost ratio of 2.0. These results are based primarily on achieving efficiencies in carrier operations that would reduce carrier transport costs by 2.0%. As a break-even point for this case application, trucking firms would only have to achieve operating efficiencies that would reduce their transport costs by 1.0% to cover the system capital and operating costs of GPS/satellite communication and fleet management system over the twenty-year period.

On an annualized basis, costs per trucking firm for this case application total $1.8 million (expressed in equivalent, annualized 1995 dollars), while total annual benefits accrued would be $3.9 million.

Table 5.26 Case 2: Summary of Benefits and Costs

Benefit/Cost Summary	**Total Period 1995 - 2014 (Millions, Discounted 1995 dollars)**	**Annualized Per Trucking Firm (Thousands, Annualized 1995 dollars)**
System Costs		
Capital Costs	$438.5	$61.9
Operating Costs	$893.0	$126.2
Total System Costs	$1,331.5	$188.1
System Benefits		
Reduced Impacts to Hazmat Incidents	$63.0	$8.9
Improved Operations of Hazmat Carrier	$2,677.0	$378.3
Total System Benefits	$2,740.0	$387.2
Benefit/Cost Ratio	2.06	

5.7.3 Case #3: Medium Trucking Application Results

Total system costs, over a twenty-year (1995-2014) period for this case application, are presented in Table 5.27. For a medium trucking case application, total system costs would exceed $374.1 million (discounted 1995 dollars), of which $93.4 million (25%) are for fleet and dispatch center capital costs and the remaining $280.7 million are for recurring fleet communication and dispatch center operating costs. In-vehicle fleet equipment and fleet communication costs total $232.5 million (discounted 1995 dollars), or 62% of the total system costs of this application, while costs for fleet dispatch center equipment and dispatch center Hazmat operations, which total $141.6 million (discounted 1995 dollars), account for the remaining 38% of the cost. The total system cost of this case application in constant 1995 dollars is $693.2 million, of which $151.7 million is for system capital costs and $541.6 million is for operating costs over the twenty-year analysis period.

For this case application, the total system benefits are projected to be $610.3 million (discounted 1995 dollars) or $1,177.7 million (constant 1995 dollars), as shown in Table 5.28. Of the total system benefits for this case, $572.5 million (discounted 1995 dollars), or 94% of the total, are derived from improved carrier operations and fleet utilization efficiencies resulting from the application of GPS/satellite communication technologies and fleet management systems within the trucking operations. These benefits are based on savings on all carrier operations (not just Hazmat shipments), since it was assumed that the total truck carrier fleet of this case application would be equipped and monitored with GPS and satellite communications.

Table 5.27 Case 3: System Costs

System Costs (Period: 1995-2014 in Constant 1995 Dollars)			
	Capital Costs (Millions, 1995 dollars)	**Operating Costs (Millions, 1995 dollars)**	**Total Costs (Millions, 1995 dollars)**
Fleet	$147.0	$277.4	$424.3
Dispatch Center	$4.7	$264.2	$268.9
Total	$151.7	$541.6	$693.2
System Costs (Period: 1995-2014 in Discounted 1995 Dollars)			
	Capital Costs (Millions, 1995 dollars)	**Operating Costs (Millions, 1995 dollars)**	**Total Costs (Millions,1995 dollars)**
Fleet	$88.7	$143.7	$232.5
Dispatch Center	$4.7	$136.9	$141.6
Total	$93.4	$280.7	$374.1

Table 5.28 Case 3: System Benefits

System Benefits	**System Benefits Period 1995-2014 (Millions, Constant 1995 dollars)**	**System Benefits Period 1995-2014 (Millions, Discounted 1995 dollars)**
Reduced Cost of Emergency Response	$0.6	$0.3
Reduced Impacts of Hazmat Injuries	$1.7	$0.9
Reduced Impacts of Hazmat Fatalities	$2.5	$1.3
Reduced Impacts of Hazmat Property Damages	$1.0	$0.5
Reduced Impacts of Hazmat Evacuations	$67.2	$34.8
Improved Operations of Hazmat Carrier	$1,104.7	$572.5
Total System Benefits	$1,177.7	$610.3

The remaining 6% of the total projected system benefits, which total $37.8 million (discounted 1995 dollars), are benefits derived from savings in Hazmat incident emergency response costs and reduced impacts of Hazmat incident-related injuries, fatalities, property damages, and site evacuations. Primary among these are benefits in reduced costs for Hazmat incident site evacuations, which are expected to total $34.8

million (discounted 1995 dollars), Hazmat incident fatalities averted, which are expected to total $1.3 million (discounted 1995 dollars), and Hazmat incident-related injuries averted, which are expected to total $0.9 million (discounted 1995 dollars). These benefits are based on cost savings in response to over 7,800 Hazmat incidents, and reduced impacts on a projected 335 Hazmat incident-related injuries, 18 Hazmat incident-related fatalities, 6,390 Hazmat property damage incidents, and 1,178 Hazmat incident site evacuations over the twenty-year case analysis period.

A summary of the total system benefits and costs of this case application is presented in Table 5.29. As shown, total system benefits exceed total system costs by over $236.0 million (discounted 1995 dollars), with an overall system benefit/cost ratio of 1.6. These results are based primarily on achieving efficiencies in carrier operations that would reduce carrier transport costs by 2.0%. As a break-even point for this case application, truck carriers would only have to achieve operating efficiencies that would reduce their transport costs by 1.2% to cover the system capital and operating costs of GPS/satellite communication and fleet management system over a twenty-year period.

Table 5.29 also identifies the annualized costs and benefits (expressed in equivalent, annualized 1995 dollars) for this case application. On an annualized basis, costs per trucking firm would total $321.0 thousand (expressed in equivalent, annualized 1995 dollars), while total benefits accrued would be $524.0 thousand per year.

Table 5.29 Case 3: Summary of Benefits and Costs

Benefit/Cost Summary	**Total Period 1995-2014 (Millions, Discounted 1995 dollars)**	**Annualized Per Trucking Firm (Thousands, Annualized 1995 dollars)**
System Costs		
Capital Costs	$93.4	$80.1
Operating Costs	$280.7	$240.8
Total System Costs	$374.1	$320.9
System Benefits		
Reduced Impacts to Hazmat Incidents	$37.8	$32.4
Improved Operations of Hazmat Carrier	$572.5	$491.3
Total System Benefits	$610.3	$523.7
Benefit/Cost Ratio	1.63	

5.7.4 Summary of Results

Table 5.30 and Figure 5.6 present a comparative summary of the overall benefits and costs of the case applications considered in this analysis.

The following summarizes the principal findings of this study:

- GPS- and satellite-based vehicle tracking and communications systems are proven technologies within the transportation industry. Over the past decade, there has been a significant and growing application of these technologies, especially within the trucking industry.
- The application of GPS- and satellite-based tracking/communications and fleet management systems within the rail and trucking industries require significant cost outlays for fleet equipment and fleet communications. System capital costs for in-vehicle equipment and recurring costs for fleet communications dominate the overall costs of these system applications.
- Current applications of these systems (within the trucking industry) appear to produce benefits to carriers in areas of improved operations, reduced operating costs, and improved fleet utilization. Savings in carrier transport costs, ranging from 0%-2%, were assumed for the case applications considered in this analysis. As a break-even point, rail and trucking carriers would only need operating efficiencies that would reduce carrier transport costs by 0.5%-1.0% to recover the capital and recurring costs of the application of these technologies over a twenty-year period.
- The application of GPS- and satellite-based tracking/communications and fleet management systems within the rail and trucking industries can provide significant benefits in the form of reduced impacts from Hazmat incidents. Primary among these are benefits derived from savings in Hazmat incident emergency response costs and reduced impacts of Hazmat incident-related injuries, fatalities, property damages, and site evacuations. For the rail and trucking applications considered, the benefits derived from reduced impacts associated with Hazmat incidents ranged from $32.0 million to $63.0 million (discounted 1995 dollars) over a twenty-year analysis period.
- All case applications considered have positive ratios of total benefits to total costs. The benefits derived from reduced impacts associated with Hazmat incidents are significantly less that overall system costs. Each of the case applications require savings from fleet operations to recover the costs of the application of GPS- and satellite-based tracking/communications and fleet management systems.
- The rail application provides the highest level of system benefits to total system costs; however, the application of satellite tracking and communications systems within the rail industry is limited. Both trucking case applications have positive ratios of benefits to costs. These applications

have significantly lower costs per carrier firm as compared to rail case considered.

Table 5.30 Comparative Summary of Benefits and Costs

System Costs and Benefits Millions of Discounted 1995 Dollars (for the period 1995-2014)	Case # 1 Large Rail Application	Case # 2 Large Trucking Application	Case # 3 Medium Trucking Application
System Costs			
Capital Costs	$136.1	$438.5	$93.4
Operating Costs	$232.6	$893.0	$280.7
Total System Costs	$368.7	$1,331.5	$374.1
System Benefits			
Reduced Impacts to Hazmat Incidents	$32.0	$63.0	$37.8
Improved Operations of Hazmat Carrier	$1,273.5	$2,677.0	$572.5
Total System Benefits	$1,305.5	$2,740.0	$610.3
Benefit/Cost Ratio	3.54	2.06	1.63

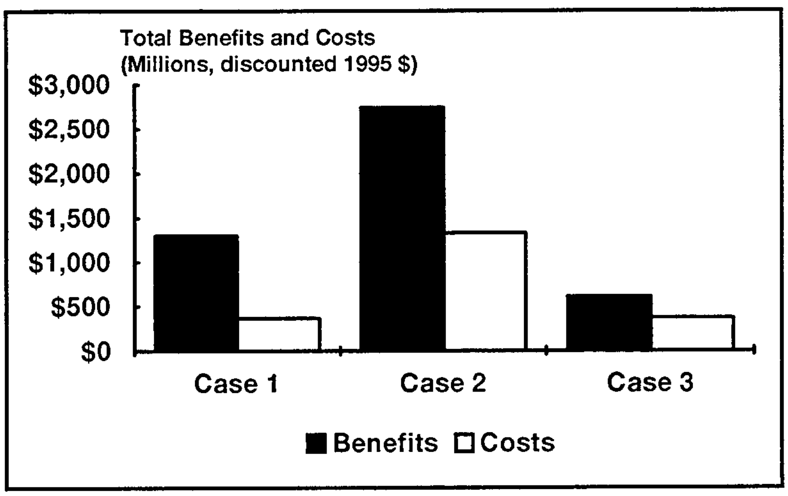

Figure 5.6 Total Benefits and Costs

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APPENDIX - EMERGENCY RESPONSE CENTERS

Summary Descriptions of Existing Transportation Emergency Response Centers

Within the United States and Canada there exist several centralized emergency response and information centers that support emergency response activities and/or monitor the movements of highly sensitive and dangerous cargoes. Presented below are summary descriptions of some of these centers.

National Response Center (NRC) [30]
U.S. Coast Guard Headquarters, Washington, DC

The NRC, which began operations in 1974, serves as the primary Federal contact for the reporting of any pollution discharges into the environment and the reporting of transportation accidents involving hazardous materials. In 1991, the NRC received reports of approximately 26,300 incidents.

The NRC has access to the following information systems and databases:

- Incident Reporting Information System (IRIS) for HAZMAT incident reporting.
- Chemical Hazard Response Information System (CHRIS) for information on chemical properties of hazardous materials.
- Marine Safety Information System (MSIS) for information on the registration and safety inspections of ships authorized for goods movement in US waters.

The NRC was established and its operations are funded through the budgets of the USCG, the DOT/RSPA, and the EPA. The 1992 funding for the NRC was $2.1 million.

Chemical Transportation Emergency Center (CHEMTREC) [30, 31]
Chemical Manufacturers Association (CMA), Washington, DC

CHEMTREC was established by members of the Chemical Manufacturers Association to provide information and technical assistance to first responders, the transportation industry, and chemical producers/shippers for incidents involving hazardous materials. The CHEMTREC Center, which is staffed 24 hours per day, has access to information systems, databases, and communications systems to provide direct emergency response information to help mitigate accidental chemical releases. Primary among these is its Materials Safety Data Sheet (MSDS) database (approximately 1 million data sheets on record), which provides data on the properties of chemicals and information on the handling of chemicals under emergency situations.

Through its CHEMNET data communications network, CHEMTREC maintains direct interfaces with established, specialized emergency response teams (a Chemical Industry Mutual Aid Network that provides specialized, for-hire contractors under contract to the CMA), the National Response Center (NRC), and the Association of American Railroads

(AAR). In 1992, CHEMTREC received calls on over 6,700 incidents, 83% of which were transportation-related, 10% non-transportation-related, and the remaining 7% medical. In addition to its emergency response center, CHEMTREC also conducts training and "hands-on" workshops to emphasize emergency preparedness and the safe transportation of chemicals. The CHEMTREC center this past year (1994) received over 220,000 calls, of which only 8% were reported as being spill-related. The current staffing and budget of the CHEMTREC center was reported to be 30-35 persons with an annual budget of $3.5 million.

Canadian Transport Emergency Centre (CANUTEC) [30]
Place de Ville, Ottawa, Ontario

CANUTEC, established in 1979, is a 24-hour emergency response center operated by Transport Canada. This center provides information on chemical properties and handling instructions in response to situations and incidents involving the transport of hazardous materials. The center also provides information, on a non-emergency basis, concerning Canadian HAZMAT regulations. CANUTEC maintains an extensive database on chemical properties, Canadian and foreign chemical manufacturers, shippers and carriers, and directories of emergency response groups and equipment suppliers. CANUTEC has access to a large number of industry databases and has direct communications with key Canadian emergency response centers and with CHEMTREC.

CANUTEC receives approximately 17,000-19,000 calls a year, the majority (88%) of which is for technical information, regulatory information (8%), and emergency response (4%). CANUTEC does not field HAZMAT emergency response teams. No information is available on the size, staffing, or annual operating budget of the CANUTEC center.

DOE HAZMAT Information and Vehicle Tracking System [30, 32]
Sandia National Laboratories, Albuquerque, NM

The DOE/Sandia National Labs (SNL) has developed, maintains and operates a HAZMAT data fusion and vehicle tracking system to provide immediate response to transports of highly radioactive materials and other dangerous cargoes on an emergency basis. The SNL Security Communications Center (SECOM) has been operational for over 14 years. The SNL Security Tracking and Response Base (STARBASE) provides two-way communications between vehicles (and fleets of vehicles) and a central control center. The STARBASE control center receives encrypted position/data messages and tracks DOE HAZMAT fleets utilizing high-resolution color maps. The SNL STARBASE system is integrated with their developed TRANSNET model, which is a compilation of vehicle routing, risk, and cost assessment programs and related databases used by SNL control personnel to plan, schedule and route HAZMAT shipments. Tracking of DOE HAZMAT fleets is accomplished using the Global Positioning Satellite (GPS) system. Communications with vehicles is handled through satellite communications (primary) and/or High Frequency (HF) transmissions (secondary). In 1994, the number of DOE HAZMAT shipments tracked by STARBASE was 624. No information is available on the size of the equipped DOE HAZMAT fleet. The capital and annual operating cost of this system was reported by DOE/SNL to be $6.5 million.

The SNL STARBASE system is undertaking a new generation of system upgrades. In addition to the tracking of DOE HAZMAT fleets, new markets for this system application are being identified in areas of monitoring US Customs border crossings, DEA drug interdiction programs, and Department of State, Department of Treasury, and DOD law enforcement programs.

DOD Defense Tracking System (DTTS) [33]
Naval Ordnance Center, Indian Head, MD

Through its Naval Ordnance Center DTTS system, the DOD maintains intransit tracking of its shipments of arms, ammunition, and explosives (AA&E). The DTTS system was initiated in 1984 and has been fully operational since 1989. The DTTS, through its contract carriers/shippers, monitors/tracks AA&E shipments in CONUS, utilizing commercially available satellite tracking services. These satellite services provide hourly position reports on active shipments, along with an emergency position location and data messaging capability to notify the DTTS and the contract carrier of an accident or incident. The DTTS maintains a two-way digital communications interface with its commercial satellite tracking/communications centers and with selected major contract carriers. DTTS data processing system consists of two AT&T 3B2/600 computers (UNIX-based operating system) and a database management system that continuously tracks shipments and shipment status in near real-time.

Since 1989, the volume of shipments tracked by DTTS has increased significantly from 12,460 in FY-1989 to over 49,000 in FY-1994. DTTS use of satellite tracking of shipments began in 1989 on a small percentage of shipments and has expanded each year so that all of its shipments are now being tracked by satellite. The volume of satellite-tracked shipments projected by DTTS for FY-1995 is expected to be 60,000. Currently, DTTS utilizes 24 contract carriers/shippers (all trucking) with a total fleet of around 1,200 vehicles with satellite communications/tracking equipment. Vehicle position reports are reported on an hourly basis (unless polled at a more frequent rate); position accuracy is within a quarter-mile (100-300 yards).

The DTTS center is staffed on a 24-hour basis with 6-8 trackers/shift. Total staffing of the facility is approximately 28-30 persons. The annual operating budget of the DTTS center is around $1.0 million. In 1994, the DTTS has expanded its services to include tracking special "high-value" shipments for the U.S. Postal Service.