HMCRP

REPORT 4

HAZARDOUS MATERIALS COOPERATIVE RESEARCH PROGRAM

Sponsored by the Pipeline and Hazardous Materials Safety Administration

Emerging Technologies Applicable to Hazardous Materials Transportation Safety and Security

TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

HMCRP REPORT 4

Emerging Technologies Applicable to Hazardous Materials Transportation Safety and Security

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Safety and Human Factors • Security and Emergencies • Terminals and Facilities • Vehicles and Equipment

Research sponsored by the Pipeline and Hazardous Materials Safety Administration

TRANSPORTATION RESEARCH BOARD

WASHINGTON, D.C.
2011
www.TRB.org

HAZARDOUS MATERIALS COOPERATIVE RESEARCH PROGRAM

The safety, security, and environmental concerns associated with transportation of hazardous materials are growing in number and complexity. Hazardous materials are substances that are flammable, explosive, or toxic or that, if released, produce effects that would threaten human safety, health, the environment, or property. Hazardous materials are moved throughout the country by all modes of freight transportation, including ships, trucks, trains, airplanes, and pipelines.

The private sector and a diverse mix of government agencies at all levels are responsible for controlling the transport of hazardous materials and for ensuring that hazardous cargoes move without incident. This shared goal has spurred the creation of several venues for organizations with related interests to work together in preventing and responding to hazardous materials incidents. The freight transportation and chemical industries; government regulatory and enforcement agencies at the federal and state levels; and local emergency planners and responders routinely share information, resources, and expertise. Nevertheless, there has been a long-standing gap in the system for conducting hazardous materials safety and security research. Industry organizations and government agencies have their own research programs to support their mission needs. Collaborative research to address shared problems takes place occasionally, but mostly occurs on an ad hoc basis.

Acknowledging this gap in 2004, the U.S. DOT Office of Hazardous Materials Safety, the Federal Motor Carrier Safety Administration, the Federal Railroad Administration, and the U.S. Coast Guard pooled their resources for a study. Under the auspices of the Transportation Research Board (TRB), the National Research Council of the National Academies appointed a committee to examine the feasibility of creating a cooperative research program for hazardous materials transportation, similar in concept to the National Cooperative Highway Research Program (NCHRP) and the Transit Cooperative Research Program (TCRP). The committee concluded, in *TRB Special Report 283: Cooperative Research for Hazardous Materials Transportation: Defining the Need, Converging on Solutions,* that the need for cooperative research in this field is significant and growing, and the committee recommended establishing an ongoing program of cooperative research. In 2005, based in part on the findings of that report, the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU) authorized the Pipeline and Hazardous Materials Safety Administration (PHMSA) to contract with the National Academy of Sciences to conduct the Hazardous Materials Cooperative Research Program (HMCRP). The HMCRP is intended to complement other U.S. DOT research programs as a stakeholder-driven, problem-solving program, researching real-world, day-to-day operational issues with near- to mid-term time frames.

HMCRP REPORT 4

Project HM-04
ISSN 2150-4849
ISBN: 978-0-309-21314-1
Library of Congress Control Number 2011927850

Published reports of the

HAZARDOUS MATERIALS COOPERATIVE RESEARCH PROGRAM

are available from:

Transportation Research Board
Business Office
500 Fifth Street, NW
Washington, DC 20001

and can be ordered through the Internet at:

http://www.national-academies.org/trb/bookstore

Printed in the United States of America

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AUTHOR ACKNOWLEDGMENTS

The research reported herein was performed under Hazardous Materials Cooperative Research Program (HMCRP) Project HM-04 by Battelle, the contractor for this study. Mr. William Tate, Principal Research Scientist at Battelle, Columbus, Ohio, was the Project Director and Principal Investigator and an author of this report. The other author of this report was Dr. Mark Abkowitz, Professor of Civil & Environmental Engineering at Vanderbilt University, Nashville, Tennessee. Other contributors were the American Transportation Research Institute, Minneapolis, Minnesota, and Atlanta, Georgia, led by Mr. Dan Murray; Visionary Solutions, LLC, Oak Ridge, Tennessee, led by Mr. Dan Hoglund; Mr. Don Loftis of Olin Chlor Alkali Products, Charleston, Tennessee, and Dr. Arthur Greenberg, Senior Research Scientist at Battelle, Columbus, Ohio. The work was done under the general supervision of Mr. Tate.

FOREWORD

By William C. Rogers
Staff Officer
Transportation Research Board

HMCRP Report 4: Emerging Technologies Applicable to Hazardous Materials Transportation Safety and Security describes near-term (less than 5 years) and longer-term (5–10 years) technologies that are candidates for enhancing the safety and security of hazardous materials transportation for use by shippers, carriers, emergency responders, or government regulatory and enforcement agencies. Using extensive reviews of the literature and interviews with numerous technology providers, the research identifies emerging generic technologies that hold the greatest promise of being introduced during these near- and longer-term spans. It also identifies potential impediments (e.g., technical, economic, legal, and institutional) to, and opportunities for, their development, deployment, and maintenance. The research focused on all modes used to transport hazardous materials (trucking, rail, marine, air, and pipeline) and resulted in the identification of nine most promising emerging technologies.

Shipments of U.S. DOT-regulated hazardous materials may pose risks to the public if they are accidentally or intentionally released. The long-term safety records of these shipments is excellent, due in large part to the efforts of shippers, carriers, and receivers working closely with federal, state, and local agencies responsible for regulation, enforcement, and emergency response. Technological advancements have been important in minimizing the occurrence and consequences of accidental releases by improving industry and government capabilities in areas such as shipment handling, packaging, monitoring, and emergency response. Ensuring that hazardous materials shipments are also secure from terrorist attacks and deliberate releases likewise requires the concerted efforts of government and industry—aided by technology.

Under HMCRP Project 4, Battelle Memorial Institute was asked to (1) conduct a thorough survey and document all emerging technologies that have potential application to hazardous materials transportation safety and security in the near and longer terms; (2) develop criteria for the selection of the most promising technologies; (3) develop a preliminary list of technologies considered to be most promising; and (4) develop recommendations for advancing the most promising technologies for the safe and secure transportation of hazardous materials. The final result is a commentary on each of the nine most promising emerging technology areas, an examination of the individual technology developments within them, and the projected paths of the technologies to the marketplace, including needs and perceived obstacles.

CONTENTS

Note: Many of the photographs, figures, and tables in this report have been converted from color to grayscale for printing. The electronic version of the report (posted on the Web at www.trb.org) retains the color versions.

SUMMARY

Emerging Technologies Applicable to Hazardous Materials Transportation Safety and Security

Introduction

Project Objectives

The objectives of this project were to (1) develop a list of near-term (less than 5 years) and longer-term (5–15 years) technologies that are candidates for use in enhancing the safety and security of hazardous materials (Hazmat) transportation, as applied by shippers, carriers, emergency responders, or government regulatory and enforcement agencies; (2) identify emerging technologies that hold the greatest promise (in terms of effectiveness) of being introduced during these near- and longer-term spans; and (3) identify potential impediments to and opportunities for their development, deployment, and maintenance (e.g., technical, economic, legal, and institutional). The time frames for near term and longer term were considered to be the periods of 2009 to 2013 and 2014 to 2023, respectively.

Problem Statement and Discussion

A significant challenge in the planning and conduct of this project was to identify a research methodology that recognized and captured the needs of the various transportation modes, and then in the wide universe of technologies, to find the emerging ones that appear to best meet those needs. An additional challenge was the reality that, by definition, these technologies would not already be in the marketplace. Rather, they would be found in the research departments of companies, government laboratories, universities, and consortia. Some would not be far along in development; moreover, for the emerging technologies farthest out on the development horizon, there would not be nearly as much concrete information to go on. Once the most promising emerging technologies were identified, finding their developers, obtaining enough pertinent information, and making judgments about the perceived characteristics of the path to the marketplace for each of the technology areas were themselves challenges that had to be met.

Background Research and Information Gathering

To appreciate the significance and departure point for emerging technologies, it was appropriate to be aware of existing systems as well as current and planned research. A number of prior and current initiatives relating to transportation safety and security in general and Hazmat transportation in particular were examined. These included development efforts, tests, studies, reports, capabilities, and tools. Within the past decade, the transportation industry, including Hazmat transport, has undergone a remarkable technological revolution. Carriers and shippers have adopted a number of new technologies to optimize productivity and minimize the costs of operation. Many new technologies applicable to transportation have been developed in recent years, and others are in planning or development stages. Consider, for example, that advances in motor vehicle technologies are edging closer to the time when the technologies will be able to drive the vehicle.

Assumptions and Observations

Discussions among research team members (hereafter, the "team") and with outside Hazmat authorities produced many observations pertinent to the project, which resulted in assumptions that helped frame project understanding for the eventual research approach. These were shared with the project panel to ensure that the boundaries of the unfolding research were properly defined. On the basis of these assumptions and observations, any candidate emerging technology to be considered under this task was assumed to fall into one of three categories:

- Evolutionary (i.e., an incremental performance improvement to an existing product)
- Revolutionary (i.e., something not seen before, such as certain biometrics-based identity management applications)
- Application of a technology used in, or being developed for, another industry but not currently adapted to transportation (e.g., impulse radar, which has been used for oilfield exploration and could be used for vehicular target tracking in conjunction with predictive software algorithms).

Project Approach

The project obtained information relevant to all five Hazmat transportation modes identified in the solicitation—highway, rail, marine, air, and pipeline. (NOTE: the terms *highway mode* and *truck mode* are used somewhat interchangeably in this document, as are the terms *marine* and *maritime.*) After basic data on emerging technologies were gathered and compiled, the team developed a systematic analysis approach to produce a short list of most promising emerging technologies from the universe of technology candidates. The process started with a definition of functional requirements that are considered necessary to provide safe and secure transport on a given transportation mode. For each mode, an assessment was made as to the extent to which current practices meet the stated requirements, taking both existing technology capability and its market penetration into consideration (Functional Requirement Gap Rating). Separately, based on the volume of Hazmat transport on each mode (proxy for event likelihood) and the potential consequences associated with a significant safety or security incident (proxy for serious consequence), a determination was made as to which modes warranted greater development attention as a result of their associated risk (Mode Importance Rating).

The results of the Functional Requirement Gap Ratings and Mode Importance Ratings were then combined to determine the corresponding technology development priorities (Technology Development Priority Rating). Within each technology development priority, more specific technology needs were then defined (Technology Need Areas) and each previously identified technology was associated with each need area to which it aligns. Those technologies that fell into the priority need areas were then considered on the "short list" of technology candidates, and the technologies that were tied to the greatest number of priority need areas were consequently designated as "most promising." Figure S-1 illustrates the selection process.

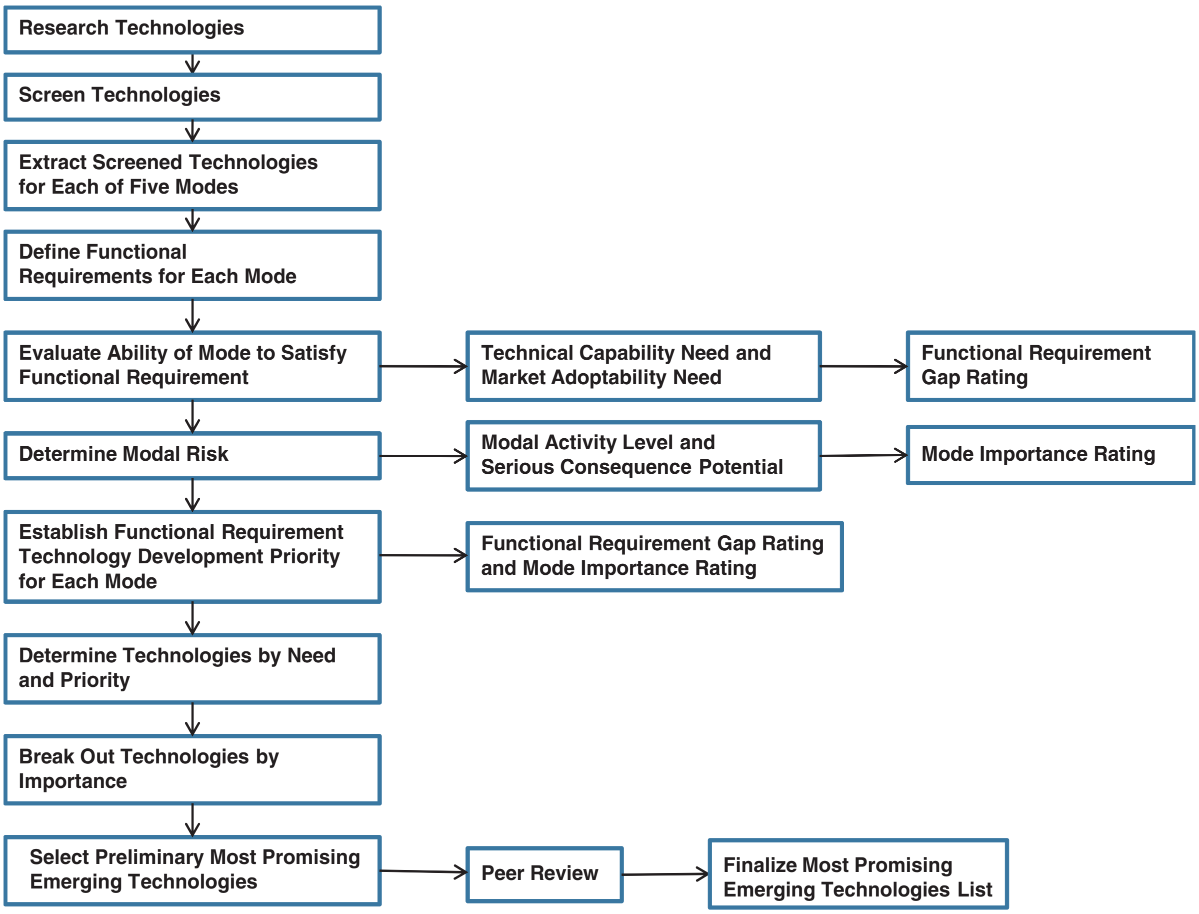


Figure S-1. Process for selecting most promising technologies.

Findings

Table S-1 provides a characterization of the nine most promising emerging technology areas that resulted from that process. They are segregated into three functional groups:

- Monitoring and Surveillance
- Alternative Power Generation
- Infrastructure

It is interesting to note that the Alternative Power Generation group, with its three technology areas, as well as certain technology areas within the Monitoring and Surveillance group, contains most promising emerging technologies that were not developed primarily for transportation applications, yet they are clearly relevant to enhancing Hazmat transportation safety and security.

To gain a better understanding of the development status and expectations in these technology areas, technology developers in these respective areas were identified and contacted. Recognizing that many technology developers are sensitive to providing public information, the goal of this effort was to at least gain a representative outlook from each of the nine technology areas. Consequently, 23 interviews were conducted with technology developers (see Table S-2).

Table S-1. Characterization of most promising emerging technology areas.

Technology Description	Concept	Importance to Hazmat Transportation
Monitoring and Surveillance Group		
Networked radio frequency identification (RFID)/Global Positioning System or Global Locating System (GPS/GLS) monitoring/networked ubiquitous sensors and cargo monitoring	This refers to the concept of multiple sensors tied into a central monitoring site where system control functions also may exist. Ubiquitous sensors refers to the concept of a "system of systems," possibly a nationwide sensor network.	If these sensors are deployed on commercial vehicles carrying Hazmat, any alerts or problems with the cargo condition could be detected by fixed sensors at locations such as truck stops, or even by other vehicles. That detection capability could not only enable quicker response to an anomalous condition such as a chemical leak, but could also provide a real-time early-warning system for a wide array of chemical, biological, and nuclear threats across the United States.
Pressure gauges and chemical detection sensors NOTE: this is a category of two related technology needs with functionally similar purposes, within each of which is found emerging technologies.	Improved sensors that can accurately detect pressure changes and chemical releases with very low false alarm rates.	The capability of event-based alerts is limited by sensitivity of sensors as well as their false alarm rates. High false alarm rates are detrimental to the acceptance of any technology being implemented. As the number of Hazmat shipments being tracked continues to increase, the capability of embedded sensors to detect anomalous conditions at lower thresholds and higher reliability is needed so that an alert can be automatically generated. This needed capability also applies to pipelines as well as vehicles.
Fiber-optic/photonic sensors and optical scanners for monitoring of cargo, or for fixed point monitoring of infrastructure health and environment problems.	Photonics refers to the generation, emission, transmission, modulation, signal processing, switching, amplification, detection and sensing of light, that in this case carries information. Fiber-optics is a form of photonics.	The amount of information capable of being transmitted via photonic means is great. Use of fiber-optics to replace copper wire in aircraft for control mechanisms is being considered. Fiber-optics is being used on some warships in their combat systems and for lighting and illumination devices. Photonics has the potential to provide significant performance improvements such as increase in bandwidth, weight savings, and improved compartment integrity. Application of photonics to other types of vehicles, as well as pipelines and other fixed structures such as tunnels and bridges, may help monitoring and detection of anomalous conditions at reduced cost.
Improved locking with fiber-optic seals, low power RFID, and remote monitoring of seal array.	Seals and locks, possibly with advanced encryption and other features that make them very difficult to defeat, which can be remotely monitored for intrusion and system functioning.	The ability to protect sealed Hazmat cargo is improved by defeating sophisticated intrusion attempts and reporting their occurrence.
Intelligent video tracking and surveillance system with capability for automated handoff to a sequence of cameras.	Software capable of capturing the image of a specific vehicle and passing this image from one linked camera to another so that its passage is tracked, if the area of interest has sufficient cameras. This technology uses the current generation of cameras.	A Hazmat vehicle carrying especially toxic material could be tracked by a series of video cameras that automatically hand off the truck's image from camera to camera as it passes through a High-Threat Urban Area. Law enforcement could link video cameras around major cities, map video panoramas to publicly available aerial maps, and use software to provide a higher level of "location awareness" for surveillance.
Alternative Power Generation Group		
Wireless power	Wireless energy transfer or wireless power transmission refers to the process that takes place in a system where electrical energy is transmitted from a power source to an electrical load, without interconnecting wires. Wireless transmission is useful in cases where instantaneous or continuous energy transfer is needed but interconnecting wires are inconvenient, hazardous, or impossible.	This is an enabling technology in that it helps to provide electrical power for sensors and other technologies that would be more expensive due to battery maintenance and replacement costs.

Table S-1. (Continued).

Technology Description	Concept	Importance to Hazmat Transportation
Nanopiezoelectronics Nanotechnology refers to technology involving manipulation of objects whose dimensions are approximately 1 to 100 nanometers. The piezoelectric effect refers to applying a mechanical stress (e.g., deformative) to applicable piezoelectric material (e.g., certain ceramics, quartz, etc.) that causes production of an electrical charge.	The combined term "nanopiezoelectronics" refers to generation of electrical energy (electricity) at the nanometer scale (e.g., to power nano-devices) via mechanical stress to the nanopiezoelectronic device. For example, bending of a zinc oxide nanowire transforms that mechanical energy into electrical energy; a flag with nanowire could generate power while fluttering.	This is an enabling technology in that it helps to provide electrical power for sensors and other technologies that would otherwise be more expensive due to battery maintenance and replacement costs.
Plastic thin-film organic solar cells	These solar cells are not rigid panels and can be molded into a variety of shapes to occupy space that would not be possible for current, conventional solar cells. They operate with flexible polymer batteries that never need to be recharged.	This is an enabling technology in that it helps to provide electrical power for sensors and other technologies that would be more expensive due to battery maintenance and replacement costs.
Infrastructure Group		
Container integrity This is a category represented by a number of different structural improvements such as ▪ Specialty and treated steels ▪ Engineered metal structures (e.g., egg crate, honeycomb, lattice block, corrugated) ▪ Structural foams and adhesives ▪ Composites/fiber-reinforced plastics ▪ Insulation and thermal protection ▪ Armor and self-sealing technologies ▪ Impact resistant coatings ▪ Valves and fittings ▪ Railcar couplers (cushioning)	Improvements to containers such as rail and truck tank cars, casks, and pipelines.	The chemical shipping industry considers strengthened containers a top priority. There are a number of approaches being investigated to make large containers better able to withstand impacts without increasing weight. Much of this work is associated with the Next-Generation Rail Tank Car Project.

Table S-2. Type of technology developers interviewed.

Technology Area	Respondents	Interviews
Networked RFID/ubiquitous sensors and cargo monitoring	▪ Company ▪ National Laboratory ▪ National Laboratory ▪ Company ▪ National Laboratory	5
Pressure gauges and chemical detection sensors	▪ Company ▪ Company (4 related but separate technologies)	5
Fiber-optic/photonic sensors and optical scanners	▪ Company	1
Advanced locks and seals	▪ National Laboratory ▪ Company	2
Intelligent video tracking and surveillance	▪ Company ▪ Company	2
Wireless power	▪ Company ▪ Company	2
Nanopiezoelectronics	▪ University	1
Plastic thin-film organic solar cells	▪ Company ▪ Company ▪ Company	3
Container integrity	▪ U.S. DOT Research Organization ▪ Company	2
	Total	**23**

Table S-3. Technology maturity comparison.

	Short Term	2–5 Years	6–10 Years	Category Totals
Networked RFID/ubiquitous sensors and cargo monitoring	3	2		5
Pressure gauges and chemical detection sensors	2		3	5
Fiber-optic/photonic sensors and optical scanners			1	1
Advanced locks and seals	1	1		2
Intelligent video tracking and surveillance	1	1		2
Wireless power	2			2
Nanopiezoelectronics		1		1
Plastic thin-film organic solar cells	1	2		3
Container integrity	1		1	2
Totals	**11**	**7**	**5**	**23**

Based on this survey sample, Table S-3 shows the relative maturity of each technology area in terms of developmental timeframe. (NOTE: While the solicitation defines "longer-term" technologies as maturing in the 6–15 year horizon, no developing technologies were identified that appear to be maturing in the latter half: the 11–15 year horizon. This perhaps indicates the motivation that developmental organizations have to bring technologies to maturity in a timely manner. It could also indicate that in today's world of rapid technology change, planning too far in the future may simply carry too much risk of being overtaken by agile competitors. Consequently, the long-range horizon in subsequent tables is truncated at 10 years instead of 15.)

Figure S-2 provides a development roadmap for each of the nine most promising emerging technology areas based on the survey sample. The columns to the right of the technology area correspond to the five technology development levels defined by the team:

- Level 1—basic technology principles have been observed
- Level 2—equipment and process concept formulated
- Level 3—prototype demonstrated in laboratory environment
- Level 4—technology product operational in limited real-world environment
- Level 5—technology product fully operational in real-world environment

The length of the bar portrays the relative maturity of the technology area. This involves some interpolating and averaging because a given technology area is usually represented by more than one technology, and developing products may reach the marketplace at different times. The black part of the bar is intended to show the team's perceptions of where the majority of development has progressed to date, while the gray part of the bar shows advance entries approaching or having reached the marketplace.

Conclusions

The team characterized the development status in each of these areas, as well as the future outlook for each technology in reaching and being adopted in the marketplace. This led to the following summary observations:

- Surveillance and Monitoring Group
  - Potential benefits are new capabilities to detect and report out of normal conditions and improved measures to deter unauthorized access.

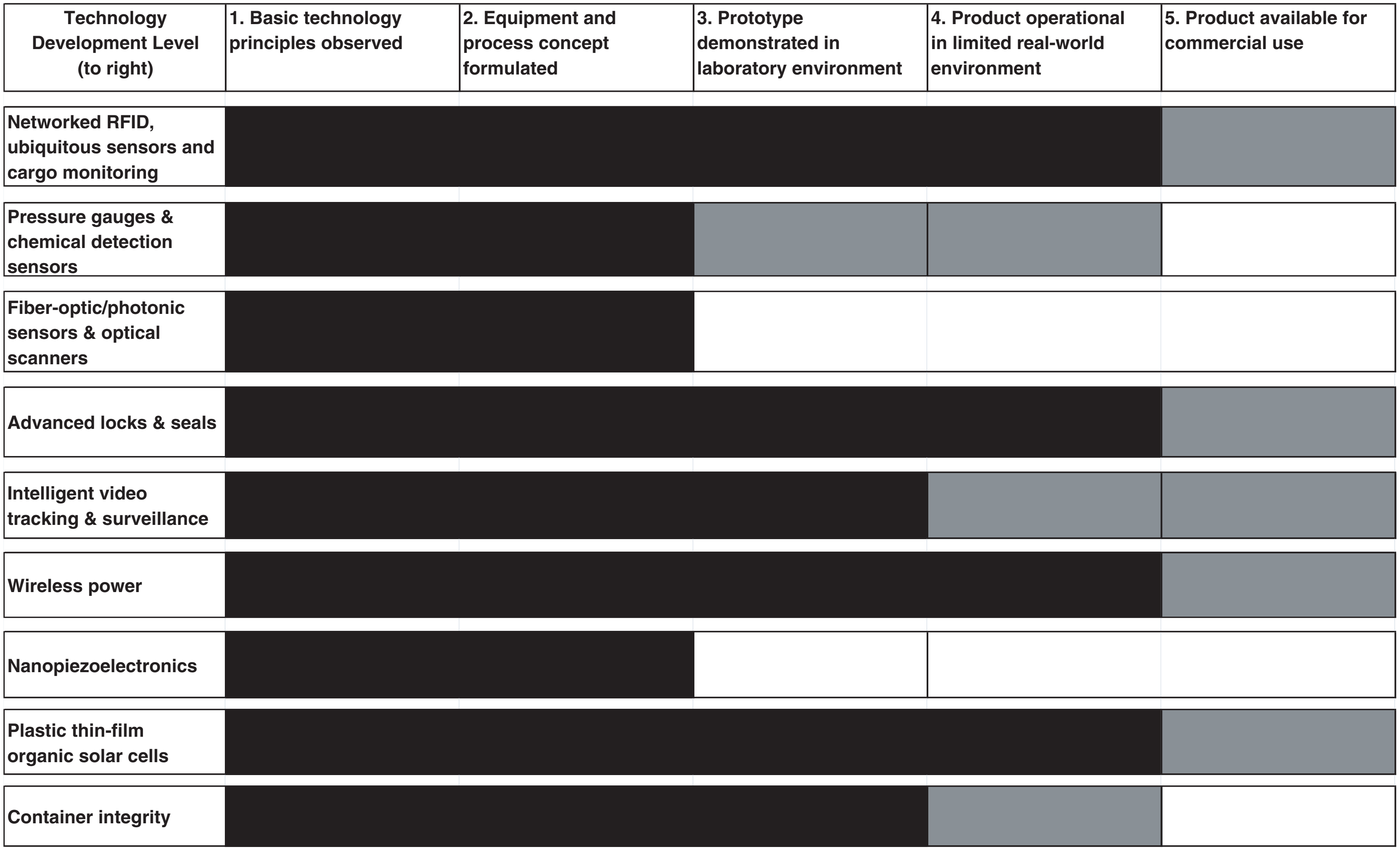


Figure S-2. Development roadmap for the nine most promising emerging technologies.

  - Challenges that need to be overcome include making the systems more user friendly, more affordable with low life cycle costs, compliant with power and bandwidth standards, and capable of reading with high reliability at lower detection thresholds, in a rugged environment, with very low false positive alarm rates.
  - If development continues along the anticipated path, this capability should be substantially available in the marketplace in the near term (within 5 years) for the majority of most promising technologies examined, with a number of chemical detection sensors maturing in the longer term (6–10 years).
- Alternative Power Generation Group
  - Potential benefits are electrical power available to sensors and communications devices that would not otherwise be put into use without that supply, and the potential to reduce the size of batteries or even eliminate them.
  - Challenges that need to be overcome include manufacturing at larger scale, certain physical application requirements, and integration with other technologies.
  - If development continues along the anticipated path, this capability should be substantially available in the marketplace in the near term.
- Infrastructure Group
  - Potential benefits are stronger Hazmat containers (especially large tanks) that are more resistant to punctures or able to seal some leaks caused by punctures.
  - Challenges that need to be overcome include providing the extra strength for an affordable price within acceptable weight and size limitations.
  - If development continues along the anticipated path, this capability should be substantially available in the marketplace in the near term (based largely on current program goals for technologies that are in addition to the most promising technologies examined).

One of the factors that continue to inhibit more widespread technology deployment is that a demonstrated business case is lacking for some transportation segments to invest more in technologies primarily for the sake of safety and security. Because technology adoptability is fundamentally cost-based, market penetration usually does not happen until the products are mass-produced or otherwise become affordable. For example, recent research indicates that the emerging use of sensors may provide major benefits to transportation efficiency (*1*); if this is the case, then products using sensor technology are likely to be embraced by industry.

As a cautionary note, however, commercially available sensors may operate with limited potential to enhance Hazmat transport safety and security today. Until the technology exists that can satisfy functional requirements such as withstanding harsh climates, being resistant to tampering, and working with very low false alarm rates, additional development will be needed before the Hazmat transportation market will respond.

Recommendations

It is hoped that the project findings will help the HMCRP and its stakeholders gain a better understanding of the most promising emerging technologies to improve Hazmat transportation safety and security. Consequently, this will aid the public and private sectors in making informed decisions about emerging technologies that they may wish to deploy. Moreover, it is conceivable that the information from the report could in some ways help accelerate development of certain technologies if the common interest among groups is recognized.

CHAPTER 1

Background

1.1 Project Objectives

The objectives of this project were to (1) develop a list of near-term (less than 5 years) and longer-term (5–15 years) technologies that are candidates for use in enhancing the safety and security of Hazmat transportation, as applied by shippers, carriers, emergency responders, or government regulatory and enforcement agencies; (2) identify emerging technologies that hold the greatest promise (in terms of effectiveness) of being introduced during these near- and longer-term spans; and (3) identify potential impediments to and opportunities for their development, deployment, and maintenance (e.g., technical, economic, legal, and institutional).

The remaining organization of this report includes the following:

- Chapter 2: Research Approach (All Tasks) and Preliminary Findings (Tasks 1 through 3)
- Chapter 3: Findings and Applications (from executing the Task 4 work plan)
- Chapter 4: Conclusions and Recommendations

NOTE: The findings and applications for Tasks 1 through 3 are provided in Chapter 2. These findings include the selection and general characterization of the preliminary most promising emerging technologies, which sets the stage for the final research. It was considered necessary to provide these findings before Chapter 3 to most effectively show the logical progression of the research as it built on the findings. However, in Chapter 2, Task 4 is presented in terms of planned activities. Thus, the findings and applications discussed in Chapter 3 focus on results obtained from executing the Task 4 work plan, which defines Task 6 activity. (NOTE: Task 5 is submission of the interim report, capturing the activities and results of Tasks 1 through 4, and Task 7 is the final report documenting the entire research effort.)

1.2 Problem Statement and Discussion

A big challenge in the planning and conduct of this project was to identify a research methodology that recognized and captured the needs of the various transportation modes, and then in the wide universe of technologies, finding the emerging ones that will best meet those needs. An additional challenge was the reality that by definition, these technologies would not already be in the marketplace. Rather, they would be found in the research departments of companies both big and small, government laboratories, universities, and consortia. Some would not be far along; for the emerging technologies farthest out on the 15-year development horizon, there would not be nearly as much concrete information to go on. Once the most promising emerging technologies were identified, finding their developers, collecting enough pertinent information from them, and making judgments about the anticipated path to the marketplace for each of the technology areas were themselves challenges that had to be met.

CHAPTER 2

Research Approach

The project consisted of performing the following tasks:

1. Conduct a survey and document emerging technologies (short term and long term) that have potential application to Hazmat transportation safety and security.
2. Develop criteria for selecting the most promising technologies.
3. Develop a preliminary list of the most promising technologies based on the aforementioned criteria.
4. Develop a detailed work plan for more in-depth exploration of the most promising technologies.
5. Submit an interim report documenting Tasks 1 through 4 for review by the HMCRP Project 04 panel.
6. Upon approval by HMCRP Project 04 panel, execute the work plan developed in Task 4 and develop recommendations for advancing the most promising technologies.
7. Prepare a final report documenting the entire research effort.

The following sections describe the approach followed through the project's task progression. Definitions of acronyms are found in Appendix A.

2.1 Research and Information Gathering

To understand the challenge of protecting Hazmat shipments, consider first the U.S. transportation system which encompasses the following:

- 452 commercial airports
- 361 major seaports
- 3.9 million miles of public roads
- 140,000 miles of major railroads
- 25,000 miles of commercial navigable waterways
  - million miles of pipelines, including 2.2 million miles of hazardous liquid and natural gas pipeline (*2*).

Each year, 3.1 billion tons of Hazmat are transported throughout the United States by truck, rail, pipeline, and water.

- More than 800,000 Hazmat shipments are transported daily
- 500,000 daily shipments involve chemical and allied products
- 300,000 daily shipments involve petroleum products
- 10,000 daily shipments involve hazardous and medical waste
- 94 percent of individual shipments are carried by truck
- 5 percent of individual shipments are carried by air
- Less than 1 percent of individual shipments are carried by rail, pipeline, and water; however, these shipments are the largest (*3*)
- 1.2 million trucking companies operate 15.5 million trucks including 42,000 Hazmat trucks
- 10 million licensed commercial vehicle drivers include 2.7 million Hazmat drivers (*4*).

To appreciate the significance and departure point for identification of emerging technologies applicable to Hazmat transportation, it is appropriate to be aware of existing safety and security systems as well as current and planned research. The following discussion of these topics is intended to be illustrative, not all inclusive.

Within the past decade, the transportation industry including Hazmat transport has undergone a remarkable technological revolution. Carriers and shippers have adopted a number of new technologies to optimize their productivity and minimize the costs of their operation. Many new technologies for transportation have been developed in recent years, and others are in planning or development stages. Advances in motor vehicle technologies are edging closer to the time when the technologies will be able to drive the vehicle. Sensors provide information to systems that improve both performance and safety. Engine and performance information can be read remotely. In-vehicle sensors can be tied to the vehicle's system in a way that allows automatic adjustment of settings according to the vehicle's speed, steering, and road surface conditions.

With adaptive cruise control, vehicles equipped with radar can look hundreds of feet ahead for safe positioning or collision warning. An adaptive cruise control (ACC) system can adjust speed and following distance with collision warnings and automatic triggering of brakes. While ACC works only at speeds of greater than 25 mph, the next version, called Full Speed Range ACC, will work if the vehicle is traveling very slowly or is even stopped (*5*). There are systems to warn of lane drift, side collision alert, or the presence of another vehicle in the visual blind spot (*6*). Roll alert sensors can help prevent tank trucks, such as those that carry Hazmat, from turning over.

One prominent development effort is the U.S. Department of Transportation's (U.S. DOT's) IntelliDrive℠ initiative (NOTE: use of the term IntelliDrive℠ is with U.S. DOT's permission). This initiative includes the establishment of technologies that wirelessly link vehicles with the transportation infrastructure and with value-added services using, among others, dedicated short range communications (DSRC) and commercial cellular networks. Significant research has been devoted to the study and application of communications technologies that would support wireless data exchange and the integration of vehicles with the national transportation infrastructure. This communication between vehicle and roadside (and more recently, advances in the capability of vehicle-to-vehicle communication) make it possible that this research will lead to advances in Hazmat transportation safety and security for motor carriers (*7*).

If the IntelliDrive℠ initiative is successful in integrating wireless communications as commonplace on Hazmat vehicles in the future, events that are happening with the vehicle will be shared with other vehicles as well as the roadside. For example, if a windshield wiper is operating, that can be an indication of precipitation at that location. If safety systems such as electronic stability control are activated on a vehicle, that activation can be an indication of a slick road surface. A mass of vehicles showing very low velocity will indicate traffic jams. The vehicle could sense a red light and warn the driver to take action or even stop the vehicle if the driver does not appear to be reacting properly (*8*).

In its Hazmat Truck Security Pilot project, the Transportation Security Administration (TSA) researched the state-of-the-practice in Global Positioning System (GPS)/Global Locating System (GLS) tracking and alerting features (*9*). Concurrently, the system and communication architecture and software were developed. The operational possibilities of a national Hazmat truck tracking center prototype, incorporating a Universal Communication Interface (UCI) for electronic exchange of manifest information, were explored. The University of Kentucky, including the Kentucky Transportation Center (KTC) and its partners such as the National Institute of Hometown Security (NIHS), are continuing the work originally developed in the Hazmat Truck Security Pilot. The North American Transportation Security Center program aims to track motor carrier shipments of security-sensitive materials. It seeks to build a functional prototype of a Hazmat truck tracking center and take the tracking center into full operational status through an implementation program (*10*).

The TSA has delineated voluntary security practices (referred to as Security Action Items or SAIs) that they recommend be implemented to increase the security of certain highway security-sensitive materials transported by motor vehicles (*11*). TSA has conducted research on tracking of bulk Toxic Inhalation Hazards (TIH) transported by rail and event-based alerts (*12*). TSA has also conducted research on technology alternatives to Hazmat placarding (*13*). TSA has instituted grant programs for motor and rail carriers to encourage more widespread use of GPS-based locating and alerting systems.

The freight rail industry has been involved with much public and private research. A substantial amount of research has gone into improving rail tank car container integrity, including the Next Generation Rail Tank Car effort being conducted by a joint project team involving Dow Chemical Company, Union Pacific Railroad, and Union Tank Car Company (*14*).

The Chemical Transportation Emergency Center (CHEMTREC) assists emergency responders in dealing with incidents involving Hazmat and dangerous goods, and also helps shippers of hazardous materials comply with government regulations (*15*). The partnerships between CHEMTREC and CSX Railroad involving CSX's Network Operating Workstation (NOW) system have produced a working model of cooperation for response to rail Hazmat incidents. There are additional agreements between CHEMTREC and Dow Chemical that provide in-transit visibility for Dow's rail Hazmat shipments.

Operation Respond Emergency Information System (OREIS™) is a software tool that provides emergency responders with crucial information for dealing with incidents involving railroads and highways, including hazardous materials incidents. Among other features, OREIS™ provides emergency responders with real-time information about the chemical contents of railcars and trucks that have been involved in an incident. The software also contains equipment schematics of tank cars, bulk containers, Hazmat trucks, and locomotives.

A number of reports give insight into the types of technologies that are commercially available and in use for various transportation modes capable of transporting Hazmat. For example, relevant highway mode publications include the following:

- Federal Motor Carrier Safety Administration (FMCSA) *Vehicle Immobilization Technologies* (*16*)
- FMCSA *Untethered Trailer Tracking and Control System* (*17*)

- FMCSA *Expanded Satellite-Based Mobile Communications Tracking System Requirements* (*18*)
- FMCSA *Hazardous Materials Safety and Security Operational Test* (*19*), especially its technology compendium
- TSA *Hazmat Truck Security Pilot/National Truck Tracking Center Prototype* (*20*) (an update to the FMCSA technology compendium)
- International Truck & Engine Corporation *Homeland Security for the Trucking Industry* (*21*).

The HMCRP Project 04's objective took a distinctly different direction from much of the prior research in that it is focused on technologies that are not yet in the commercial marketplace. The project solicitation directs that "This research reviewed generic technologies and did not evaluate specific name-brand products." Therefore, the technologies being sought are in some stage of development whether by a company, laboratory, university, or consortium. The HMCRP Project 04 searched for these technology developments out to a 15-year horizon. It also looked at technologies that can benefit all five transportation modes: highway, rail, marine, air, and pipeline. (NOTE: the terms *highway mode* and *truck mode* are used somewhat interchangeably in this document, as are the terms *marine* and *maritime.*) The HMCRP Project 04 panel emphasized that the team should not limit its research to the United States.

2.2 Assumptions and Observations

At the HMCRP Project 04 kickoff meeting, participants covered a number of aspects of Hazmat transportation and from that drew observations that helped frame project understanding for the eventual research approach. Discussions among team members and with an outside Hazmat authority produced dozens of observations pertinent to the task. Among the more significant of these are the following:

- Evolutions to current products are as valid as new developments and would be expected to be more numerous than new developments.
- Some Hazmat transportation occurs in closed systems with many existing controls. This applies to the air mode as well as surface transportation under controlled measures such as the Department of Defense (DOD) Defense Transportation Tracking System (DTTS) or the DOE's Transportation Tracking and Communications (TRANSCOM) System.
- Packaging of multiple technologies can produce a potentially large benefit.
- A technology that can provide benefits across multiple modes is attractive.
- There may be vulnerabilities and gaps, with some larger than others; the most important of these gaps warrant priority consideration.
- Hazmat is often stolen for its value, not for terrorist purposes (e.g., cyanide used for gold mining, increasing thefts of gasoline as costs rise).
- The majority of promising technologies in the future are expected to evolve from current technologies that are capable of multiple functionalities and enhancements.
- Most new technologies with promise for Hazmat transportation are not DOD derivatives; they are coming from commercial product development.
- Some technologies that were not designed specifically for Hazmat may still offer large benefits to Hazmat (e.g., anti-rollover technology).
- Safety and security are given essentially equal treatment in the project solicitation; however, efficiency, cost, and safety are well ahead of security as the main reasons why technologies are implemented for Hazmat transportation in the current environment.
- If security can be added on top of safety, it is easier than basing a business decision on security alone. There are few pure security tools on the market.
- Hazmat security is not driving the market for technology—high value is.
- However, if a significant incident were to occur involving the intentional release of a high consequence substance, the relative importance of security would be dramatically and quickly escalated. [NOTE: this primarily refers to intentional release of a bulk quantity of a substance such as those classified as Certain Dangerous Cargo (CDC), Especially Hazardous Cargo (EHC), Poison Inhalation Hazard (PIH), and TIH].
- Logistics is now the largest part of product cost in the TIH Hazmat industry.
- A high rate of false alarms/false positive alerts can kill a new technology.

On the basis of these assumptions and observations, any candidate emerging technology to be considered under this task was assumed to fall into one of three categories:

- Evolutionary (i.e., an incremental performance improvement to an existing product)
- Revolutionary (i.e., something not seen before, such as certain biometrics-based identity management applications)
- Application of a technology used in, or being developed for, another industry but not currently adapted to transportation.

The team sought to clarify the thrust and boundaries of the research, by clarifying a number of key assumptions prior to fully implementing the research approach. Those assumptions, which were subsequently accepted by the HMCRP Project 04 panel, are as follows:

- While the team will not confine its research to the United States when looking for emerging technology developments, for this project the focus for technology use is Hazmat transportation within the United States and by extension Canada, since it is so similar.

- The Hazmat transportation phase that the emerging technologies are intended to protect is in-transit—even if not moving. (This usually means the Hazmat is in the custody of someone other than the manufacturer, shipper, or customer. However, it is possible that the product could be not moving but still in the custody of the shipper, for example, at a consolidation point, intermodal exchange, or simply stored enroute for a period of time.) Thus, the team did not seek technologies applicable to safety and security of Hazmat manufacture, storage, loading/unloading, and disposal, although those phases could also benefit from technologies meant for in-transit shipments.
- The definition of serious consequence potential (the significance of which is discussed in Section 2.4.4) does not include the factor of likelihood of occurrence.
- Consequence potential is defined for the United States and its rules and regulations. An example of where this might differ outside of the United States is in the pipeline transportation of flammable substances. In the United States, regulations would not permit the pipeline to pass under a high-density residential area as it might in a developing country.
- Certain existing technologies that are in use by other industries—but have not been adopted by transportation—are valid candidates for consideration. Strictly speaking, this category of technologies was not addressed by the project solicitation, but rather was considered applicable as "due diligence" to ensure that the most promising technologies are considered.

The team adopted two additional assumptions. First, the team considered that to "identify emerging technologies that hold the greatest promise of being introduced . . . " (from the project solicitation) is comparable to "identify emerging technologies that will have the greatest effectiveness if introduced. . . . " Second, the team defined the type and quantity of Hazmat for which emerging technologies for safety and security is a concern for this project, as follows:

In June 2008, TSA's Transportation Sector Network Management (TSNM) Highway and Motor Carrier Division published a list of Tier 1 and Tier 2 Highway Security-Sensitive Materials (HSSMs) with applicable Voluntary SAIs (*22*). The HSSMs were divided into Tier 1 and Tier 2 materials according to the risk to national security while being transported in commerce because of the potential use of the material in an act of terrorism. The documentation notes that "The voluntary security practices have been developed by TSA Office of Transportation Sector Network Management, Highway and Motor Carrier Division after consultation with individual stakeholders including chemical manufacturers, chemical carriers and transportation industry representatives, as well as appropriate Federal agencies."

This documentation included a matrix consisting of the DOT Hazard Class (33 listings); Threshold Quantity (which is "any quantity" for some substances such as Division 1.1-1.3 explosives); Tier Level (1 or 2); and SAIs including the categories of General Security, Personnel Security, Unauthorized Access (detection and prevention), and En-Route Security (see 49 CFR 171.8 for definitions of these hazard classes and threshold quantities). In May 2009, TSA added another category of Hazmat that was originally intended to be among the Tier 2 HSSMs.

While TSA's recommendations only apply to the highway mode, the HMCRP Project 04 team believed that the matrix provided a comprehensive list and recognized TSA's Hazmat Class listing as the team's assumption of the types and quantities of Hazmat that apply to this project.

[NOTE: among the total 23 SAIs in the TSA documentation, several appear to relate directly to technologies. Two are within the category of Unauthorized Access (Access Control System for Drivers and Access Control System for Facilities Incidental to Transport; access control as defined here may include a biometric component.) Five of the SAIs are within the category of En-Route Security (Seals, Locks, Tractor Activation Capability, Panic Button Capability, and Tractor and Trailer Tracking Systems). Tractor activation requires driver identification by login and password or biometric data to drive the tractor (truck). "Panic Button" technology enables a driver to remotely send an emergency alert notification message either via Satellite or Terrestrial Communications, and use the remote Panic Button to disable the vehicle. Tractor and Trailer Tracking Systems are intended to incorporate satellite and land-based wireless GPS communications systems, geofencing and route monitoring capabilities, and the ability to remotely monitor trailer "connect" and "disconnect" events. While the SAIs include measures such as plans, programs, protocols, policies and procedures, processes, and training, other technologies that may be inferred from the items are supply chain tracking and route planning].

Currently, implementation of technologies within the supply chain is predominantly based on the expectation of return on investment (ROI) within a supply chain context. In the for-profit sector, if a technology will not increase efficiencies, reduce costs, or provide a competitive advantage, it is not voluntarily implemented outside of tests. However, that criterion could change overnight if a security incident of national importance occurred in which bulk Hazmat fell into the wrong hands and was successfully used as a weapon of mass destruction. This situation must be considered.

(NOTE: In the report, the related disciplines of emergency management, incident response, and first response are referred to under the single term *emergency response.)*

2.3 Details of Task 1: Conduct Survey and Document Potential Emerging Technologies

A more in-depth characterization of steps followed in the project tasks is provided.

2.3.1 Literature Review

The literature search for this project focused on gathering publications, data, and other sources to identify relevant information concerning potential emerging technologies. Conducting a literature review for HMCRP Project 04 proved to be a challenge. During the literature review process, the first few keyword searches produced a large amount of useful quality information, yet also included many articles that were not relevant to the project. Consequently, the team devised a list of simple terms that should be included in the search for new and emerging technologies. This list was segmented into categories, base keywords, modes, and technology. The search was confined to English language publications. For currency and relevance, the baseline for the search was established as research published on or after January 1, 2007.

This literature search was performed by the Battelle Technical Information Center. Searches were approached consistently with a scan of databases in the DIALOG system covering the files in the categories "Transportation" and "Electrical Engineering." A single, comprehensive search statement was used to determine the approximate numbers of results in the various databases within those categories.

After ranking the files by the number of potential results, databases in which to perform the search were selected. Among the files searched were Transportation Research Information Services (TRIS), the National Technical Information Service (NTIS), Energy Science and Technology to cover government-funded research and collections of information, and Motor Industry Research Association (MIRA) to cover the global automotive industry. Other databases representing the secondary literature in areas such as electrical engineering, communications and information technologies, and related fields were also considered appropriate. This included the following:

- TEME-Technology and Management
- Ei Compendex®
- Civil Engineering Abstracts
- SciSearch® Cited Ref Sci
- ANTE: Abstracts in New Technology and Engineering
- CMP Computer Full Text
- Mechanical and Transport Engineer Abstracts

These databases contained pertinent information for extracting new technologies. The findings consisted of approximately 917 abstracts, approximately one-third of which were of high or medium importance.

In several of the searches, terms such as developments, future, new, novel, state-of-the-art, advances, trends, and emerging were used to identify papers which addressed new and forthcoming technologies. Also, using search terms that included all modes and safety and security, freight, cargo, and shipment as key words increased the relevance of the abstracts obtained.

2.3.2 Patent Searches

There were 188 patents granted since 2004 that were identified through the search as being possibly relevant. In these results, the abstract of a technology associated with a patent was generally brief and not particularly informative. Consequently, the patent descriptions did not significantly benefit the intent, or add to the process, of the literature review.

2.3.3 Interviews

A total of 34 interviews were conducted involving 49 interviewees from 24 organizations that included personnel representing regulators, security agencies, national laboratories, research consulting organizations, academics, carriers and their associations, manufacturers, shippers, technology providers, and emergency responders/incident managers. Interviewees included representatives of all Hazmat transportation modes, and within any one mode there typically was a variety of perspectives on emerging technologies for Hazmat transportation safety and security. The majority of the interviews were conducted by telephone, and overall the interviewees were helpful in providing names and contact information for other qualified candidates.

The interviews served to validate the lists of functional requirements that were concurrently developed by the team as part of the research approach. The interviews also sought to understand interviewees' perspectives on the technologies available to fill perceived gaps and obstacles to wider deployment of technologies for Hazmat safety and security. Interviewers had a standard format with which to guide the discussions, but the best use of the interviewees' time often turned out to be letting them expound on areas in which they held strong beliefs or opinions.

Appendix B contains the template used for initial research interviews, and Appendix C presents a synopsis of the interview results.

2.3.4 Subject Matter Expert (SME) Research

The team had a designated lead for each of the five transportation modes (i.e., highway, rail, marine, air, and pipeline).

These modal leads were also SMEs who identified developing technologies from a variety of sources. (NOTE: while this research has much in common with the Section 2.3.1 Literature Review, the distinction is that the Literature Review was carried out by library experts using designated terms to search selected databases chosen for their transportation-oriented compilations; SME research was based more on finding or recognizing information relevant to the objectives, whether transportation-related or not.) Among the SME Research resources were a number of online Internet sources, including periodic newsletters going back to January 1, 2007. One of these is the TRB's E-Newsletter published weekly (*23*) and accessible through the TRB website's publications drop-down (*24*). Another valuable source that often had links to articles on emerging technologies was the Transportation Communications Newsletter (*25*), published each workday. Other newsletters included the *ITS International* monthly E-newsletter (26), the "ERTICO" – ITS Europe eNewsletter (*27*), the Institute for Electrical and Electronic Engineering (IEEE) Intelligent Transportation Systems Society Newsletter (*28*), and periodic newsletters from the Department of Homeland Security (DHS) Lessons Learned Information Sharing (LLIS) site (*29*).

The magazines *Thinking Highways* and *ITS International* were reviewed for relevant content. One interesting find as a research tool was the website for the Transport Research Knowledge Centre (TRKC), a project of the European Commission's Directorate General for Energy and Transport. This organization has as its primary aim to disseminate and promote the results of transport research, stimulating knowledge transfer within the European Research Area (ERA) (*30*).

The Massachusetts Institute of Technology (MIT) *Technology Review* publishes an annual list of "10 Most Promising Emerging Technologies" (*31*), generally released in November. Two of the research team's most promising technology selections appear in these lists, one from the 2009 and one from the 2008 issue. The Association of American Railroads (AAR) Transportation Technology Center, Inc. (TTCI) (*32*) is a source of much valuable and interesting information on rail technologies and ongoing research. The National Transportation Safety Board (NTSB) maintains a "Most Wanted Technologies" website (*33*), including links to specific technologies for different modes.

SME research was conducted at conferences such as the 2008 and 2009 TRB Annual Meetings of the Hazmat Committee and individual Hazmat presentation sessions and at the 2008 Ohio Hazmat Teams Conference. More than 150 SME research items were part of the research resources, many of which were online articles.

One source useful to the preliminary understanding of security technologies was the November/December 2007 issue of *Thinking Highways,* which featured an article entitled, "Preventive Measures, ITS Role in the War on Terrorism" (*34*). Table 2-1 lists the variety of Intelligent Transportation Systems (ITS) sensor or field device technologies from that article and their utility in Pre-Terrorist and Post-Terrorist Attack. This information represents detection and response capabilities for a certain type of Hazmat security concern.

The April 2005 FMCSA *Hazardous Materials Serious Crash Analysis: Phase 2 Final Report* (*35*) was a useful preliminary reference for Hazmat safety information. A researcher involved in this analysis summarized the causes of spills for Hazmat motor vehicles shown in Table 2-2 (NOTE: this research did not involve other modes such as trains and barges). The first two columns (causes and data) are from the report. The third column (potential technologies) was developed for the team's consideration based on SME experience. Some of these technologies listed are already being developed and were valid candidates for the research in HMCRP Project 04.

2.3.5 Screened Research List

Initial research findings consisted of 917 literature review abstracts, 188 patent abstracts, 34 interviews, and considerable SME research. These findings were subsequently screened for those of greatest apparent significance to the objectives of the project. This screening resulted in a list of 174 technology entries, which included some redundancy. Each entry included information on the following:

- Type of source
- Technology in terms of both a need and a solution
- Transportation mode(s) with which it is associated (highway, rail, maritime, air, and pipeline)
- Technology category (personnel, conveyance, cargo, back office, public sector, and infrastructure, with subcategories in the last three)
- Safety and security role
- Functional requirements

The screened research list became the basis for carrying forward a manageable number of technologies into the selection process of Task 2.

2.4 Details of Task 2: Develop Criteria for Selection of Most Promising Technologies

Given the very large numbers of technologies that could potentially be considered, the team recognized that a structured, logical, analytic, traceable approach was needed. This approach would be used to seek, identify, collect information on, prioritize, and down-select candidate technologies to arrive at the final list of most promising emerging technologies. The following information provides details on the research approach that was followed.

Table 2-1. ITS technologies applicable to pre- and post-terrorist attack.

ITS Sensor or Other Field Device	Pre-Terrorist Attack	Post-Terrorist Attack
Closed-Circuit Television (CCTV) Surveillance	▪ Suspicious Activity	▪ Damage Assessment, Evacuation Route Surveillance, Assistance in Attack Area, Security Surveillance, Post-Attack Assistance in Identifying Terrorist
Hazmat	▪ Vehicle Transporting Hazmat Detection/Location/Reporting	▪ Possible Identification of Attack Agent Used
Video Identification System (VIDS)	▪ Suspicious Vehicle Activity ▪ Detection/Location/Reporting	▪ Evacuation Route Surveillance ▪ Congestion Statistics/Evacuation Progress Reporting
Vehicle Detection Sensors (Radar, Microwave, Infra-red, Acoustic, etc.)	▪ Detection of Unauthorized Vehicle Entry	▪ Supports in Determining Evacuation Route Congestion and Speed (Evacuation Progress)
Road Weather Information System (RWIS)	▪ Initial Conditions	▪ Weather Conditions Impacting Weapons of Mass Destruction (WMD) Plume Propagation Prediction
Video License Plate Readers	▪ Detection/Identification/Location Report of Vehicle of Interest by Homeland Security	▪ Post Attack/Assistance in Identifying Terrorist Vehicle and Identity
Dynamic Message Sign	▪ Seek Citizen Assistance in Locating a Suspicious Vehicle Identified by DHS	▪ Evacuation Messaging to Citizens on Corridors
Reversible Lane Signs	▪ No Assistance	▪ Allocation of Lanes to Evacuation; Closing Vehicle Access to Areas
Electronic Pathfinder Signs	▪ Special Routing for Special Events in Support of Enhanced Surveillance	▪ Dynamic Establishment of Appropriate Evacuation Routes Based on Attack Locations and Pluming
Traffic Signal Controllers	▪ No Assistance	▪ Central Control of Evacuation Route Signalization
Commercial Vehicle Electronic Tag	▪ Possible Support in Apprehending Illegal Transport of Hazmat	▪ Identification of Vehicles Authorized to Support Evacuation
Public Works and Police Vehicles	▪ Possible Manual Sighting of Suspicious Activity and Reporting to DHS	▪ Tracking and Digital Management of Vehicles Associated with Post-Attack Response and Emergency Evacuation
Police Vehicle Cameras	▪ Automatic License Plate Read/Check Resulting in Possible Detection/Reporting of a Vehicle of Interest to DHS	▪ Local/Video Supporting Evacuation ▪ Attack Site Security Management and Coordination
Security Sensors around Critical Infrastructure	▪ Possible Early Detection of Suspicious Activity around Critical Infrastructure	▪ Post-Attack Securing of Critical Infrastructure

Source: Preventive Measures, ITS Role in the War on Terrorism, *Thinking Highways*, November/December 2007, with permission of the author.

2.4.1 Overview of Technology Selection Process

After basic data on emerging technologies were gathered and compiled, the team used a systematic analysis approach to down-select the short list of most promising emerging technologies from the universe of technology candidates. The following six steps illustrated in Figure 2-1 describe the approach used to select the most promising technologies (i.e., those that have been identified to receive more detailed examination in the succeeding phases of the HMCRP Project 04). Each step in this process is described in the following subsections. A more detailed and thorough explanation of the technology selection process for each mode is described in Appendix D.

Section 2.3.4 mentioned that the team had a designated lead for each of the five transportation modes who served as a SME for the technologies involved with that mode. These modal SMEs worked in conjunction with the principal investigator (PI) who also conducted SME research, some of which was on technologies outside of those generally associated with transportation. In addition, the PI identified technologies that were cross-cutting (from a modal standpoint) and intended these selections to be possible tie-breakers, not technologies to over-ride the choices of the modal leads. The modal SMEs' and PI's findings were given an internal peer review.

The steps shown in Figure 2-1 end with selection of the most promising emerging technologies. After the preliminary list of most promising emerging technologies was generated, several external peer reviewers were asked to evaluate the findings and comment on whether they found the research to be valid and its conclusions supported. The peer review results appear in Appendix E.

2.4.2 Define the Functional Requirements, Technical Capability, and Market Adoptability for Each Mode

2.4.2.1 Functional Requirements

The project's research methodology was based on performing a modal functional requirements evaluation, resulting in a gap rating and aimed at deriving criteria by which the list of

Table 2-2. Major causes of truck crashes with Hazmat spills and potential technologies.

"Causes" of Hazmat Spills	Data	Potential Technologies
Rollovers	Only about 22% of serious crashes but 88% result in spills.	▪ Simulator to train drivers in negotiating curves properly ▪ Electronic braking system to apply differential braking when negotiating a curve ▪ Computer system to record driver speed and steering wheel movements ▪ Technology to warn driver when cargo center of gravity is shifting ▪ System to wake driver when he/she is about to doze
Impaired drivers	Impaired drivers have a considerably higher spill to crash rate than unimpaired drivers—30% compared with 15%. Drivers under the influence of alcohol had about a 50% rate.	▪ System to wake driver when he/she is about to doze. Could include light-emitting diode (LED) with blue light or alarm system triggered by a nodding head ▪ Ignition lock system that screens drivers for alcohol ▪ National driver database that provides driver data for such conditions as sleep apnea which may affect driver performance if untreated ▪ Enhanced GPS technology to monitor driver location and ensure he/she does not exceed hours of service
Young and inexperienced drivers have a higher crash rate	Spills occur in 20% of all serious crashes, but for drivers with 3 years of experience or less the rate is 30%. Young drivers, 18 to 24, had the highest percentage of their crashes, 32%, result in spills. For drivers 45 to 54, 15% of the crashes resulted in spills.	▪ Use a technology to monitor driving patterns such as speed turn angles, braking. Develop training using simulators to correct problems before a crash results ▪ Use tracking technology and instrument sensors to more closely monitor young and inexperienced drivers ▪ Use training vehicles equipped with warning technology to alert a new driver to reckless or unsafe actions
Two lane and non-divided highways are less safe than divided highways	On divided highways, there are 15 spills per 100 crashes but on un-divided highways there are 20 spills per 100 crashes.	▪ Use sensor technologies such as sonar and video to identify vehicles close to the truck ▪ Use technology to transmit speed limit changes (such as on a curb) into the cab and announce changes in LED display or by voice command ▪ Use sonar or radar to identify vehicles during poor visibility conditions such as those associated with smoke and fog ▪ Use sensors to transmit ice/temperature on bridges and overpasses into the cab and notify announce in LED display or by voice command ▪ Use ITS technology to warn drivers on un-divided highways of problems ahead

Source: Columns 1 and 2 adapted from FMCSA Hazardous Materials Serious Crash Analysis: Phase 2 Final Report, April 2005.

most promising emerging technologies could be selected. A set of eight generic functional requirements was defined along with three others that apply to certain modes. The functional requirements are described in the following subsections, and the detailed functional requirements and attributes that the team tailored to each mode are provided in Appendix D.

The following definitions were generated primarily to provide guidance, clarity, and consistency for the functional requirements evaluation. The definitions helped document the approach followed by the team.

Whenever dangerous Hazmat cargo is transported from one point to another (e.g., origin to destination), a number of requirements would ideally be satisfied for the Hazmat to be safely and securely transported. These requirements apply regardless of whether the cargo is in constant movement or stops while enroute. As defined, these requirements are *functional* in nature even though in name they may appear to be tied to regulatory compliance.

Each transportation mode under consideration (i.e., highway, rail, marine, air, and pipeline) was defined as having a

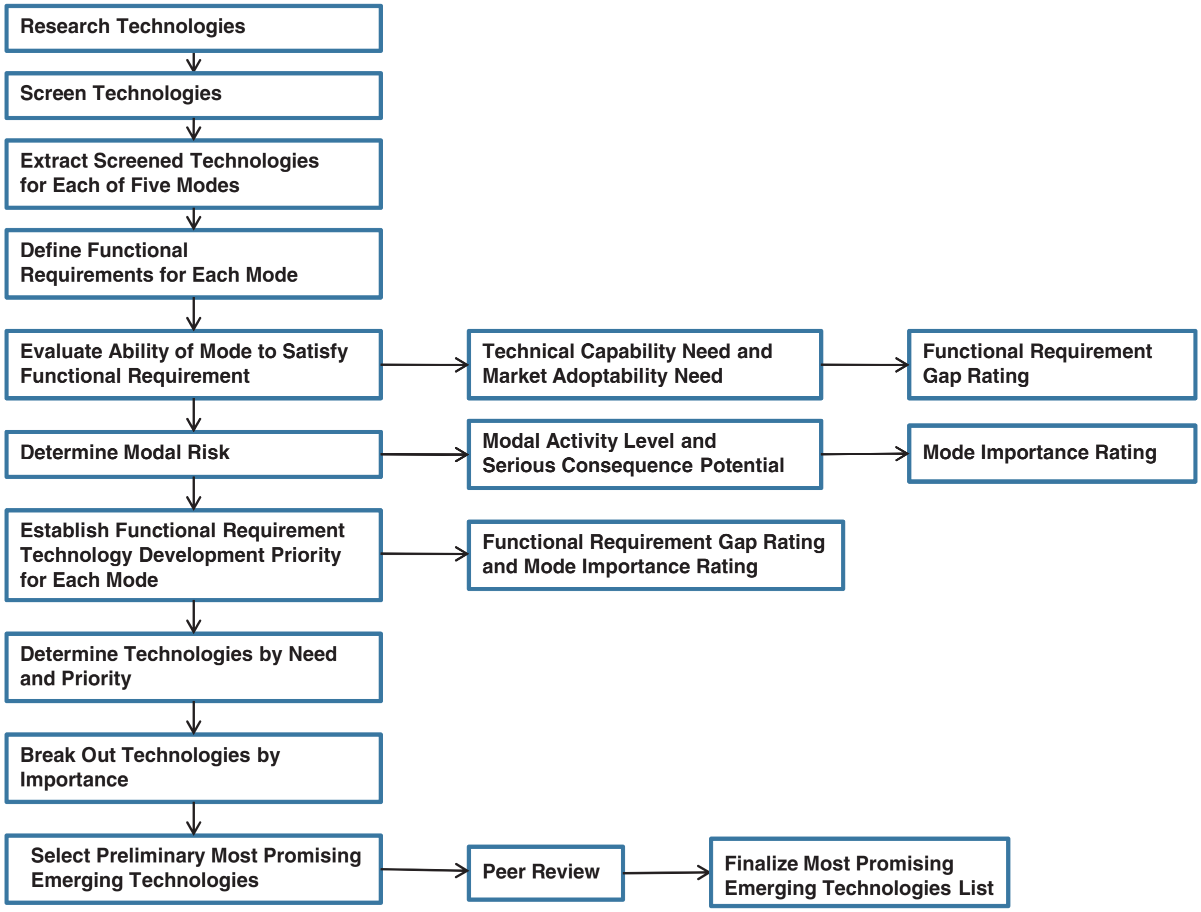


Figure 2-1. Process for selecting most promising technologies.

complement of functional requirements associated with that mode. Intermodal aspects were considered within the context of each transportation mode involved. Public sector aspects such as emergency/incident response and regulatory compliance were also considered within the context of each transportation mode.

Pipeline is clearly different with regard to the terms "vehicle, cargo, and operator," but for consistency those terms are retained. The functional requirements that apply to all modes (with one pipeline-related exception noted) were defined as follows:

A. **Package Integrity**—Package is robust such that material contents are not breached during normal transport operations and typical accident conditions. Capability exists to detect pressure build-up and material release.
B. **Equipment Reliability**—Vehicle and cargo equipment are structurally sound and properly maintained. Capability exists to detect problems such as engine failure or loss of steering. Vehicle is able to protect its crew from serious injury under most accident circumstances.
C. **Operator Performance**—Operator is able to successfully maneuver vehicle under normal and off-normal conditions. Capability also exists to sense operator performance degradation due to fatigue, acute health problem, substance abuse, etc., and alert the operator and back office to this situation.
D. **Hazmat Commodity Identification**—Ability to identify the cargo being shipped either in person or via remote access.
E. **Communication**—Vehicle operator and back office have two-way communication capability at all times.
F. **Tracking**—Vehicle and cargo location are known at all times. (NOTE: this functional requirement does not apply to pipeline mode.)
G. **Security**—Vehicle, cargo, and operator are resistant to theft, diversion, sabotage, and other intentional acts.
H. **Emergency Response**—Qualified emergency response is delivered to any incident site in a timely manner.

In addition to these eight generic functional requirements, there are two functional requirements that apply only to the highway and rail modes:

I. **Vehicle Identification**—Vehicles can be quickly identified by first responders as well as back office personnel.

J. **Hazmat Route Restrictions**—Hazmat shipments of certain types are prohibited from using some roadways, bridges, and tunnels. Additionally, motor carriers and railroads may have further route restrictions on trucks and trains hauling Hazmat shipments through High-Threat Urban Areas (HTUAs).

One functional requirement applies only to the highway mode:

K. **Driver ID Known**—The present system used for identifying drivers is the Commercial Drivers License (CDL). Operators of vehicles hauling hazardous materials are required to possess both a valid CDL and a Hazmat Endorsement. Capability exists to quickly verify that a driver is credentialed to operate a commercial motor vehicle and certified to haul Hazmat.

2.4.2.2 Technical Capability

Typically, more than one technology may be available to provide the capability for meeting each of these functional requirements, although there is often a dominant technology among them. "Technology" is not used in the narrowest sense. That is because receiving an alert that a Hazmat tank truck is outside a geofenced boundary or that a chemical leak has been detected on a rail tank car, for example, may involve GPS and communications technology working in conjunction with back office software.

Technical Capability Rating and Rationale. In order to arrive at a technical capability rating for a functional requirement, a determination was made that took into account all of the perceived individual technology scores for that functional requirement. ("Technical Capability" as used in this sense is not tied to the standardized Technology Readiness Level, or TRL construct.) Thus, each functional requirement received a composite rating from 1 (lowest) to 9 (highest) that represents a subjective determination of the degree to which the technologies associated with it collectively support the complete realization of that functional requirement for a transportation mode. Ratings of 1–3 are low, ratings of 4–6 are medium, and ratings of 7–9 are high. The capability is provided by existing products.

Emerging Technologies That Address Capability Gap. Any technical capability rating of less than 9 by definition reveals a need to some degree: a technology gap that is desirable to close with emerging technologies or, in some cases, current technologies that have not been previously applied to this functional requirement. At this point in the process, there is no determination of the *importance* of the gap. These technologies are developmental efforts, not current products.

2.4.2.3 Market Adoptability

Even if a technology is represented by one or more products that have demonstrated sufficient technical capability, there may be reasons why the technology has not been well-adopted in the market. This may be due to a higher price than the market is willing to bear, an institutional issue such as privacy or liability concerns, technical issues, or unfamiliarity of the transportation community with the possibilities of a technology that has been used successfully for another industry.

One such example is GPS locating system communication technology that allows a GPS device to attempt to communicate by lower-cost terrestrial means, but if several tries are unsuccessful (for example, due to cellular fade zones) the device will switch to satellite communication. This increases reliability but results in extra cost, which is perhaps why the technology is not yet in widespread use.

Market Adoptability Rating and Rationale. Each of the technologies that support the technical capability associated with a functional requirement was also rated for market adoptability. This subjective adoptability rating was made independent of the technology's technical capability. Similar to the technical capability rating, a composite market adoptability rating on a 1–9 scale was derived for the functional requirement. Ratings of 1–3 are low, ratings of 4–6 are medium, and ratings of 7–9 are high. This is the market adoptability of technologies that are current products.

Challenges/Obstacles to Closing Market Adoptability Gap. Any technology's market adoptability rating of less than 9 indicated there is at least one challenge or obstacle to greater market acceptance.

[NOTE: Because a gap in technical capability or market adoptability indicated a *need* (i.e., the status quo is not fully satisfying the requirement), there is an inverse relationship between a technical capability or market adoptability rating and its corresponding need. Said another way, if a certain technology is very capable for its functional requirement, the need for equal or more capable technology is low. Similarly, if at least one capable technology has been well-adopted by the marketplace, the need for others to be adopted is low. This is an important distinction to grasp to understand the remaining steps in the research approach and the graphics that support the concept.]

2.4.3 Evaluate the Ability of Each Mode to Satisfy Each of Its Functional Requirements

The purpose of this step was to generate a functional requirement gap rating. This was established using a qualitative rating scale of high, medium, and low, based on the following criteria: (1) technical capability need (extent to which the capability falls short in meeting the functional requirement) and (2) market

Table 2-3. Functional requirement gap rating—highway.

Market Adoptability Need Rating	Technical Capability Need Rating: Low	Medium	High
High	**Medium** H. Emergency Response K. Driver ID Known	**High** G. Security	**High**
Medium	**Low** A. Package Integrity C. Operator Performance D. HM Commodity ID E. Communication J. HM Route Restrictions	**Medium** F. Tracking	**High**
Low	**Low** B. Equipment Reliability I. Vehicle ID	**Low**	**Medium**

adoptability need (extent to which the market falls short in adopting the capability, if it exists, into operational practice). If the rating of either the technical capability or market adoptability is high, their need for improvement is correspondingly low. The functional requirements gap ratings are presented for the transport modes of highway, rail, marine, air, and pipeline, respectively, in Tables 2-3 through 2-7.

(NOTE: Consider that functional requirement "F. Tracking" does not apply to pipeline mode; functional requirements "I. Vehicle Identification" and "J. Hazmat Route Restrictions" apply only to highway and rail modes; and functional requirement "K. Driver ID Known" applies only to the highway mode.)

2.4.4 Evaluate the Significance of Each Mode with Respect to Hazmat Transport Safety and Security

This step was accomplished by establishing a mode importance rating (high, medium, or low). The rating was based on the following criteria: (1) exposure, as measured by a mode's annual activity level, and (2) consequence severity—the potential for a serious consequence arising out of an incident involving a Hazmat shipment on that mode as measured by the cargo capacity of a Hazmat shipment on that mode. Although Hazmat shipment sizes on the air mode are quite small, because an incident would threaten the lives and health of all people aboard the aircraft and perhaps others on the ground, it was assigned a high consequence severity rating.

The selected measure for estimating a mode's annual activity level is ton-miles. The information in Figure 2-2 illustrates Hazmat shipment ton-miles per four modes of transportation (*36*):

As shown, truck is the dominant mode from a ton-miles perspective, followed by rail and water (marine) at a significant but lower level of activity, with air lagging far behind. Note that valid pipeline data were not available through this source; for pipeline shipments, ton-miles are not shown in the tables. For most of these shipments, respondents to the CFS reported the shipment destination as a pipeline facility on the main pipeline network. Therefore, according to the CFS, for the majority

Table 2-4. Functional requirement gap rating—rail.

Market Adoptability Need Rating	Technical Capability Need Rating: Low	Medium	High
High	**Medium**	**High** F. Tracking	**High**
Medium	**Low** C. Operator Performance	**Medium** A. Package Integrity B. Equipment Reliability	**High** G. Security
Low	**Low** D. HM Commodity ID I. Vehicle ID J. HM Route Restrictions	**Low** E. Communication H. Emergency Response	**Medium**

Table 2-5. Functional requirement gap rating—marine.

Market Adoptability Need Rating	High	**Medium**	**High**	**High**
	Medium	**Low** C. Operator Performance	**Medium** F. Tracking G. Security	**High**
	Low	**Low** A. Package Integrity B. Equipment Reliability D. HM Commodity ID E. Communication	**Low** H. Emergency Response	**Medium**
		Low	Medium	High

Technical Capability Need Rating

Table 2-6. Functional requirement gap rating—air.

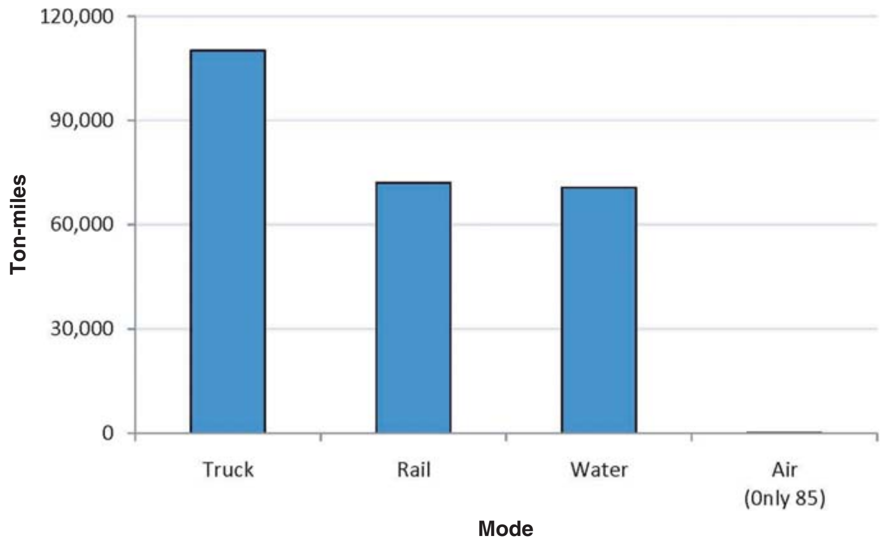
Market Adoptability Need Rating	High	**Medium**	**High**	**High**
	Medium	**Low** A. Package Integrity B. Equipment Reliability D. HM Commodity ID H. Emergency Response	**Medium**	**High**
	Low	**Low** C. Operator Performance E. Communication F. Tracking G. Security	**Low**	**Medium**
		Low	Medium	High

Technical Capability Need Rating

Table 2-7. Functional requirement gap rating—pipeline.

Market Adoptability Need Rating	High	**Medium** C. Operator Performance	**High** B. Equipment Reliability	**High**
	Medium	**Low** D. HM Commodity ID H. Emergency Response	**Medium**	**High** G. Security
	Low	**Low** A. Package Integrity	**Low** E. Communication	**Medium**
		Low	Medium	High

Technical Capability Need Rating



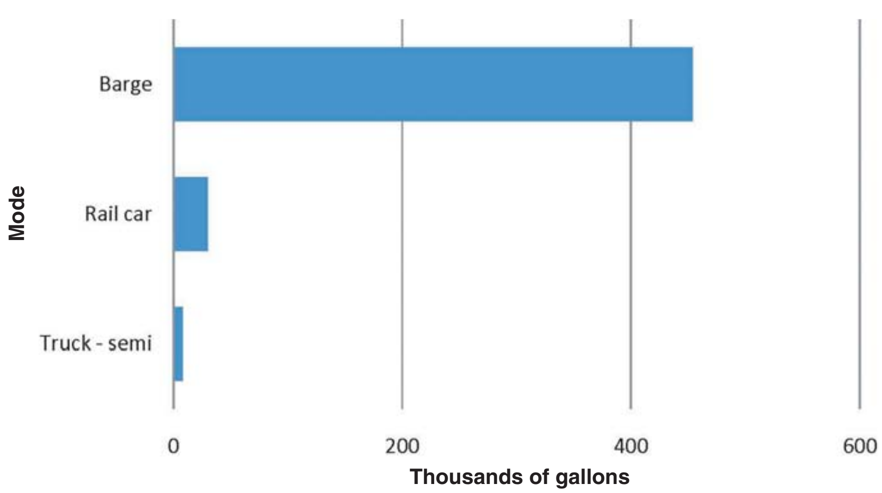
Source: 2002 Commodity Flow Survey (CFS), Table 1a, Hazardous Material Shipment Characteristics by Mode of Transportation for the United States: 2002.

Figure 2-2. Modal activity levels.

of these shipments, the resulting mileage represented only the access distance through feeder pipelines to the main pipeline network, and not the actual distance through the main pipeline network. However, per the CFS, the number of tons shipped by pipeline is more than six times the tonnage shipped by rail and nearly half that shipped by truck. Based on this information, annual modal activity is rated as high for truck and pipeline, medium for rail and water (marine), and low for air.

The selected measure for a mode's serious consequence potential was the cargo capacity of a single unit of shipment (i.e., truck trailer, rail tank car, barge, etc.). The information in Figure 2-3 was used to delineate shipment size for three of the principal freight modes (using a unit of thousands of gallons of capacity) (*37*). To give perspective, in general, one barge = 46 rail tank cars = 144 truck tank cars (*38*).

In this instance, barge is the dominant mode at approximately 454,000 gallons per shipment, so marine shipments are assigned a high serious consequence rating. (NOTE: barge is shown in Figure 2-3 as the marine conveyance in the CFS information, but the team considered the high serious consequence potential to apply to "blue water," or open ocean vessel shipments as well as "brown water," or inland waterway shipments.)



Source: U.S. Department of Transportation Maritime Administration, Inland Rivers, Ports & Terminals, Inc., website.

Figure 2-3. Cargo capacity by mode (thousands of gallons).

Table 2-8. Mode importance rating.

Serious Consequence Potential (Volume Per Shipment) \ Modal Activity Level (Ton-Miles)	Low	Medium	High
High	**Medium** Air	**High** Rail Barge	**High**
Medium	**Low**	**Medium**	**High** Truck Pipeline
Low	**Low**	**Low**	**Medium**

At 30,000 gallons per railcar, rail shipments were also assigned a high rating. At 7,600 gallons, Truck, being significant but at smaller shipment volumes, was assigned a medium consequence rating. Although Hazmat shipments on the air mode are quite small in terms of weight or volume, because an incident would threaten the health of all people aboard the aircraft and perhaps others on the ground, it was also assigned a high consequence rating. Pipeline shipment statistics are not expressed in a way that allows for convenient comparisons to other modes; however, the team evaluated the pipeline serious consequence rating as medium.

Combining the measures of modal activity level and potential per shipment consequence allows for the following mode importance ratings listed in Table 2-8. This table contains the importance ratings for all modes and thus is used in combination with other tables in the Modal Screening Process (see Appendix D).

2.4.5 Determine a Technology Development Priority Rating

This step determined a rating of high, medium, or low for technology development priority based on the functional requirement gap rating and the mode importance rating. Those functional requirements that receive a high technology development priority rating were then considered prime candidates for technology development consideration. The functional requirement technology development priority ratings are presented for the transport modes of highway, rail, marine, air, and pipeline, respectively, in Tables 2-9 through 2-13.

2.4.6 Conduct Modal and Capabilities Gap Analysis Review

Once the detailed functional requirements had been derived for each of the modes, a lengthy modal screening process

Table 2-9. Functional requirement technology development priority—highway.

Mode Importance Rating \ Functional Requirement Gap Rating	Low	Medium	High
High	**Medium** A. Package Integrity B. Equipment Reliability C. Operator Performance D. HM Commodity ID E. Communication I. Vehicle ID J. HM Route Restrictions	**High** F. Tracking H. Emergency Response K. Driver ID Known	**High** G. Security
Medium	**Low**	**Medium**	**High**
Low	**Low**	**Low**	**Medium**

Table 2-10. Functional requirement technology development priority—rail.

Mode Importance Rating	Functional Requirement Gap Rating: Low	Functional Requirement Gap Rating: Medium	Functional Requirement Gap Rating: High
High	**Medium** C. Operator Performance D. HM Commodity ID E. Communication H. Emergency Response I. Vehicle ID J. HM Route Restrictions	**High** A. Package Integrity B. Equipment Reliability	**High** F. Tracking G. Security
Medium	**Low**	**Medium**	**High**
Low	**Low**	**Low**	**Medium**

Table 2-11. Functional requirement technology development priority—marine.

Mode Importance Rating	Functional Requirement Gap Rating: Low	Functional Requirement Gap Rating: Medium	Functional Requirement Gap Rating: High
High	**Medium** A. Package Integrity B. Equipment Reliability C. Operator Performance D. HM Commodity ID E. Communication H. Emergency Response	**High** F. Tracking G. Security	**High**
Medium	**Low**	**Medium**	**High**
Low	**Low**	**Low**	**Medium**

Table 2-12. Functional requirement technology development priority—air.

Mode Importance Rating	Functional Requirement Gap Rating: Low	Functional Requirement Gap Rating: Medium	Functional Requirement Gap Rating: High
High	**Medium**	**High**	**High**
Medium	**Low** A. Package Integrity B. Equipment Reliability C. Operator Performance D. HM Commodity ID E. Communication F. Tracking G. Security H. Emergency Response	**Medium**	**High**
Low	**Low**	**Low**	**Medium**

Table 2-13. Functional requirement technology development priority—pipeline.

Mode Importance Rating / Functional Requirement Gap Rating	Low	Medium	High
High	**Medium** A. Package Integrity D. HM Commodity ID E. Communication H. Emergency Response	**High** C. Operator Performance	**High** B. Equipment Reliability G. Security
Medium	**Low**	**Medium**	**High**
Low	**Low**	**Low**	**Medium**

began, as documented in Appendix D. To summarize, for each of the functional requirements, its specific definition was stated for that mode. The technical capability rating, a number from 1–9, was assigned for each functional requirement. The rationale for technical capability rating and a listing of emerging technologies that address the capability gap were provided, each with a discussion. Similarly, the market adoptability rating, itself a number from 1–9, was assigned for each functional requirement. The rationale for market adoptability rating and a listing of challenges/obstacles to market adoption were provided, each with a discussion.

With the technical capability rating and market adoptability rating available, a series of graphs were used with low, medium, high metrics. A rating of 1–3 was defined as low, 4–6 was medium, and 7–9 was high. Each of the graphs had 9 cells (3 x 3), and each of the cells was designated as low, medium, or high. The functional requirement gap rating (low, medium, or high) was established for each functional requirement of each mode by graphing the technical capability rating against the market adoptability rating. Graphing serious consequence potential against modal activity level produced the mode importance rating (low, medium, or high), which was the same for each functional requirement within that mode.

Graphing the functional requirement importance rating against the functional requirement gap rating produced the functional requirement technology development priority for that mode. The next step was to extract the technologies from the screened research list that applied to a given mode. In extracting the screened technologies, modal leads were not asked to purposely seek any representative balance between technologies whose development horizon is initially perceived to be near term (less than 5 years) and far term (from 5–15 years) or to establish any other type of balance, such as between detection and protection technologies. Each modal lead applied the methodology independently, enabling the research team to have a good indication of what technology needs were deemed most compelling. This prepared the team to eventually select those technologies that were considered most promising and worthy of more in-depth investigation. This process appears to have nonetheless resulted in a reasonable balance between the near-term and far-term technologies eventually selected.

The research approach was based on (1) the concept of the functional requirement and its technical capability and market adoptability and (2) a gap analysis. This approach gave emphasis to technologies that were not part of a regulatory response or an ongoing government or industry technology development and specific implementation effort. Thus, while a development priority may currently be great, if there is a funded program to develop and implement technology for it, its need may not be considered as great as in the absence of such a program.

In using the extracted screened technologies list for each mode in Appendix D, if any of the technologies extracted was deemed by the research team's modal lead to be one that addressed a high functional requirement technology development priority for that mode, it was designated as having special significance in the selection methodology.

It was during this stage that the research team briefed the HMCRP Project 04 panel on the research approach. At that point, *functional requirements* with associated *technical capability* and *market adoptability* assessments and extracted screened technologies had been drafted as packages for the rail, marine, highway, and air modes; the package for the pipeline mode was still in progress. The briefing concentrated on the research approach and how it was designed to produce the selection of most promising technologies, which would be taken forward to analysis of the technologies' perceived paths to the marketplace.

2.4.7 Determine Technology Need Areas

The next step in the research approach was to define groupings of like technologies for the purpose of structure and perspective. Twelve such groupings were identified, referred to as *technology need areas.* These twelve areas were initially numbered in the following order:

1. Cargo Content Identification
2. Cargo and Infrastructure Condition Sensors
3. Operator Condition Monitoring Systems
4. Overcoming Communication Gaps
5. Innovative Power Sources for Vehicle Components
6. Vehicle and Cargo Integrity
7. Advanced Cargo Locks and Seals
8. Screening and Inspection
9. Vehicle Location Status
10. Alert and Incident Notification Systems
11. On-Scene Response Capability
12. Operator Access Control.

Next, in the "technology by area and redundancy" spreadsheet (not herein due to size), technology need areas that apply to technologies extracted by modal leads from the screened research list were displayed for each mode. The technology need areas were numbered as in the preceding list. To the right in the same row, the technology or technologies associated with that technology need area for that mode were populated, under columns titled "description" and "potential solution." If the technology was associated with a high priority functional requirement need, it retained the designation of that from the mode's extracted screened technologies. If it was associated with a medium or low priority functional requirement need, it did not have that designation.

A column titled "technology need redundancy" listed other places where that same technology need area appeared on the spreadsheet, by mode and row number. There also appeared 16 technology entries under "principal investigator's choice of modal cross-cutting technologies." These were based on SME research findings that the PI considered to be candidate promising technologies that had applicability to multiple modes. Five of these were added subsequent to the screened research list, and three of those were deemed as high priority needs. Finally, technologies were segmented and coded for ease of recognition.

2.4.8 Prioritize Need Areas

Table 2-14 shows the technology need areas and their importance ranking as determined by the number of high priority functional requirement gaps in those need areas by mode. The results brought forward from the "technology by area and redundancy" spreadsheet were associated with each technology need area. Along a row, identified by a technology need area, are intersections with columns representing the technology screening results by mode and by the cross-

Table 2-14. Technology need areas ranked by order of importance.

Technology Need Area Ranking	Marine	Rail	Highway	Air	Pipeline	Cross-Cutting	Total High Priority	Total Medium-Low Priority
1. Cargo and Infrastructure Condition Sensors	✓	✓✓	✓✓		xxxxx	xx	5	7
2. Vehicle and Cargo Integrity	x	✓			xx	✓✓✓ x x	4	5
3. Operator Access Control		✓	✓✓✓	xx		x	4	3
4. Vehicle Location Status	✓	✓	✓✓				4	
5. Alert and Incident Notification Systems	✓	✓ x	✓	x	x	xxx	3	6
6. Innovative Power Sources for Vehicle Components	✓	✓	✓			xx	3	2
7. Overcoming Communication Gaps	✓ x	✓✓		x			3	2
8. Advanced Cargo Locks and Seals	✓	✓	✓	x			3	1
9. Cargo Content Identification	✓	✓		xxx		x	2	4
10. Screening and Inspection	✓	✓		x			2	1
11. Operator Condition Monitoring Systems	x			xx			0	3
12. On-Scene Response Capability				xx		x	0	3

Key: ✓ = high priority functional requirement need
x = medium to low priority functional requirement need

cutting technology grouping. If a technology was associated with a designated high priority functional requirement need area, it is represented as a "✓" in the cell that marks that intersection of row and column. If it was associated with a medium or low priority need area, it is represented as an "x." The tally of total high priority "✓'s" and total medium-low priority "x's" provided the rationale for how the technology need areas were prioritized in Table 2-14, yielding the technology need area ranking.

2.4.9 Determine Technology Importance by Need and Priority

In the "technologies by need and priority" spreadsheet (not herein due to size), the technology need areas appeared as rows in priority order. In each row was the set of technology needs identified by mode or cross-cutting area and the associated row number in the "technology by area and redundancy" spreadsheet. If the technology needs were high priority functional requirement needs, they retained that designation. The number of total high priority and total medium-low priority "hits" by technology need area was the same number that was on the prioritization of need areas spreadsheet described in Section 2.4.8.

2.4.10 Conduct Technology Breakout and Importance

In the "technology breakout and importance" spreadsheet (not herein due to size), 72 individual technologies were listed across the top. These technologies included some redundancies. In each row, which represented a technology need area, the cell that intersected with each separate technology was assigned either a high priority designation or medium-low priority designation. The information with which to make these assignments came from the "technologies by need and priority" spreadsheet. Some technologies were described in slightly different ways in the screened research list and so it was important to note that and consolidate those marks. A prominent example is the technology area that was listed as biometrics-based identity management, which also included Chemical Facility Anti-Terrorism Standards (CFATS) credentialing and the Transportation Worker Identification Credential (TWIC), improved locking mechanisms with smart card ID credentialing, universal authentication practices using biometrics-based credentialing, and universal ID card. Any technology that received three or more symbols for high priority was designated a preliminary most promising technology selection and was emphasized on the spreadsheet. As expected, the selections generally corresponded to the higher priority technology need areas. This was the final step in designing criteria for selection of the most promising emerging technologies.

2.5 Details of Task 3: Select Most Promising Technologies That Address Important Technology Need Areas

2.5.1 Select the Preliminary Most Promising Emerging Technologies

The database of emerging technologies prepared by the team was reviewed for technologies whose applications are directed at the identified important technology need areas. There were several long spreadsheets referenced in the previous subsections that were used to break out individual technologies and determine how many high priority needs and total needs were associated with each technology. While those spreadsheets are not included herein, all selected technologies were grouped to appear in a single screen view. That is shown as Table 2-15, which illustrates how the technology areas with the highest number of high priority technology needs emerged as the most promising emerging technology selections.

(NOTE: The 12 technology need areas identified in Section 2.4.7 and prioritized in Section 2.4.8 were useful as a framework for breaking out the most promising emerging technologies. The numbers of high priority and medium-low priority markings in the Table 2-14 technology need areas do not match the numbers in the corresponding Table 2-15 technology need areas, and some of the Table 2-15 technology need areas do not have entries. The reason in both cases is that the Table 2-15 information is based on discrete technology areas that were identified from the screening process described in Sections 2.4.1 through 2.4.7. References to the most promising technology areas (or just "technology areas") in the remainder of this report represent a departure from, and should not be confused with, the previous nomenclature of "technology need areas.")

It is important to note that while all of the most promising technology areas identified are generic (i.e., not products), only some are specific single technologies (e.g., plastic thin-film organic solar cells and intelligent video tracking and surveillance system). Others are described in terms of a grouping within which there are several related or integrated technologies perhaps working as a system (e.g., the categories of advanced locks and seals with remote monitoring and networked RFID with GPS/GLS, ubiquitous sensors and cargo monitoring). The container integrity technology category is a collection of technologies that have

Table 2-15. Technology areas with the most high priority needs.

Prioritized Technology Need Area (Below)	Pressure Gauges and Chemical Detection Sensors	Biometrics-Based Identity Management/ Universal Security Credential	Fiber-Optic/Photonic Sensors and Optical Scanners for Cargo and Fixed Point Monitoring of Infrastructure	Wireless Power	Plastic Thin-Film Organic Solar Cells w/ Flexible Polymer Batteries	Nanopiezoelectronics	Improved Locking w/ F/O[1] Seals, RF[2], and Low Power RFID and RMSA[3]	Intelligent Video Tracking and Surveillance System	Networked RFID/GPS Monitoring/Networked Ubiquitous Sensors and Cargo Monitoring	Container Integrity Technologies
1. Cargo and Infrastructure Condition Sensors	✓✓✓ x		✓✓✓							
2. Vehicle and Cargo Integrity										✓✓✓✓
3. Operator Access Control		✓✓✓x x								
4. Vehicle Location Status								✓✓✓	✓✓✓x x	
5. Alert/Incident Notification Systems										
6. Innovative Power Sources for Vehicle Components				✓✓✓x	✓✓✓	✓✓✓x				
7. Overcoming Communication Gaps										
8. Advanced Cargo Locks and Seals							✓✓✓			
9. Cargo Content Identification									✓✓	
10. Screening and Inspection			x							
11. Operator Condition Monitoring Systems										
12. On-Scene Response Capability										

Key: ✓ = high priority functional requirement need **x** = medium to low priority functional requirement need
[1] F/O = fiber-optic
[2] FR = radio frequency
[3] RMSA = remotely monitored sealing array

the same goal of strengthening containers, especially large tanks.

2.5.2 Peer Review

The results of the Preliminary Most Promising Emerging Technologies with supporting spreadsheets were provided to a group of reviewers from industry and government. These reviewers were sought for the benefit of their background, experience, and perspective on the research approach and its findings. (NOTE: There is TRB guidance on the peer review process used to determine whether technical and scientific papers are worthy of publication. It was explained to the peer reviewers that the material they were provided for review represented findings at an earlier phase of the process. This peer review was valuable because of the project's need to select a few technologies from a very large number, and to do so in a logical, reasoned approach.)

The overarching question for which peer review comments were sought was "Is the research valid, and are the conclusions supported?" The peer reviewers were provided with a standardized format to record their thoughts and observations. In that format, there were a number of other questions whose responses were helpful as lessons learned or improved perspective with which to better reach the intended audience for the project's results. In general, peer reviewers believed that the process and the findings were appropriate. Results of the peer review in the format provided appear in Appendix E.

NOTE: The preliminary list of most promising technologies that was briefed to the HMCRP Project 04 panel on March 16, 2009, and that was provided to the peer reviewers included two technology areas that were not retained in the final list. The first was biometrics-based identity management tied to a universal credential for transportation workers. The concept is that there would be a single, universally recognized credential that establishes (a) identity; (b) eligibility to access secure areas; and (c) eligibility to obtain or hold transportation-related licenses, credentials, and other government certifications, required of persons who transport Hazmat by all modes in the United States. The TWIC already had this functionality but is not the only transportation credential required or recognized. That technology area was not pursued because while it was being identified by the project team, the HMCRP released a pre-solicitation notice that identified the concept as prospective HMCRP Project 08.

The second technology area that was not retained was fast power charge and storage. One recognized problem to making tracking, sensing, alerting, and communications systems more widespread is the lack of power. Like several other technologies, this is an enabling technology in that it helps to provide electrical power for devices of other technologies through its capability to more quickly recharge a battery than with current technology, However, it was determined that the technology had passed into products and was not emerging to the extent that other technology selections were.

These removals were not related to the peer review process, but the peer review process resulted in identifying one addition to the list. Based on review comments, the research team recognized that Container Integrity should be included among the most promising technologies due to its importance to the chemical and transportation industries. Container Integrity is an umbrella category representing a variety of different solutions to strengthen materials, for example, to provide better protection against puncture. This is a category represented by a number of different structural improvements such as the following:

- Specialty and treated steels
- Engineered metal structures (e.g., egg crate, honeycomb, lattice block, corrugated)
- Structural foams and adhesives
- Composites and fiber-reinforced plastics
- Insulation and thermal protection
- Armor and self-sealing technologies
- Impact resistant coatings
- Valves and fittings
- Railcar couplers (cushioning)

Container integrity is clearly considered important to the chemical manufacturing and shipping industries. As an example, the Next Generation Rail Tank Car Project is a joint industry-government initiative to improve the safety of pressurized tank cars, also known as jacketed pressure cars. These tank cars have generally consisted of a 500 pounds per square inch (PSI) pressure tank around which is several inches of fiberglass, outside of which is a relatively thin steel shell (the jacket). These have been vulnerable to punctures, and the solution was not to simply make the steel shells thicker (which adds weight and requires more fuel to haul). Rather, the Next Generation Rail Tank Car Project has examined other industries to find alternative design approaches that can provide strength and puncture resistance (*39*). One related technology researched on this project involves a urethane compound developed for the military that is sprayed on the outside of fuel tankers that will be hauled by trucks in combat zones. If a bullet fired at the tank penetrates the outer metal shell, the urethane compound reacts with the fuel in a way that causes it to seal the bullet hole, whereas without the coating the bullet hole would have caused a leak that may have resulted in a conflagration.

2.5.3 Finalization of Most Promising Emerging Technology Selections

The preliminary most promising emerging technologies list that was presented to the HMCRP Project 04 panel on March 16, 2009, was adjusted due to the subsequent realizations and peer review interaction. The final most promising emerging technology area selections that resulted are listed in Tables 2-16 and 2-17.

Table 2-16 captures and characterizes those most promising technology areas recommended for consideration of further exploration in Task 6 of the project. The technology areas are segregated into the following groups:

- Monitoring and Surveillance
- Alternative Power Generation
- Infrastructure

For each entry, Table 2-16 includes a list of modes that could potentially benefit from implementation of the technology area in addressing functional requirement gaps. Each of the most promising technology areas applies to multiple transportation modes. In fact, all technology areas are considered to be able to support all five modes except one (plastic thin-film organic solar cells for the air mode).

Table 2-17 provides a more detailed description of the technology areas with their perceived importance to Hazmat transportation.

2.6 Details of Task 4: Develop Detailed Work Plan for More In-Depth Exploration in Phase 2

The Detailed Work Plan for a more in-depth exploration of the most promising near- and longer-term technologies to be carried out in Phase 2 of the project was drawn up as the Most Promising Emerging Technologies selections were being finalized. This assessment was expected to include at least the following: (1) plans currently in place for development and deployment; (2) additional activities needed to bring the technology to the deployment stage and associated costs; (3) potential interactions with other technologies (both complementary and conflicting); (4) impediments to

Table 2-16. Most promising emerging technology area selections.

Most Promising Emerging Technology Areas	Applicable Transportation Modes
Monitoring and Surveillance Group	
Description: Networked RFID/GPS monitoring/networked ubiquitous sensors and cargo monitoring	Marine, Rail, Highway, Air, Pipeline
Description: Pressure gauges and chemical detection sensors	Marine, Rail, Highway, Air, Pipeline
Description: Fiber-optic/photonic sensors and optical scanners for monitoring of cargo, or for fixed point monitoring of infrastructure health and environment problems	Marine, Rail, Highway, Air, Pipeline
Description: Improved locking w/ fiber-optic seals, radio frequency, low power RFID and remote monitoring of seal array	Marine, Rail, Highway, Air, Pipeline
Description: Intelligent video tracking & surveillance system with capability for automated handoff to sequence of cameras	Marine, Rail, Highway, Air, Pipeline
Alternative Power Generation Group	
Description: Wireless power	Marine, Rail, Highway, Air, Pipeline
Description: Nanopiezoelectronics	Marine, Rail, Highway, Air, Pipeline
Description: Plastic thin-film organic solar cells with flexible polymer batteries that never need to be recharged	Marine, Rail, Highway, Pipeline
Infrastructure Group	
Description: Container integrity	Marine, Rail, Highway, Air, Pipeline

implementation; and (5) opportunities and means of addressing the impediments.

The sources for technology developments were expected to be companies; laboratories, including national laboratories; universities; and other government operations. It was recognized that private technology developers would not be as inclined as government organizations to share information such as funding data or details of a design that is intended to become proprietary. A technology developer with a relatively mature technology that is getting close to being ready for the marketplace may be overly optimistic about the technology's capabilities. The technology developer may lack sufficient test data to provide details on projected operational capability. In general, the farther out the development in time, the more uncertainties and lack of information would be expected to be encountered.

When making initial contact with organizations identified as having a role in development of the most promising technologies, research team members were expected to follow the script template found in Appendix F. They were also interested in technology implementation best practices that appeared to be prerequisites for deployment success.

It was proposed that team members conduct an online search for the most recent information on the technology. They would seek to identify as many developers of the most promising technologies as possible, including searching website and contact information and bookmarking articles or publications that were in the public domain. Team members would also attempt to establish whether there was a competitive or collaborative approach between or among the developers. In addition, they would try to determine whether the technology developers had the same technical function or market niche in mind and, if there were multiple technology developers, who appeared to be the leader.

Any recent information published by the developers on the technologies and their goals, what plans were in place for developing and deploying the technology, and what the developers' needs and intentions were was also of interest. If the technologies in question were not being developed for transportation applications, team members were prepared to help the developer understand how they might be applied to Hazmat transportation (as in the case of wireless power, plastic thin-film organic solar cells, and nanopiezoelectronics, which are not being developed with primarily a transportation market in mind). Queries would also be made to determine how the technology development was being funded.

As part of this process, it was anticipated that team members would be able to establish the technology readiness level of the subject technology and consider the roadmap necessary for the technology to reach the marketplace, such as field testing and the cost and schedule impacts associated with those additional efforts. One area of interest in interviewing technology developers was to be in a position to identify and assess actual and potential interactions between the selected technologies and other technologies (whether most promising technologies or not) that could be applied to Hazmat transport. The intent was

Table 2-17. Characterization of most promising emerging technology areas.

Technology Description	Concept	Importance to Hazmat Transportation
Monitoring and Surveillance Group		
Networked RFID/GPS/GLS monitoring/ networked ubiquitous sensors and cargo monitoring	This refers to the concept of multiple sensors tied into a central monitoring site where system control functions may also exist. Ubiquitous sensors refers to the concept of a "system of systems," possibly a nationwide sensor network.	If these sensors are deployed on commercial vehicles carrying Hazmat, any alerts or problems with the cargo condition could be detected by fixed sensors at locations such as truck stops, or even by other vehicles. That detection capability could not only enable quicker response to an anomalous condition such as a chemical leak, but could also provide a real-time early-warning system for a wide array of chemical, biological, and nuclear threats across the United States.
Pressure gauges and chemical detection sensors NOTE: this is a category of two related technology needs with functionally similar purposes, within each of which is found emerging technologies.	Improved sensors that can accurately detect pressure changes and chemical releases with very low false alarm rates.	The capability of event-based alerts is limited by sensitivity of sensors as well as their false alarm rates. High false alarm rates are detrimental to the acceptance of any technology being implemented. As the number of Hazmat shipments being tracked continues to increase, the capability of embedded sensors to detect anomalous conditions at lower thresholds and higher reliability is needed so that an alert can be automatically generated. This needed capability also applies to pipelines as well as vehicles.
Fiber-optic/photonic sensors and optical scanners for monitoring of cargo, or for fixed point monitoring of infrastructure health and environment problems	Photonics refers to the generation, emission, transmission, modulation, signal processing, switching, amplification, detection, and sensing of light, that in this case carries information. Fiber-optics is a form of photonics.	The amount of information capable of being transmitted via photonic means is great. Use of fiber-optics to replace copper wire in aircraft for control mechanisms is being considered. Fiber-optics is being used on some warships in their combat systems and for lighting and illumination devices. Photonics has the potential to provide significant performance improvements such as increase in bandwidth, weight savings, and improved compartment integrity. Application of photonics to other types of vehicles, as well as pipelines and other fixed structures such as tunnels and bridges, may help monitor and detect anomalous conditions at reduced cost.
Improved locking with fiber-optic seals, low power RFID, and remote monitoring of seal array	Seals and locks, possibly with advanced encryption and other features that make them very difficult to defeat, that can be remotely monitored for intrusion and system functioning.	The ability to protect sealed Hazmat cargo is improved by defeating sophisticated intrusion attempts and reporting their occurrence.
Intelligent video tracking and surveillance system with capability for automated handoff to a sequence of cameras	Software capable of capturing the image of a specific vehicle and passing this image from one linked camera to another so that its passage is tracked, if the area of interest has sufficient cameras. This technology uses the current generation of cameras.	A Hazmat vehicle carrying especially toxic material could be tracked by a series of video cameras that automatically hand off the truck's image from camera to camera as it passes through a High-Threat Urban Area. Law enforcement could link video cameras around major cities, map video panoramas to publicly available aerial maps, and use software to provide a higher level of "location awareness" for surveillance.

(continued on next page)

Table 2-17. (Continued).

Technology Description	Concept	Importance to Hazmat Transportation
Alternative Power Generation Group		
Wireless power	Wireless energy transfer or wireless power transmission refers to the process that takes place in a system where electrical energy is transmitted from a power source to an electrical load, without interconnecting wires. Wireless transmission is useful in cases where instantaneous or continuous energy transfer is needed but interconnecting wires are inconvenient, hazardous, or impossible.	This is an enabling technology in that it helps to provide electrical power for sensors and other technologies that would be more expensive due to battery maintenance and replacement costs.
Nanopiezoelectronics Nanotechnology refers to technology involving manipulation of objects whose dimensions are approximately 1–100 nanometers. The piezoelectric effect refers to applying a mechanical stress (e.g., deformative) to applicable piezoelectric material (e.g., certain ceramics, quartz, etc.) that causes production of an electrical charge.	The combined term "nanopiezoelectronics" refers to generation of electrical energy (electricity) at the nanometer scale (e.g., to power nano-devices) via mechanical stress to the nanopiezoelectronic device. For example, bending of a zinc oxide nanowire transforms that mechanical energy into electrical energy; a flag with nanowire could generate power while fluttering.	This is an enabling technology in that it helps to provide electrical power for sensors and other technologies that would otherwise be more expensive due to battery maintenance and replacement costs.
Plastic thin-film organic solar cells	These solar cells are not rigid panels and can be molded into a variety of shapes to occupy space that would not be possible for current conventional solar cells. They operate with flexible polymer batteries that never need to be recharged.	This is an enabling technology in that it helps to provide electrical power for sensors and other technologies that would be more expensive due to battery maintenance and replacement costs.
Infrastructure Group		
Container integrity This is a category represented by a number of different structural improvements: ▪ Specialty and treated steels ▪ Engineered metal structures (e.g., egg crate, honeycomb, lattice block, corrugated) ▪ Structural foams and adhesives ▪ Composites/fiber-reinforced plastics ▪ Insulation and thermal protection ▪ Armor and self-sealing technologies ▪ Impact resistant coatings ▪ Valves and fittings ▪ Railcar couplers (cushioning)	Improvements to containers such as rail and truck tank cars, casks, and pipelines.	The chemical shipping industry considers strengthened containers a top priority. There are a number of approaches being investigated to make large containers better able to withstand impacts without increasing weight. Much of this work is associated with the Next-Generation Rail Tank Car Project.

to evaluate those that could work together (i.e., complementary), ones that would be competing in nature, or ones that would be in apparent conflict (e.g., bandwidth issues and frequency allocations, and power allocations for equipment on vehicles that provide no hardwired power, such as railcars and untethered trailers). The three technologies related to supply of electrical power (i.e., wireless power, nanopiezoelectronics, and plastic thin film organic solar cells) automatically fell into the category of complementary technologies. They are significant developing technologies to meet the objectives of this project. Interviews with developers of technologies related to cargo monitoring, sensing, detection, and alerting stated that available power with which to fully use their technologies is one of the key challenges.

NOTE: there is an effort that has been underway for the past several years to capture the energy used in slowing freight trains through regenerative braking. This term refers to a mechanism that captures energy otherwise lost as heat in conventional brakes, and it stores or feeds the power back into the locomotive's power supply. Reportedly, the energy used in braking a locomotive throughout a year is about equal to the power used by 160 homes (*40*). However, it was not perceived that regenerative braking necessarily results in greater availability of power to devices or systems that benefit Hazmat transportation safety and security, so it was not included among the most promising technology selections.

Team members were also seeking to determine known, perceived, and expected impediments or hindrances to developing, deploying, and maintaining the technology. These were expected to include technical, economic, liability, institutional/organizational, and human factors. In the case where impediments were identified, efforts would be made to identify preventive or mitigating factors or workaround tactics that could be applied. Special attention was devoted to any impediment perceived to be so large as to seriously jeopardize or even preclude full implementation.

2.7 Details of Task 5: Submit Interim Report Documenting Tasks 1 through 4

The draft interim report covered all activities in the first four tasks. It included the following major sections:

- Introduction
- Background Research and Information Gathering
- Research Approach Overview
- Modal Screening Process
- Selection of Most Promising Emerging Technologies
- Detailed Work Plan for Technology Exploration
- Conclusions, Lessons Learned, Next Steps

No comments from the HMCRP Project 04 panel required changes to the interim report. Panel acceptance of the report resulted in authorization to proceed with Phase 2 of the project, starting with execution of the proposed work plan.

2.8 Details of Task 6: Execute Task 4 Work Plan and Develop Recommendations for Advancing the Most Promising Technologies

Upon receipt of notice to proceed from the HMCRP Project 04 panel, a technology developer interview research template was generated (see Appendix F). Simultaneously, researchers conducted primarily Internet searches to determine the organizations that appeared to be desirable candidates for interviews as developers of the nine most promising emerging technologies. When a candidate technology developer was identified, initial contact was typically made by telephone. From the initial contact, team members were able to identify the appropriate person(s) with whom to communicate. Researchers sent the interview research template to the point of contact with a request that it be completed by a certain date with the option for a telephone interview.

From this effort, 67 contacts (with a small amount of redundancy) were identified as candidates for interviews, 26 of the organizations were eventually interviewed, and 23 were considered valid for the research objective. Potential interviewees were screened out for one of the following three reasons:

- Non-responsive despite repeated requests for interviews
- A subsequent determination that the source was not truly developing technology

Table 2-18. Type of technology developers interviewed.

Technology Area	Respondents	Interviews
Networked RFID, ubiquitous sensors and cargo monitoring	▪ Company ▪ National Laboratory ▪ National Laboratory ▪ Company ▪ National Laboratory	5
Pressure gauges and chemical detection sensors	▪ Company ▪ Company (4 related but separate technologies)	5
Fiber-optic/photonic sensors and optical scanners	▪ Company	1
Advanced locks and seals	▪ National Laboratory ▪ Company	2
Intelligent video tracking and surveillance	▪ Company ▪ Company	2
Wireless power	▪ Company ▪ Company	2
Nanopiezoelectronics	▪ University	1
Plastic thin-film organic solar cells	▪ Company ▪ Company ▪ Company	3
Container integrity	▪ USDOT Research Organization ▪ Company	2
	Total	**23**

- Those who declined to be interviewed, typically because of the confidentiality of their work

The technology developers whose interview results were compiled and analyzed are represented in Table 2-18. While there are 23 interviews listed, one national laboratory is represented by interviews in two technology areas, and one company had four separate interviews. Some organizations provided filled-out interview templates, others gave a verbal interview in which researchers filled out the template, and some did both. As seen in the technology developer interview research template in Appendix F, confidentiality was promised to all unless researchers were specifically given permission to use the name of the organization. (NOTE: while some organizations did give permission for use of their name, ultimately no organizations interviewed were identified in this report.)

The interview findings and resulting analysis are addressed in Chapter 3. Conclusions and recommendations are addressed in Chapter 4.

2.9 Details of Task 7: Prepare Final Report Documenting Entire Research Effort

All findings are presented in *HMCRP Report 4* including responses to HMCRP Project 04 panel comments resulting from the panel review.

CHAPTER 3

Findings and Applications

3.1 High-Level Commentary on a 15-Year Timeline

In reviewing research materials for this project, a cross-section of current concerns specific to Hazmat transported within each mode was evident. In terms of shared concerns, certainly characteristics of the three surface modes (highway, rail, and marine) position those modes to have the most technologies in common. Trains and barges are physically constrained in the routes that they can follow compared with trucks, aircraft, and (to an extent) oceangoing vessels. The air mode has more in common with the surface modes than with the fixed infrastructure of the pipeline mode; yet it differs from the surface modes in that quantities of the Hazmat transported by air are much smaller, the characteristics of the Hazmat are less dangerous (from the perspective of a catastrophic incident resulting from the Hazmat), and air transport occurs within a virtual "closed loop" of long-standing safety and security processes.

Most emerging technologies discovered in the course of this project are involved with vehicles. Some are intended to serve as preventive or detection technologies for infrastructure used by vehicles such as in bridges, tunnels, or railroad tracks. Understandably, most of the pipeline technologies are involved with infrastructure. The selection of container integrity improvements encompasses all modes and includes concepts not only of strengthened materials but also ways to use the commodity itself to help seal a leak. While the focus is clearly on large tanks such as those on rail tank cars, some of the container improvements may carry over to strengthening smaller containers such as those used to transport radioactive isotopes.

As observed by one of the technology developers, "Electronics are providing more capabilities with less power and lower cost. Consumers are demanding that devices last longer without being tethered to a charger or a communication cable. Memory devices are going up and the costs are going down. Battery energy densities are up, implying that small form factors can now power the same electronics in a smaller volume." Another technology developer noted "An overwhelming problem for sensing things at any range is that everything existing uses batteries. That will drive users crazy. Passive technologies do exist, and they are capable of sensing things—but this is a very difficult problem. Power has to be somewhere."

This recognition of the importance of stand-alone devices that can operate from sources of self-generated power was noted early by the research team. Three of the most promising technology selections are associated with non-typical sources of electrical power, which is an enabler that allows other technologies to be used more economically, such as for detection and alerting. These three technologies are wireless power, plastic thin-film organic solar cells with flexible polymer batteries, and nanopiezoelectronics. (The first two were winners of the MIT Technology Review's "10 Emerging Technologies" for 2008 and 2009, respectively). These three alternative power generation technologies are not being developed for the primary purpose of transportation applications. This underscores the team's premise in Section 2.2 of this report that the research should include applications of technologies used in (or being developed for) other industries but not currently adapted to transportation. The remaining most promising emerging technology selections have each to some degree been envisioned as having a transportation application. One of the RFID technology systems whose developer, a national laboratory, was interviewed as part of this project won a 2010 *RFID Journal* award as one of three finalists in the category of "Most Innovative Use of RFID" for its use of RFID to modernize the management of nuclear materials (*41*).

One interviewee made forward-thinking observations about technology developments, grouped into three time periods with respect to technologies' anticipated time of commercialization:

- The Near Term (Present–5 Years)
  - "In the near-term, informational technologies will reign. More traditional technologies can be made to work in new ways for remediation, packaging standards, safety,

and keeping the most dangerous materials away from population centers while enabling better efficiencies."
- Mid Range (6–9 years)
  - "In the mid-range, technologies that capture information will reign. They will more easily compile data and seamlessly collect and integrate information. This information can include items such as protective equipment and response planning needed."
- Long Range (10–15 years)
  - "In the longest range, technologies will answer questions not yet asked. Response technologies and information and communications technologies will move to a predictive nature such as predicting the characteristics of a Hazmat release, what equipment will be needed for response, and where and how it needs to be used. This would include better information on the effects of substances that get missed during a Hazmat release, such as during a train derailment. In the longest range, neural networks will assist with predictive modeling."

Relatively few technologies are specialized for intermodal transfer, but some ongoing initiatives will apply squarely to that. These include the concept of electronic shipping papers to supplement hardcopies being explored in the ongoing HMCRP Project 05 and the Pipeline and Hazardous Materials Safety Administration's (PHMSA's) Hazardous Materials—Automated Cargo Communications for Efficient and Safe Shipments (HM-ACCESS) initiative (*42*). Also included is the concept of the common security credential embodied in the HMCRP Project 08, which was solicited during the period of this project's research. (NOTE: The common security credential was one of the HM Project 04's Preliminary Most Promising Technology selections, but the team considered its identification as an HMCRP project to preclude the concept from further exploration in Task 6.)

It is important whenever possible to consider emerging technologies in parallel fields, and how these might evolve over the time horizon, or their potential impact on issues involving other modes. (NOTE: "parallel" is used here in the sense of how a technology that is primarily intended for a certain application, perhaps for a certain transportation mode, can be useful for other applications and other modes that have some common characteristic. For example, while the pipeline mode is much different from any of the four other modes of transportation, the concept of parallel technologies can still relate to the materials used.) This relationship must be viewed more broadly in regard to materials science and engineering, energy sources and conversion, environmental drivers, miniaturization (e.g., nanotechnology), sensors, monitoring and controls technology, systems simulation technology, and microencapsulation.

For example, the cross between nanotechnology and microencapsulation could give rise to a leak control scheme that is cheap enough to include with the product (regardless of transport mode), does not adversely react in end-use, but activates when a leak exposes it to shear-stress flowing through a crack coupled with a trigger reaction driven by oxygen. While not viable today, with the rate of technology progression, this has potential on a 15-year timeline. (NOTE: the research team had a dialogue with several individuals involved in this type of development, but could not determine any more specific expectation for maturity.)

Likewise, "parallel" in this context could be viewed in terms of market drivers and the impact of globalization. Changes in market drivers and globalization are already evident, for example in select market sectors such as the commodities and environmental sectors. Examples here include the scarcity of steel—much less quality steel at reasonable prices, which will no doubt drive the evolution of current materials concepts. Opportunities in this regard will evolve through the use of composite systems (not reinforced polymers but rather thinner steel used within a reinforcing scheme). Alternatively, they will evolve through development of new or replacement materials for use in lieu of steel.

Several modes of transportation share similar underlying traits. For example, tank cars for trains and similar tanks in trucks and barges involve segments that are more or less cylindrical shells with end-caps of various forms. Cylinders used to transport gases at a smaller volume-scale likewise share these aspects, as do the end-capped pipeline segments with windows and wings. Indeed, the overarching importance of container integrity to the chemical and transportation industries was underscored by one of our peer reviewers, which led team members to re-think this assessment.

There are parallel themes in several categories, including threat prevention, leak detection (and control), anomaly detection, characterization (and assessment), anomaly remediation and repair, alternative fuels, and environmental aspects including pipelining in challenging areas. Even so, these aspects may reflect existing work supporting regulatory drivers rather than a comprehensive listing of global industry drivers.

3.2 Caveats on the Technology Developer Research Interview Process, Findings, and Analysis

Similar to the manner in which the project's assumptions were delineated in Section 2.2, and to amplify on the Section 2.8 comments relating to the technology developer interview process, the following caveats are offered relating to the technology developer research interview process, findings, and analysis:

- Researchers attempted to identify every technology developer of each most promising emerging technology, but they do not represent that all were identified.

- Repeated good faith attempts were made to contact every technology developer identified, but attempts did not always result in an interview.
- Among the interviews conducted, not all were ultimately considered valid for the project's objectives.
- The sample size is not large.
- Among the technology developers whose interviews were considered valid, not all results provided the same level of detail.
- Information in interview responses was not independently verified.
- Within a technology area with multiple interviews, the level of readiness can and does vary.
- Technologies mature at different rates.
- There is some overlap between capabilities of certain technology areas (such as photonic sensors and organic thin-film solar cells).
- A technology need can sometimes be satisfied in more than one way.
- While the project's research design sought to minimize subjective interpretation through the functional requirement/gap analysis approach, the research team does not represent that the findings, conclusions, and recommendations are totally objective. Indeed, some subjectivity is inevitable in a project of this type.

3.3 Individual Technology Characterization

Sections 3.3.1 through 3.3.23 contain narratives for each of the interviewees with respect to their developing technologies. Each narrative includes the following information:

- Product description and use (i.e., eventual product)
- Technology readiness level
- Development path
- Challenges to successful implementation
- Overall assessment

These narratives are meant to provide key points of each technology's status, from which the results are compiled and summarized in terms of future development expectations.

NOTE: for simplification, the team used a modification of the widely used nine-level National Aeronautics and Space Administration's (NASA's) TRL grading scheme in assessing the level of maturity of the technologies discussed with their developers. The team's modification, more fully defined in the Appendix F technology developer interview template, recognizes the following five technology development levels:

- Level 1—basic technology principles have been observed
- Level 2—equipment and process concept formulated
- Level 3—prototype demonstrated in laboratory environment
- Level 4—technology product operational in limited real-world environment
- Level 5—technology product fully operational in real-world environment

The following subsections consist of a narrative for each of the 23 interviews conducted with technology developers.

3.3.1 Technology Developer Narrative 1—Company

Technology Area. Networked RFID, ubiquitous sensors and cargo monitoring

Product Description and Use. The technology is two-way wireless monitoring capabilities between battery-operated sensors and readers for outdoor applications. It uses active RFID for real-time monitoring of cargo and vehicle and allows two-way command and control and data collection of sensor status and location. Information is transmitted to remote monitoring centers. The system provides an immediate alert for any change in cargo status, including movement off-route (using geofencing). In real-time, it helps identify a person in connection with a specific operation in the field, and it sends an alert in the event of tampering. This permits fast response, visibility of operations in the field, and information flow to allow organizational optimization. It claims easy connectivity to public networks and security systems. It is said to be Federal Communications Commission (FCC) and Underwriters Laboratories (UL) compliant. Its primary market is carriers working with customs authorities and revenue-collecting government agencies as well as commercial fuel distribution companies.

Technology Readiness Level: 4–5. Product is fully operational in a real-world environment while spiral development continues.

Development Path. Part of the development challenge involved advancing unique sensing capabilities in real-time and in severe outdoor conditions. The product development requires final evaluation with users and setup of final standards and procedures.

Challenges to Successful Implementation. No particular impediments to implementation were noted. The cost to acquire and operate the product depends on implementation, and the developer feels the payback time to customers would be approximately 3 to 6 months.

Overall Assessment. It appears that this product has entered the marketplace and offers the potential for enhancing

Hazmat transportation safety and security. However, insufficient information was provided on user cost and other characteristics associated with product implementation to judge market adoptability.

3.3.2 Technology Developer Narrative 2—National Laboratory

Technology Area. Networked RFID, ubiquitous sensors and cargo monitoring

Product Description and Use. The technology is involved with a wide range of security systems for Hazmat, using locators and tracking devices. The devices are for shipments carrying high-security level shipments (i.e., radioactive materials). The technology provides increased security through location detectors at the vehicle or package level.

Technology Readiness Level: 3–5. Different products are at various development stages (on average, 2–5 years).

Development Path. Those technologies not already in the marketplace will be subjected to demonstrations in a limited real-world environment, followed by making the product fully operational. In general, each product is anticipated to cost the user "a few thousand dollars" to obtain and operate.

Challenges to Successful Implementation. These systems are generally not user-friendly. Hence, if something goes wrong or breaks, a special technician is needed. Also, there are concerns as to whether the products are sturdy enough to withstand the harsh conditions of daily use. Interactions could be positive or negative on the systems, so the developer is prepared to work with customers to customize their systems to work together.

Overall Assessment. Products in this technology area are evolving to the point where they are continuing to add capability while making user benefit/cost more attractive. Improving product durability and maintenance appears to be the next hurdle to overcome.

3.3.3 Technology Developer Narrative 3—Company

Technology Area. Networked RFID, ubiquitous sensors and cargo monitoring

Product Description and Use. The technology involves several systems including (1) RFID units for physical access control and customized RFID (passive, semi-active, and active) enabled sensors for distribution; (2) passive infrared (IR) and microwave intrusion detection systems for home and military security detection; (3) biometrics using advanced fingerprint scanners for vehicle ignition and access control; and (4) wireless sensor and actuator networks that report location via GPS and sensor data such as temperature, humidity, and radiation detection. Products are compatible with a wireless network protocol. The technology enables both security and remote monitoring of many types of customers. Access control is via both RFID and biometrics. Security is enabled via intrusion detectors, biometrics, and active RFID sensors monitoring a location. Remote monitoring of a distribution network is enabled via field-deployed RFID units with sensor and GPS technology. Detectors report emergencies to a dispatch location. The primary target market is clients that require security and asset management.

Technology Readiness Level: 4–5. The developer has an existing product base but is always in the process of bringing new products to Level 5 maturity.

Development Path. Continued packaging of capabilities and reduction of costs is key. User costs vary by product, ranging from under $100 to thousands of dollars per unit.

Challenges to Successful Implementation. There are always technological, manufacturing, and regulatory risks that need to be monitored and addressed in future product development, and the developer tracks those.

Overall Assessment. Many of these technology products have been developed initially for other target markets, yet they appear to be readily transferable to meet the needs of the Hazmat transportation industry.

3.3.4 Technology Developer Narrative 4—National Laboratory

Technology Area. Networked RFID, ubiquitous sensors and cargo monitoring

Product Description and Use. The technology is passive, unpowered sensing and monitoring technology that can take many different forms. These applications could include cargo tampering and leak detection (currently used) and analysis of Hazmat or biochemical threats (potential uses). Passive tags that can detect unauthorized access to cargo can be very useful. The technology uses also include infrastructure monitoring such as pipeline leaks (e.g., an oil drilling company could attach tags to drill pipes). Another form of infrastructure monitoring in which there has been interest is bridge monitoring (i.e., embedded strain gauges in bridges and passive chips that could provide information to inspectors who would only need to drive by the area). Current customers include NASA, the aerospace industry, and government agencies including DOE and DOD. A sophisticated device that this organization has developed is a micro-chemical lab that can detect Hazmat or bio-agents, and in principle it could be configured to work with passive, unpowered sensing and reporting technology. For example, such integration could help emergency responders remotely identify leaked Hazmat at the scene of an incident.

Technology Readiness Level: 4. The technologies are essentially at the pilot demonstration level.

Development Path. This path requires third parties that are interested in using this technology in their product applications and can deliver it to the marketplace at a reasonable cost. This process could take several years before coming to fruition. Whereas probably millions of dollars have been spent on battery-powered tags, much less has been spent for passive tags, and much more would need to be spent to bring them to market. For analog cell networks, probably only a tiny percent of what would be needed for development has been spent to date.

Challenges to Successful Implementation. Development costs are substantial, and therefore may require a forcing function (e.g., regulation) to make available the appropriate resources. Use of battery power, rather than wireless, is the current technology for reading information from 100 meters away. This requires user monitoring and replacement of batteries.

Overall Assessment. Eventually both the development funds and technology advancement will provide a solution for using this type of product, operating within a wireless network. It is only a matter of time before this occurs, likely within the next couple of years.

3.3.5 Technology Developer Narrative 5—National Laboratory

Technology Area. Networked RFID, ubiquitous sensors and cargo monitoring

Product Description and Use. The technology is for monitoring and tracking high-value items in transportation and storage using RFID tags equipped with sensors. The transporting vehicle is tracked and the state of its cargo's health is monitored and reported. Package manifest and event history is stored in tag memories and relayed by satellite and secure Internet to a command center. In case of an incident, a GIS-based report is immediately issued to assist with emergency response. The focus to date has been on truck transportation and storage of sensitive nuclear materials for the DOE. The technology has interacted with vehicle tracking technologies and satellite and cellular communication technologies. It has successfully completed initial integration of its RFID technology and a well-known tracking and communication system. In 2010, this system was selected by industry judges as one of the three finalists of the *RFID Journal*'s "Most Innovative Use of RFID award."

Technology Readiness Level: 4. The product has been operational in several on-the-road field demonstrations with staged incidents.

Development Path. More extensive field trials are underway. Large-scale industrial production of tags, readers, and other system components are needed for product to become fully operational, in addition to training of personnel and establishment of infrastructure. These developments are expected to occur within the coming year. Anticipated user costs are several thousand dollars for the fixed system, which includes one RFID reader and one communication transponder. Each transportation package would be fitted with a tag costing between $100 and $200 each.

Challenges to Successful Implementation. Between $500,000 and $1 million is needed to bring the technology into the marketplace. There is continued interaction with industry on development of sensors to expand the RFID functionality.

Overall Assessment. This technology product offers an intriguing hybrid solution to the immediate problem associated with making reliable wireless power available in tracking shipments in transit. The wireless problem is overcome because of the short transmission distance from the package to the reader (located in the truck cab), allowing the sensors to be powered by long-life batteries that can run for several years before needing replacement.

3.3.6 Technology Developer Narrative 6—Company

Technology Area. Pressure gauges and chemical detection sensors

Product Description and Use. The technology involves the embedding of sensors in products to detect chemical releases. Of the more than 140 products the technology developer has produced, three in particular are applicable to Hazmat transportation: (1) chemical sensors that can detect the presence of chlorine, ammonia, hydrogen cyanide, sulfur compounds, nitrogen, and several other materials; (2) photo ionization detectors useful for identifying hydrocarbons, styrene, gas, or diesel in units of parts per billion; and (3) scintillation sensors that can detect gamma or neutron rays. These products are compatible with an open platform that allows integration with third party providers.

Technology Readiness Level: 4–5. Some of these products are fully operational in a real-world environment, while others are at the stage of being operational in a limited real-world environment. Those products currently at Level 4 are anticipated to be at Level 5 within the coming year.

Development Path. Acquisition costs are product-dependent. However, the average payback time to the customer is estimated to be 3 months.

Challenges to Successful Implementation. There were none specified, other than acknowledging that sensors have a finite life and will need to replaced over time.

Overall Assessment. This technology developer's products are in the marketplace already, with additional products nearly ready for commercial use. If these products can accurately detect chemical releases with very low false alarm rates, it represents a promising Hazmat transportation safety and security enhancement. Given the large number of Hazmat shipments warranting active monitoring, the capability of embedded sensors to detect anomalous conditions at low thresholds and high reliability will benefit shippers, carriers, emergency responders, and government officials.

3.3.7 Technology Developer Narrative 7—Company: Technology No. 1

Technology Area. Pressure gauges and chemical detection sensors

Product Description and Use. The technology is nanowire technology used to detect chemical, biological, and radiological threats while cargo is in transport. The company's primary target markets are shipping container manufacturers, carriers, and seaports.

Technology Readiness Level: 2. The equipment and process concept has been formulated.

Development Path. Proceeding with a prototype demonstrated in a laboratory environment, testing the technology product in a limited real-world environment, and having the product fully operational in a real-world environment is expected to be a 6–9 year development process. It is anticipated that once available, the unit cost to the user will be roughly \$300 to obtain the product and \$100 to operate it.

Challenges to Successful Implementation. Funding in the amount of approximately \$10 million will be necessary to bring this product to the marketplace. The technology will also have to be designed to be interactive with communication devices.

Overall Assessment. The development and use of nanowire technology is in its early stages, and therefore more product development and testing is needed before it can compete in the marketplace. However, this technology offers the potential to achieve improved performance over what is being used in conventional sensors.

3.3.8 Technology Developer Narrative 8—Company: Technology No. 2

Technology Area. Pressure gauges and chemical detection sensors

Product Description and Use. The technology is color metric barcodes used to detect homemade explosives and precursors for various forms of explosives. The product is targeted for security use in conflict areas.

Technology Readiness Level: 2. The equipment and process concept has been formulated.

Development Path. Proceeding with a prototype demonstrated in a laboratory environment, testing the technology product in a limited real-world environment, and having the product fully operational in a real-world environment is expected to be a 6–9 year development process. It is anticipated that once available, the unit cost to the user will be roughly \$100 to obtain the product and less than \$100 to operate it.

Challenges to Successful Implementation. Funding in the amount of approximately \$3 million will be necessary to bring this product to the marketplace.

Overall Assessment. Color metric barcoding is in an early development stage, requiring several years of effort before products relying on this technology will become commercially available. When it reaches that point, the benefits derived from product use will be primarily enhanced security from terrorist attacks, although applications to support Hazmat transport safety could possibly evolve.

3.3.9 Technology Developer Narrative 9—Company: Technology No. 3

Technology Area. Pressure gauges and chemical detection sensors

Product Description and Use. The technology is gas chromatography integrated into systems that detect agents, primarily chemicals and explosives. The primary target market is buildings with heating, ventilating, and air conditioning (HVAC) systems.

Technology Readiness Level: 2. The equipment and process concept has been formulated.

Development Path. Proceeding with a prototype demonstrated in a laboratory environment, testing the technology product in a limited real-world environment, and having the product fully operational in a real-world environment is expected to be a 6–9 year development process. It is anticipated that once available, the unit cost to the user will be roughly $100 to obtain the product and less than $100 to operate it.

Challenges to Successful Implementation. Funding in the amount of approximately $3 million will be necessary to bring this product to the marketplace.

Overall Assessment. As the use of gas chromatography for this purpose is just being conceptualized, the emergence of a commercially available product is not likely to occur for many years. Once in the marketplace, the product's use will be limited to building infrastructure, unless the technology can be integrated with other products to serve transport vehicles and sensitive cargo.

3.3.10 Technology Developer Narrative 10—Company: Technology No. 4

Technology Area. Pressure gauges and chemical detection sensors

Product Description and Use. This technology is a 24/7 indoor air monitoring system that is capable of detecting aldehydes, oxidizers, acids, and bases. Information can be transmitted via wireless communication. The primary target market is buildings and other facilities that are important to homeland security.

Technology Readiness Level: 4. The technology product is operational in a limited real-world environment.

Development Path. It is expected that the technology product will be fully operational and commercially available within the coming year. The anticipated user cost is approximately $80,000.

Challenges to Successful Implementation. No challenge or impediment was identified.

Overall Assessment. At such a high user cost, it would appear that the demand for this product will be limited to large organizations with sizeable fixed infrastructure. Some shippers (chemical manufacturers) may fall into this category. However, unless the technology is customized for smaller, mobile operations, and made available at an affordable cost, its adaptation by the Hazmat transport industry is likely to be extremely limited.

3.3.11 Technology Developer Narrative 11—Company

Technology Area. Fiber-optic/photonic sensors and optical scanners

Product Description and Use. The technology is fiber-optic sensors as well as optical scanning systems. Fiber-optic sensors can be used for many Hazmat needs; their use depends on the amount of Hazmat and the sensor sensitivity, dynamic range, and resolution. Also, avoiding false signals is one of the critical parameters, whatever the application medium. Fiber-optic sensors and optical scanners can be placed in space or on ground; they can be hand-held, surface-mounted, or embedded into structures.

Technology Readiness Level: 1–2. This technology developer studies the problem and designs the proper sensors for appropriate applications. As soon as the proof of concept is completed and a prototype is developed and tested, it is delivered to the customer.

Development Path. There will be development of a series of fiber-optic sensors depending on the sensitivity required for each application, and costs are based on sensitivity. The range can vary considerably. Optical scanner costs also vary based on the size and whether they are hand-held or large lab testers. The scanners' range can also vary considerably for mass production, and the cost depends on the mass production numbers.

Challenges to Successful Implementation. There are no special needs identified in the development. In general, as with any early stage developments, financial support is the critical issue.

Overall Assessment. This appears to be a very flexible and versatile technology. Fiber-optics is recognized for the quantity and quality of data it is capable of transmitting. It has promise for not only vehicle and cargo monitoring but also infrastructure, such as identifying the type and concentration of toxic gas in a tunnel or the degree of movement of bridge support structures.

3.3.12 Technology Developer Narrative 12—National Laboratory

Technology Area. Advanced locks and seals

Product Description and Use. The technology is a Secure Sensor Platform (SSP) provides a framework of functionality to support the development of low-power autonomous sensors primarily for nuclear safeguards. This framework provides four primary functional blocks of capabilities required to implement autonomous sensors. These capabilities are security-based communication protocol for radio frequency and hardwire mediums; active, passive, and indicative security features for secure housings; power management for extended battery-powered autonomous operation; and cryptographic processes providing Advanced Encryption Standard (AES)-based authentication and encryption as well as a public key cryptography option. Using this framework establishes a common set of functional capabilities for seamless interoperability of any sensor based on the SSP concept. The SSP communication protocol stack can readily support wired or wireless communication by simply replacing the physical layer. The entire protocol stack has been optimized to minimize the energy required for effective communication. Its original basis is as a high-end security and safeguard system providing sensors to remotely monitor nuclear processes and nuclear material storage. Many of the sensors used for that purpose cannot rely on existing infrastructure for power or communications and therefore must be self-contained.

The sensor monitoring system configuration consists of a host computer, a translator, many sensor platforms, and data management tools for data collection and verification. The sensors and the translator store and forward all collected data. This capability creates redundant data stores, allowing recovery of sensor data to support the requirement for complete data sets. Examples of possible sensors are magnetic, glass break, passive IR, IR break beam, authenticated switch, fiber-optic receiver, fiber-optic loop seal, vibration, and microwave. All of the SSP-based sensors are active devices. They detect and report out-of-normal conditions in near real time. The SSP framework provides three categories of security features. These are active tamper monitoring to protect secret cryptographic keys, intrinsic features for forensic examination, and a passive feature which causes the initiation of an active tamper. Data are encrypted and authenticated at the sensor. Authentication and encryption are based on National Institute of Standards and Technology (NIST) standards. Power management uses techniques such as multiplexed sensors, high-energy density battery technologies, and wake-on-radio features.

A current example of an SSP sensor application is the RMSA which inherits all of the SSP core capabilities as described. The RMSA uses a low life cycle cost fiber-optic seal sensor. The fiber optic material is inexpensive 1-mm plastic fiber that can be cut in the field in loop lengths up to 50 meters. The fiber loop is actively monitored with light pulses. The seal uses the unlicensed RF bands to periodically communicate its status and immediately communicate alerts. Each seal can store several years' worth of transmitted messages.

Technology Readiness Level: 4. The SSP framework has been in development for several years with the primary sponsor being the National Nuclear Security Administration (NNSA) Office of Nuclear Verification. The first use of this framework has been the development of the RMSA, which is a monitoring system for a large number of active fiber-optic seals providing worldwide, secure and remote access to the array of seals. Its originating national laboratory is going through the production process with a commercial partner and is on the verge of providing a prototype system to the International Atomic Energy Association (IAEA). Two other sensor developments based on the SSP are the tiny gamma-ray spectrometer and the authenticated switch. Both are autonomous and battery powered.

Development Path. SSP future trends include stronger cryptology; greater resistance to tampering; and higher confidence of detection while still maintaining low cost for wide deployment, longer autonomous operation, more supported sensor technologies, and more user interfaces to provide choices for monitoring and review platforms. Initially, costs for the RMSA system components are anticipated to be approximately \$500 or less in volumes above 500 for the fiber-optic seal, and the translator would cost approximately \$6,000 if tamper-indicating and \$1,500-\$2,000 for a non tamper-indicating commercial version.

Challenges to Successful Implementation. The SSP technology is specifically designed to have low life cycle cost, but it is initially a more expensive solution than the commercial marketplace can deploy for Hazmat shipments. The SSP has been designed for large, dry, outdoor storage of large numbers of adjacent spent fuel containers. It provides deterrence by detection. It is currently designed to give alerts to a control center in near real time. Achieving mobility will require some additional R&D (for example, connecting to a GPS/GLS device with terrestrial or satellite communications, possibly with a camera triggered by an authenticated switch). This would not have a big hardware impact but could involve software licenses and royalties. Finally, there may be RF emission restrictions in some nuclear facilities.

Overall Assessment. The SSP and its RMSA application have resulted from a lot of thought and research. Security of containers has remained a vexing problem. Many different seals (including tamper-indicating seals) have been defeated by vulnerability assessment researchers, often with surprising speed. Security of some particularly dangerous or high-value Hazmat shipments could be improved by defeating sophisticated intrusion attempts and reporting their occurrence. As the cost of this technology comes down, carriers of cargo such as explosives and bulk TIH may find that the SSP's ability to protect sealed Hazmat cargo with low maintenance, high confidence in collected information, and lower staff-hours for inspection make it affordable.

3.3.13 Technology Developer Narrative 13—Company

Technology Area. Advanced locks and seals

Product Description and Use. The technology is locks and seals that can be remotely monitored for intrusion and system functioning.

Technology Readiness Level: 4–5. The technology product is fully operational in a real-world environment, although user evaluations and development of standards and procedures are ongoing.

Development Path. Although user cost will depend on the type of system implementation, average customer payback time is estimated to be between 3 and 6 months.

Challenges to Successful Implementation. No challenges or impediments were identified.

Overall Assessment. In its current form, this product appears to be limited in function to being a device for detecting product tampering and providing alerts, while lacking advanced encryption and other features that make seals and locks difficult to defeat.

3.3.14 Technology Developer Narrative 14—Company

Technology Area. Intelligent video tracking and surveillance

Product Description and Use. The technology is security and safety cameras that capture images, replicate them to a hard drive and compresses them, then give them to the user interface to view online recorded images. Intelligent video analytics provides a length of a queue line by counting people, recording features by frames based on tripwire, detecting camera blinding attempts, and conducting image stabilization. This can also be in High Definition 1080p. (NOTE: 1080p is a very high resolution video format and screen specification intended to deliver a smoother image that stays sharper during motion.) This technology can be used to detect a person presenting an illicit card at a secured door that could either trigger an alarm, or alternatively, let that person have access and trip video cameras to automatically record images of his/her movement. The technology can be used to protect container ports and other sites with imports and exports. Cameras can capture tag numbers on trucks and tail numbers on airplanes with a time and date stamp on the image. The technology can conduct entry/exit monitoring of restricted areas and any other areas without restriction, such as for a remote, usually unoccupied pipeline facility.

Technology Readiness Level: 4–5. Acquisition and operation cost and ROI are currently difficult to determine because this technology developer works through a dealer and quantities can range from a few hundred to a few thousand.

Development Path. Incremental improvements to a proven technology are being made by this company. Every transportation mode can conceivably benefit by advanced video surveillance and monitoring features that are primarily security-related but could also include safety monitoring.

Challenges to Successful Implementation. There are no discernable impediments to developmental versions reaching the marketplace. Privacy issues could be one potential impediment, but proliferation of video surveillance in modern society has been rapid, particularly after 9/11, and privacy issues have not come into play when this technology is used for security surveillance. When video surveillance is coupled with knowledge of aspects of human behavior, it can be done in a way that focuses on what a person does, not who they are. If typical activity patterns for a given area are known, intelligent video analytics can help detect and alert when something breaks the pattern, such as an object left in a field of view. The tracking feature can be employed to virtually follow someone with suspected malicious intent without their realizing they are being followed.

Overall Assessment. Intelligent video surveillance has great promise to increase its role as the “eyes and ears” of remote and unmanned site surveillance. It has a decision support role in that it not only sees what is occurring but can help decide whether the occurrence is cause for alarm. It also provides a type of forensics in that it records and time- and date-stamps events.

3.3.15 Technology Developer Narrative 15—Company

Technology Area. Intelligent video tracking and surveillance

Product Description and Use. The technology is video content analysis software that processes and fuses live surveillance camera images for automatic recognition of suspicious events or malicious activities at a site based on a multi-layer intelligence. The main specialty of this system is site-wide identity tracking, accomplished by processing and fusing the information from all connected cameras, and tracking people, vehicles, and other objects from camera to camera. Identity tracking in this context means that by receiving information from a (third party) access control system or other primary source of identities, users can attach names or other information to the tracked people, so the system at the end not only knows that there is somebody there, but also knows who it is. The system can also be used not only to analyze but to predict behaviors.

Technology Readiness Level: 3. The development of this technology originally targeted the physical security market, above all the video surveillance/CCTV segment. Besides a number of security-related potential use cases of identity tracking technology, the developer is currently focusing on customer behavior analysis in retail. An example is not only analyzing purchases, but also predicting the behavior of customers in shops, providing invaluable data for optimizing product placement.

Development Path. Besides further research and development, appropriate test sites should be chosen to accomplish piloting. As this is a new technology providing services not previously in the market, its capabilities should be first disseminated to raise attention and generate demand.

Challenges to Successful Implementation. Privacy issues can apply to any video surveillance system. As the main benefit of the system is the increased level of security on a site by mitigating certain risks, it is challenging to estimate payback time because it highly depends on the prevalence and severity of malicious events and the damage they may cause.

Overall Assessment. This is a technology that can work in conjunction with access control, can incorporate identity management, and provide decision support. It would be feasible to track a Hazmat vehicle from camera to camera as the vehicle passes along a highway through a HTUA, as well as tracking a person such as an intruder in a seaport or rail switching yard. The software appears to works with current, standard cameras.

3.3.16 Technology Developer Narrative 16—Company

Technology Area. Wireless Power

Product Description and Use. The technology is wireless power and radio frequency energy harvesting, converting radio waves into direct current (DC) power. This is an enabling technology in that it helps to provide electrical power for sensors and other technologies that would be more expensive due to battery maintenance and replacement costs. The application is for commercial industrial and defense industries. It supplies power that various sensing and communicating devices might not otherwise have. It eliminates cords and reduces battery needs. Wireless transmission could be used to power safety warning sensors to detect unsafe or toxic substances, allow GPS/GLS devices attached to a vehicle that may be battery powered to be wirelessly charged, or power sensors for monitoring structural health in all infrastructure. Industries will save money by eliminating frequent battery changes.

Technology Readiness Level: 4. In 2007, the developer released the first version of this technology. In 2009, it released a second generation, and now has released volume production and new components of the technology.

Development Path. The developer is currently using a distributor to evolve the technology into different applications. It also has training and supportability plans implemented and an active mechanism in place to make product improvements in response to customer suggestions.

Challenges to Successful Implementation. The FCC regulates and limits a certain amount of power broadcast, so the technology has to be FCC-compliant. As power levels and distances of transmission increase, FCC regulation could take on more importance.

Overall Assessment. Wireless power has the potential to supply electricity to sensors and communications devices from a distance and without the need for power cords. It can be used to recharge batteries, and the number and size of batteries needed by a device using wireless power can be reduced.

3.3.17 Technology Developer Narrative 17—Company

Technology Area. Wireless Power

Product Description and Use. The technology uses advanced material science and proprietary software algorithms to identify, profile, and adapt wireless power delivery to various loads in varying configurations. This is an enabling technology in that it helps to provide electrical power for sensors and other technologies that would be more expensive due to battery maintenance and replacement costs. Simple examples include wirelessly charging and powering hand-held scanners and other devices and wirelessly charging and powering flashlights and other security devices to enable them to be "always ready" portable lighting for emergency responders, police, firefighters, soldiers, and so forth. Another use is in-vehicle charging and power delivery for charging and powering sensors and other devices in adverse climates and conditions. There is the potential for specialized software applications to enable devices using intelligent communications. Wireless power technologies can power a room—a "wireless coffee shop" has been demonstrated in which a laptop and cell phone were kept charged through this technology.

Technology Readiness Level: 4–5. Several new patents have been granted to the technology developer, who is helping to drive development of interoperability standards as a founding member of the Wireless Power Consortium.

Development Path. The initial market is low power consumer electronics with additional medium and high power applications that benefit industries forthcoming. Application-specific uses may require additional research and development.

Challenges to Successful Implementation. Shielding may be required to prevent interference in certain radio bands. Supply chain development may be needed for certain form factors and applications. It remains to be determined how the technology is impacted by magnetic energy. From a safety and regulatory standpoint, short distance and even some long distance wireless power meet requirements. IEEE runs the standards program that covers wireless technology.

Overall Assessment. This is a promising technology. "Universal power" at its best can eliminate cords and connections and give load power. Applications can range from milliwatts to kilowatts. It is conceptually possible to have a sensor embedded in packaging that remotely relays information that the level of a liquid or solid is getting low, by receiving a signal and then responding. The sensor would be in the packaging itself and could be detected by being in proximity to a device. If a railcar holds materials, the device could power a receiving coil on the railcar, then the railcar could ping materials carried internally. Distance depends on power levels—several railcars back from a device on a locomotive might be attainable, and it is even possible to "daisy-chain" a signal down a line of railcars.

3.3.18 Technology Developer Narrative 18—University

Technology Area. Nanopiezoelectronics

Product Description and Use. The technology uses devices made of a common, inexpensive, very thin plastic and zinc oxide to produce power for sensors, actuators, and other uses from externally applied strain (force, pressure, or small physical motion). The devices convert motion to electricity, which can be used or stored in a battery or capacitor. This is an enabling technology in that it helps to provide electrical power for sensors and other technologies that would otherwise be more expensive due to battery maintenance and replacement costs. Safe (non-toxic), low-cost, biodegradable materials are used. Primary markets include the electronic industry especially emphasizing microelectromechanical/nanoelectromechanical systems (MEMS/NEMS), multifunctional devices, and sensors in mobile electronics that can be powered without batteries. Nanogenerator technology could be used to allow small tracking devices that normally need a power source to send a signal to the user from energy created by the environment. It can also be used to power sensors, locks, and other technologies associated with pipelines using the gas flow (turbulence) to trigger the device to produce electricity. A flag with these materials could produce electricity as it flutters in the wind.

Technology Readiness Level: 1–2. The technology has already been used to store a charge in a capacitor and power an LED. The developer believes 2–5 years is a plausible timeframe for product maturity.

Development Path. About 2 to 3 years is needed to commercialize the technology, and millions of dollars will be needed to reach Level 5. Although not cited as an impediment, it is acknowledged that 2 to 3 million dollars in additional investment is needed in commercialize the technology.

Challenges to Successful Implementation. A previous obstacle was that only a low voltage could be produced, but following a technical breakthrough, 3 to 4 volts can now be produced. Another impediment includes making the system more robust and optimizing the design.

Overall Assessment: This is an environmentally friendly technology that capitalizes on motion or strain to provide power to certain devices where there otherwise would be none. It can produce power inside a vehicle where solar power is not available. This represents an extremely promising technology development in that it will enable tracking and monitoring of hazardous materials shipments to occur without the cost of battery maintenance and replacement. Moreover, this may create an opportunity to improve the precision of real-time status if GPS/GLS transmissions can be sent with greater frequency due to less concern for the amount of battery power being consumed.

3.3.19 Technology Developer Narrative 19—Company

Technology Area. Plastic Thin-Film Organic Solar Cells

Product Description and Use. The technology is a third generation, thin-film, flexible, organic photovoltaic material that is printable on plastic. This is an enabling technology in that it helps to provide electrical power for sensors and other technologies that would be more expensive due to battery maintenance and replacement costs. It allows the conversion of light (outdoor and indoor) to DC power and is very good at converting low light so collection time is expanded over the entire day. Also, there is a positive thermal coefficient so as the material warms up, it works better. The four primary markets are microelectronics, portable power, remote power and building integrated photovoltaics (i.e., photovoltaic materials that are used to replace conventional building materials in parts of a building).

Technology Readiness Level: 4–5. The next generation product is under development, with planned sampling release in late 2010 and production in early 2011. The technology is a component for integration into other technologies, so close collaboration with other technologies is vital for the success of this developing technology.

Development Path. The product has had a substantial investment and appears ready for commercialization in targeted application areas.

Challenges to Successful Implementation. The product must be adhered or laminated to other technologies, so development efforts are required in most cases to incorporate the product into other technologies. Also, the product must have an electrical connection which may require development efforts depending on the application.

Overall Assessment. This represents a very promising technology development that will enable tracking and monitoring of Hazmat shipments to occur with reduced cost of battery maintenance and replacement. Moreover, this may create an opportunity to improve the precision of real-time status if transmissions can be sent with greater frequency due to less concern for the amount of battery power being consumed.

3.3.20 Technology Developer Narrative 20—Company

Technology Area. Plastic Thin-Film Organic Solar Cells

Product Description and Use. Organic solar cell technology generates power at a low cost, cheaper than fossil fuels. This is an enabling technology that helps to provide electrical power for sensors and other technologies that otherwise would be more expensive due to battery maintenance and replacement costs. It has applications for eliminating battery usage to supplying power to other technologies. It can provide power to remote and wireless sensor networks, and perhaps a device on a chemical tank that requires wireless power. It can help supplement power supply if the grid is down. The technology can easily be integrated with other products.

Technology Readiness Level: 4. Tens of millions of dollars have already been spent in development and tens of millions remain to be invested. The products are developed, then licensed to a company, and the return is usually a small percentage of the license module.

Development Path. The targeted market includes any company with a need to generate power and operate mobile devices. The next stages are capital intensive with demonstrations. Most work is done in a research environment so it takes longer to bring technologies into production. There is a move toward the commercial environment.

Challenges to Successful Implementation. There are no known technical impediments outside of the challenges of development.

Overall Assessment. This represents an extremely promising technology development in that it will enable tracking and monitoring of Hazmat shipments to occur with reduced cost of battery maintenance and replacement. Moreover, this may create an opportunity to improve the precision of real-time status if transmissions can be sent with greater frequency due to less concern for the amount of battery power being consumed.

3.3.21 Technology Developer Narrative 21—Company

Technology Area. Plastic Thin-Film Organic Solar Cells

Product Description and Use. The technology involves putting semi-conductors (solar cells) on non-traditional surfaces depending on the substrate, which can be fairly transparent. It is a flexible printed circuit sheet that has a film battery on one side and generates electricity when exposed to light. This is an enabling technology that helps to provide electrical power for sensors and other technologies that otherwise would be more expensive due to battery maintenance and replacement costs. The solar cells can go on corners or curved surfaces. Power generated can be stored in a battery or capacitor. Colors of light absorbed and the transparency can be tuned to be narrow in its detection. "Organic" means that carbon is a major component and most of the chemicals needed are generally standard and non-toxic. Flexible organic solar cells can be very thin, relatively transparent, and thus more aesthetic in their applications than traditional solar cells, which tend to be crystalline and opaque and relatively difficult to put into a product. They could be used on the outside surfaces of a vehicle such as the roof, or applied as a film on a window to generate electricity. "Power paint" (i.e., the thin-film, relatively transparent, flexible organic solar cell coating) on outside surfaces, including windows that would otherwise be wasted surface area, could be a significant part of an electric vehicle's (EV's) budget, extending the range and reducing battery size and expense.

Technology Readiness Level: 3–4. The developer builds proof-of-concept devices and licenses to volume manufacturers. Development depends on partnerships and capital investment as well as engineering optimization and scaling.

Development Path. Economics should be favorable if the technology can reduce the amount of electrical capacity needed by a device or vehicle. In the near term, sensors, devices, and electric vehicles are the target to augment and offset the energy load from the battery. Higher frequency transmission times and data rates can be possible, which can benefit sensors and communications systems. In the longer term, power generation, especially peak power, is a target.

Challenges to Successful Implementation. Learning how to make the cells larger and at volume is key. It is currently possible to make them up to 6 in. square. The technology needs to migrate towards larger proof-of-concept devices.

Overall Assessment. This represents a very promising technology development that will enable tracking and monitoring of Hazmat shipments to occur with reduced cost of battery maintenance and replacement. Moreover, this may create an opportunity to improve the precision of real-time status if transmissions can be sent with greater frequency because of less concern for the amount of battery power being consumed.

3.3.22 Technology Developer Narrative 22—Company

Technology Area. Container Integrity

Product Description and Use. The technology is a self-healing, self-sealing substance that is resistant to bullets. The technology is currently used for fuel transport in the military in the form of a urethane compound sprayed on the outside of a fuel tanker. The compound reacts chemically with fuel to seal off a bullet hole puncture to the metal jacket of a tank, helping prevent what otherwise may result in a conflagration. The concept can be tailored to different chemistries of liquids and natural gas; its feasibility with chlorine and ammonia technologies has reportedly been demonstrated. It provides corrosion resistance which can lengthen life expectancy of tanks. It may be possible to embed tracking and monitoring devices into the coating to remotely report damage and help to determine what sort of emergency response is needed. Beyond its current military vehicle application, the technology could be used for infrastructure and by DHS and the trucking, rail, and pipeline industries. It is complementary with blast and fire mitigation technologies.

Technology Readiness Level: 3. Full-scale testing with different specialized chemistries is needed, which will be expensive.

Development Path. There is a need to find partners and to tie into government regulation guidelines and protocols for testing. There is a possible worldwide military market for the technology.

Challenges to Successful Implementation. Loss of a fuel tanker to fire or explosion or the cost to clean up a spill that results in fire are known expenses, but it is more difficult to quantify the money saved from protection. The process does add weight, which reduces fuel efficiency.

Overall Assessment. This specialty technology development evolved based on a need. Once the technology was developed, it solved a problem quickly. The technology could benefit multiple modes, helping to protect not just vehicles but also pipelines from certain kinds of damage.

3.3.23 Technology Developer Narrative 23—U.S. DOT Research Organization

Technology Area. Container Integrity

Product Description and Use. The technology is a sandwich structure to protect railroad tank cars against puncture from impacting objects in the event of derailment or collision. A sandwich structure acts like a shield to protect the commodity-carrying tank. The structure generally consists of two face sheets that are separated by a core. Protection is offered through two mechanisms: load blunting (or load distribution) and energy absorption. Both mechanisms would prevent or mitigate tank car punctures and may raise the standard for impact for tank cars above the current 18 mph. The primary target is tank car manufacturers or anyone who is interested in designing improvements to the crashworthiness of tank cars.

Technology Readiness Level: 1. This technology is in the basic research stage. It is too early to determine acquisition and operation cost and potential ROI because the technology is still in testing.

Development Path. There are a lot of collaborative efforts within the tank car community, including representation from railroads, manufacturers, and chemical companies that have a vested interest in safe Hazmat transport. Currently for this technology, there is ongoing research to develop sandwich panels to be applied to ships' hulls, including Office of Naval Research work to protect ships from explosive impacts. This can be modified for tank cars on a more mechanical level, such as wheel and car impacts rather than blasts.

Challenges to Successful Implementation. The protective structure needs to be within weight and space requirements. Some trade-offs may be necessary between sufficient protection and the weight and space budgets. The extra protection could significantly raise the cost of a rail tank car, which may hamper voluntary adoption. There was some rule-making activity 2 years ago when the Federal Railroad Administration tried to make more rigorous regulations concerning technologies of this type, but there was industry resistance. The stricter standard may be revisited.

Overall Assessment. This technology is a noteworthy approach to strengthening and protecting tanks and ships' hulls. Because this is a very new technology, industry has only recently become interested in it, and industry buy-in is important. The next steps in the development will be crucial to gain acceptance. Funding has been running low, but there may be an infusion in the next few months. Industry may become interested as time goes on and more tests and prototypes are developed.

3.4 Technology Evaluation Results

Table 3-1 contains summary evaluation results for all 23 most promising emerging technologies researched, listed in order of the technology developer narratives from Section 3.3.

Tables 3-2 through 3-4 contain the outlook for technologies maturing during certain time periods. Table 3-2 is the near-term timeframe (i.e., within the next 2 years), Table 3-3 is the 2–5 year timeframe, and Table 3-3 is the 6–15 year timeframe. These are also listed in order of technology developer narrative number from Section 3.3.

Figure 3-1 provides a development roadmap for each of the nine most promising emerging technology areas. The columns to the right of the Technology Area correspond to the five technology development levels defined by the research team and explained at the beginning of this section. The length of the bar portrays the relative maturity of the technology area. This involves some interpolation and averaging because a given technology area is usually represented by more than one technology, and developing products researched may reach the marketplace at different times. Also, as noted in Section 3.2, technologies mature at different rates. The black part of the bar is intended to show researchers' perceptions of where the majority of development has progressed to date, while the gray part of the bar shows advance entries approaching or entering the marketplace.

The two representative examples of Container Integrity technology are on opposite ends of the development path. That interpretive challenge was addressed by recognizing that research programs are in place for developing solutions in this technology area over the next 2–5 years and thus portraying that as the collective timeline.

Table 3-1. Summary evaluation results of all developing technologies.

Technology Area	Narrative No./ Organizational Type	Technology Function	Tech Dev Level	Market Availability	User Unit Cost	Impediment(s)	Comments
Networked RFID, ubiquitous sensors and cargo monitoring	1 – Company	Active RFID monitoring of cargo and fuel during transport using battery operated sensors	4-5	Short-term	Variable/not disclosed	None noted	Information transmitted to remote monitoring centers
Networked RFID, ubiquitous sensors and cargo monitoring	2 – National Laboratory	Systems featuring locators, tracking devices and disclosure of information for first responders	3-5	2-5 years	Estimated to be a few thousand dollars	Requires a special technician to make repairs; systems must withstand harsh conditions associated with trailer use	Primary market is shippers requiring high security levels (e.g., radioactive cargo) during truck transport
Networked RFID, ubiquitous sensors and cargo monitoring	3 – Company	Security and remote monitoring systems utilizing RFID, intrusion detection, biometrics, and wireless sensor and actuator networks	4-5	Short-term	Products range from under $100 to thousands of dollars	None specifically noted	Products designed from silicon up to plastics, with industry proven wireless network protocol
Networked RFID, ubiquitous sensors and cargo monitoring	4 – National Laboratory	Infrastructure monitoring using passive, unpowered sensing technology	4	2-5 years	Passive system: $0.05-$0.10 per tag and $2,000 per reader; active system: $50-$100 per tag	Finding development funding can be a constraint in customizing technology for new application, especially if no forcing function exists; desirable if power can be available to transmit information up to 100 meters	Eventually both the development funds and technology advancement will provide a solution for using this type of product, operating within a wireless network
Networked RFID, ubiquitous sensors and cargo monitoring	5 – National Laboratory	Monitor and track items in transportation and storage, using satellite and secure Internet to relay information	4	Short-term	Several thousand dollars for fixed system of one RFID reader and communication transponder; cost of $100-$200 per package tag	$500K to $1M would bring readiness to Level 5; also need large-scale industrial production of tags, readers and other system components, training of personnel, and establishment of infrastructure	Primary market is shipments of sensitive nuclear materials
Pressure gauges, chemical detection sensors	6 – Company	Chemical and radiation detection; over 140 products with different attributes	4-5	Short-term	Variable acquisition cost; average payback of 3 months	Sensors have a finite life	Open platform for integration of third party sensors; target markets include industrial safety, civil defense, and petrochemicals
Pressure gauges, chemical detection sensors	7 – Company	Indoor air monitoring	2	6-10 years	$80,000 acquisition cost	The technology will have to be designed to be interactive with communication devices	Can communicate via wireless; primary target market is buildings and homeland security
Pressure gauges, chemical detection sensors	8 – Company	Chemical, biological, and radiological threat detection using nanowire technology	2	6-10 years	Unit cost of $300 to wire and $100 to operate	Need $10M in additional funding	Interactive with communication and display devices; primary use is on shipping containers
Pressure gauges, chemical detection sensors	9 – Company	Explosives detection using color metric barcodes	2	6-10 years	Unit cost of $300 to obtain and under $100 to operate	Need $3M in additional funding	Product use will be limited to building infrastructure unless the technology can be integrated with other products in order to serve transport vehicles and sensitive cargo
Pressure gauges, chemical detection sensors	10 – Company	Chemical and explosives detection using gas chromatograph	4	Short-term	Unit cost of $300 to obtain and under $100 to operate	Need $3M in additional funding	Primary target market is buildings with HVAC systems
Fiber-optic/photonic sensors & optical scanners	11 – Company	Sensors using fiber-optics	1-2	6-10 years for optical scanner and in general, 2-5 years for some fiber-optic sensors	$25-$400 per sensor; $400-$2M per optical scanner, depending on the production scale	Need $900K in sensor development funds; need $4-6M in scanner development funds	Has promise for not only vehicle and cargo monitoring but also infrastructure monitoring

(continued on next page)

Table 3-1. (Continued).

Technology Area	Narrative No./ Organizational Type	Technology Function	Tech Dev Level	Market Availability	User Unit Cost	Impediment(s)	Comments
Advanced locks & seals	12 – National Laboratory	Secure Sensor Platform (SSP) with applications such as Remotely Monitored Sealing Display (RMSA)	4	2-5 years	Seals: $500 in volume > 500 units; translator: $6,000 if tamper-resistant, $1,500-$2,000 if not	Initial cost is high; need volumes to bring cost down. RFID may have some interference restrictions in some areas.	Encryption makes seals highly resistant to intrusion that escapes detection. SSP design represents middle ground between passive tags and active seals.
Advanced locks & seals	13 – Company	Two-way wireless monitoring and control of battery-operated sensors attached to cargo and assets	4-5	Short-term	Cost depends on application; payback expected in 3-6 months	No known impediment	Includes geofencing and alerts in the event of tampering
Intelligent video tracking & surveillance	14 – Company	Image capture and intelligent video analytics	4-5	Short-term	$100-$1,000	No known impediment	Integrates with access control; part of Open IP Alliance
Intelligent video tracking & surveillance	15 – Company	Video content analysis software that processes surveillance camera images to support identity tracking	3	2-5 years	$800-$1,000 per camera; $10,000 per server	Need $800K in additional funding; possible privacy protection issues	Interacts with multiple security-related technologies and systems
Wireless power	16 – Company	Wireless power through radio frequency energy harvesting, supporting sensing, and tracking devices	4	Short-term	$150- $200 per transmitter; $20 per receiving component	Need to be compliant with regulations and standards regarding power levels	Distributor used to bring technology into applications; training and supportability plans have been implemented
Wireless power	17 – Company	Uses advanced material science and software algorithms to identify, profile and adapt wireless power delivery to various loads and configurations	4-5	Short-term	Small per-unit cost when mass produced	Application-specific uses may require addition R&D; shielding may be required to prevent interference in certain radio bands	Primary market has been low power consumer electronics
Nanopiezoelectronics	18 – University	Enables tracking and communication devices to be powered without batteries by capturing energy created by the environment	1-2	2-5 years	Unit cost should be low, with quick payback time	Need $2-3M in additional funding; so far only 3-4 volts can be produced; system design needs to be made more robust	A very promising technology development that can produce electrical power from slight motions or vibration
Plastic thin-film organic solar cells	19 – Company	Converts light to DC power	4-5	Short-term	Dependent on application	Requires integration via adherence or lamination with other technologies; must have electrical connection	Basic product is in production
Plastic thin-film organic solar cells	20 – Company	Wireless power from organic solar cells to operate sensors, lights, and cameras	4	2-5 years	Not identified	Need at least $10M in additional funding	Product to be licensed to companies building devices requiring power
Plastic thin-film organic solar cells	21 – Company	Builds proof-of-concept organic solar cell devices and licenses product to volume manufacturers	3-4	2-5 years	Not identified	Learning curve associated with making cells larger and at volume; additional development capital needed; dependent on business partnerships	Materials used are generally standard and non-toxic
Container integrity	22 – Company	Self healing/sealing jacket that is resistant to impact, thereby keeping cargo from releasing from container	3	2-5 years	$100K-$500K, depending on the function	Need $2.5M–$5M for full-scale testing	Can embed tracking and monitoring devices; complementary with blast and fire mitigation technologies
Container integrity	23 – U.S. DOT Research Organization	Sandwich structure—load blunting and energy absorption	1	6-10 years	Not identified	Need funding; must meet weight and space requirements	Primarily intended for protecting railroad tank cars

Table 3-2. Evaluation results of technologies available in the short term.

Technology Area	Narrative No./ Organizational Type	Technology Function	Tech Dev Level	Market Availability	User Unit Cost	Impediment(s)	Comments
Networked RFID, ubiquitous sensors and cargo monitoring	1 – Company	Active RFID monitoring of cargo and fuel during transport using battery operated sensors	4-5	Short-term	Variable/not disclosed	None noted	Information transmitted to remote monitoring centers
Networked RFID, ubiquitous sensors and cargo monitoring	3 – Company	Security and remote monitoring systems utilizing RFID, intrusion detection, biometrics, and wireless sensor and actuator networks	4-5	Short-term	Products range from under $100 to thousands of dollars	None specifically noted	Products designed from silicon up to plastics, with industry proven wireless network protocol
Networked RFID, ubiquitous sensors and cargo monitoring	5 – National Laboratory	Monitor and track items in transportation and storage, using satellite and secure Internet to relay information	4	Short-term	Several thousand dollars for fixed system of one RFID reader and communication transponder; cost of $100-$200 per package tag	$500K to $1M would bring readiness to Level 5; also need large-scale industrial production of tags, readers, and other system components; training of personnel; and establishment of infrastructure	Primary market is shipments of sensitive nuclear materials
Pressure gauges & chemical detection sensors	6 – Company	Chemical and radiation detection; over 140 products with different attributes	4-5	Short-term	Variable acquisition cost; average payback of 3 months	Sensors have a finite life	Open platform for integration of third party sensors; target markets include industrial safety, civil defense, and petrochemicals
Pressure gauges & chemical detection sensors	10 – Company	Chemical and explosives detection using gas chromatograph	4	Short-term	Unit cost of $300 to obtain and under $100 to operate	Need $3M in additional funding	Primary target market is buildings with HVAC systems
Advanced locks & seals	13 – Company	Two-way wireless monitoring and control of battery operated sensors attached to cargo and assets	4-5	Short-term	Cost depends on application; payback expected in 3-6 months	No known impediment	Includes geofencing and alerts in the event of tampering
Intelligent video tracking & surveillance	14 – Company	Image capture and intelligent video analytics	4-5	Short-term	$100-$1,000	No known impediment	Integrates with access control; part of Open IP Alliance
Wireless power	16 – Company	Wireless power through radio frequency energy harvesting, supporting sensing, and tracking devices	4	Short-term	$150- $200 per transmitter; $20 per receiving component	Need to be compliant with regulations and standards regarding power levels	Distributor used to bring technology into applications; training and supportability plans have been implemented
Wireless power	17 – Company	Uses advanced material science and software algorithms to identify, profile, and adapt wireless power delivery to various loads and configurations	4-5	Short-term	Small per unit cost when mass produced	Application-specific uses may require addition R&D; shielding may be required to prevent interference in certain radio bands	Primary market has been low power consumer electronics
Plastic thin-film organic solar cells	19 – Company	Converts light to DC power	4-5	Short-term	Dependent on application	Requires integration via adherence/lamination with other technologies; must have electrical connection	Basic product is in production

Table 3-3. Evaluation results of technologies available in 2–5 years.

Technology Area	Narrative No./ Organizational Type	Technology Function	Tech Dev Level	Market Availability	User Unit Cost	Impediment(s)	Comments
Networked RFID, ubiquitous sensors and cargo monitoring	2 – National Laboratory	Systems featuring locators, tracking devices, and disclosure of information for first responders	3-5	2-5 years	Estimated to be a few thousand dollars	Requires a special technician to make repairs; systems must withstand harsh conditions associated with trailer use	Primary market is shippers requiring high security levels (e.g., radioactive cargo) during truck transport
Networked RFID, ubiquitous sensors and cargo monitoring	4 – National Laboratory	Infrastructure monitoring using passive, unpowered sensing technology	4	2-5 years	Passive system: \$0.05-\$0.10 per tag and \$2K per reader; active system: \$50-\$100 per tag	Finding development funding can be a constraint in customizing technology for new application, especially if no forcing function exists; desirable if power can be available to transmit information up to 100 meters	Eventually both development funds and technology advancement will provide a solution for using this type of product, operating within a wireless network
Advanced locks & seals	12 – National Laboratory	Secure Sensor Platform (SSP) with applications such as RMSA	4	2-5 years	Seals: \$500 in volume > 500 units; translator: \$6,000 if tamper-resistant, \$1,500-\$2,000 if not	Initial cost is high; need volumes to bring cost down. RFID may have some interference restrictions in some areas	Encryption makes seals highly resistant to intrusion that escapes detection. SSP design represents middle ground between passive tags and active seals
Intelligent video tracking & surveillance	15 – Company	Video content analysis software that processes surveillance camera images to support identity tracking	3	2-5 years	\$800-\$1,000 per camera; \$10,000 per server	need \$800K in additional funding; possible privacy protection issues	interacts with multiple security-related technologies and systems
Nanopiezoelectronics	18 – University	Enables tracking and communication devices to be powered without batteries by capturing energy created by the environment	1-2	2-5 years	Unit cost should be low, with quick payback time	Need \$2-3M in additional funding; so far only 3-4 volts can be produced; system design needs to be made more robust	A very promising technology development that can produce electrical power from slight motions or even vibration
Plastic thin-film organic solar cells	20 – Company	Wireless power from organic solar cells to operate sensors, lights, and cameras	4	2-5 years	Not identified	Need at least \$10M in additional funding	Product to be licensed to companies building devices requiring power
Plastic thin-film organic solar cells	21 – Company	Builds proof-of-concept organic solar cell devices and licenses product to volume manufacturers	3-4	2-5 years	Not identified	Learning curve associated with making cells larger and at volume; additional development capital needed; dependent on business partnerships	Materials used are generally standard and non-toxic
Container integrity	22 – Company	Self healing/sealing jacket that is resistant to impact, thereby keeping cargo from releasing from container	3	2-5 years	\$100K-\$500K, depending on the function	Need \$2.5M - \$5M for full-scale testing	Can embed tracking and monitoring devices; complementary with blast and fire mitigation technologies

Table 3-4. Evaluation results of technologies available in 6–10 years.

Technology Area	Narrative No./ Organizational Type	Technology Function	Tech Dev Level	Market Availability	User Unit Cost	Impediment(s)	Comments
Pressure gauges & chemical detection sensors	7 – Company	Indoor air monitoring	2	6-10 years	$80,000 acquisition cost	The technology will have to be designed to be interactive with communication devices	Can communicate via wireless; primary target market is buildings and homeland security
Pressure gauges & chemical detection sensors	8 – Company	Chemical, biological, and radiological threat detection using nanowire technology	2	6-10 years	Unit cost of $300 to wire and $100 to operate	Need $10M in additional funding	Interactive with communication and display devices; primary use is on shipping containers
Pressure gauges & chemical detection sensors	9 – Company	Explosives detection using color metric barcodes	2	6-10 years	Unit cost of $300 to obtain and under $100 to operate	Need $3M in additional funding	Product use will be limited to building infrastructure unless the technology can be integrated with other products in order to serve transport vehicles and sensitive cargo
Fiber-optic/photonic sensors & optical scanners	11 – Company	Sensors using fiber-optics	1-2	6-10 years for optical scanner and 2-5 years for some fiber-optic sensors	$25-$400 per sensor; $400-$2M per optical scanner, depending on the production scale	Need $900K in sensor development funds; need $4-6M in scanner development funds	Has promise for not only vehicle and cargo monitoring but also infrastructure monitoring
Container integrity	23 – U.S. DOT Research Organization	Sandwich structure—load blunting and energy absorption	1	6-10 years	Not identified	Need funding; must meet weight and space requirements	Primarily intended for protecting railroad tank cars

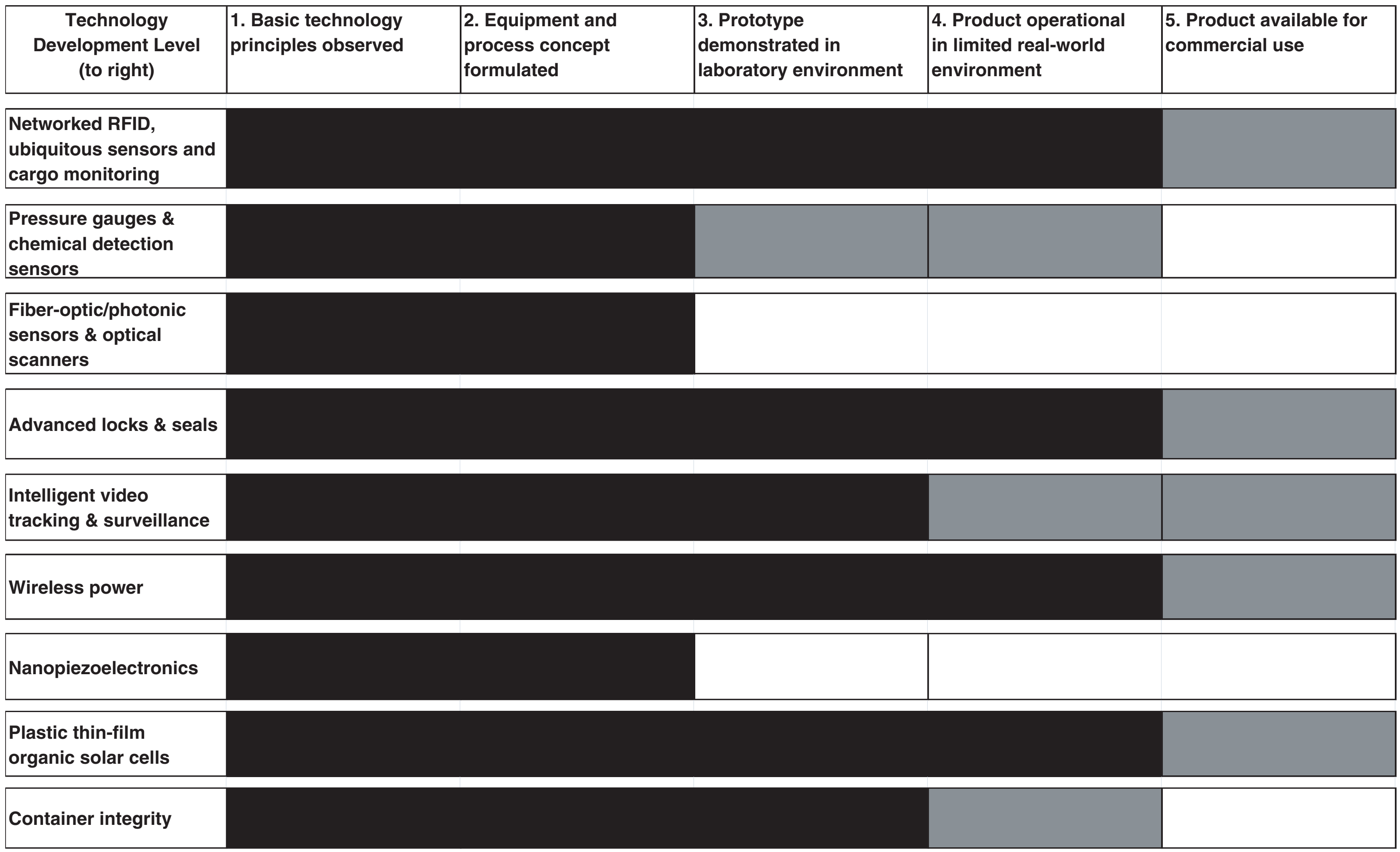


Figure 3-1. Development roadmap for the nine most promising emerging technologies.

CHAPTER 4

Conclusions and Recommendations

4.1 Conclusions

4.1.1 Context

Hazmat transportation stakeholders want to know more about which technologies are emerging, how these technologies can affect their interests, what they will be capable of doing, and when they will become available. Addressing those points has been the objective of this project.

To put this issue into the proper context, it is important to reflect on a statement noted in Section 2.2, "Currently, implementation of technologies within the supply chain is predominantly based on the expectation of return on investment (ROI) within a supply chain context. In the for-profit sector, if a technology will not increase efficiencies, reduce costs, or provide a competitive advantage, generally it is not voluntarily implemented." As a result, a primary factor influencing technology deployment is the need for a demonstrated business case for the Hazmat transportation industry to invest more in technologies that enhance safety and security. These opportunities generally seem to arise when a business case can be made for technology deployment that is based on cost savings, yet safety and security benefits accrue as well. An example of this relationship is recent research that indicates the emerging use of sensors may provide major benefits to transportation efficiency (*1*); use of sensors clearly offers safety and security benefits as well.

Safety and security considerations may become a more prominent driver when motivated by rulemaking or voluntary efforts in response to other circumstances. One of the technology developers noted that "There is always an unwillingness to adopt new technologies without some forcing function . . . often a regulation or requirement."

4.1.2 Research Process

The research involved examining more than 1,000 leads on developing technologies. It included contacts with sources outside the United States and investigation of technologies that are primarily not associated with transportation. It captured the perspectives of a wide range of Hazmat transportation and technology subject matter experts, including representatives of regulatory and compliance organizations, security agencies, academics, national laboratories, research consulting organizations, carriers, manufacturers, shippers, environmental protection agencies, emergency responders, and technology providers.

Once this information was compiled, a multi-step methodology was implemented that resulted in screening and down-selecting from a large number of potential technologies to a smaller number of candidates to the few most promising. The methodology was based on assessment of functional requirements and application of a gap analysis. Initial results were presented to the HMCRP Project 04 panel and also received a peer review. A few modifications were made to the candidate list, resulting in selection of the nine most promising emerging technology areas. The team identified and interviewed technology developers to obtain a more in-depth understanding of each of the areas.

The result of this engagement was summarized in a series of narratives and comprehensive tables that captured the characteristics, relevance, status, and outlook for maturity of technology area products in both the near and far terms. A graphic roadmap was prepared, showing the comparative progress of product development in each technology area. Collectively, it is intended for this material to help transportation professionals and other stakeholders, who are users of technologies, gain a better understanding of the most promising emerging technologies that could enhance the safety and security of Hazmat transportation. This knowledge can help these stakeholders make more informed decisions about technology investments.

4.1.3 Lessons Learned

4.1.3.1 Research Approach

The team made certain assumptions to help formulate a systematic methodological approach. This process produced a logical framework with which to screen and select the most promising emerging technologies. The framework was also somewhat "modular" in that if a certain criterion in the selection process was found to have received more or less emphasis than it should have in light of more recent findings, the new information could be incorporated. A case in point was where it was discovered that one of the technologies selected had substantially passed into the product stage, while a peer review and other evidence suggested that another group of technologies had more compelling traits than originally recognized.

The methodology developed to identify a small number of emerging technology areas proved to be effective in screening a large number of technologies and selecting the most promising from the many that were considered. The process encompassed factors such as multiple transportation modes; differing needs such as protection, detection, and mitigation; and a technology's ability to benefit safety or security or both as well as other operational factors.

It was not difficult to identify developers of the technology areas selected in this research, but it was challenging to obtain interviews with many of them. While some developers talked freely of their plans and progress, others were more guarded, especially in terms of capital investments made or needed. Many conveyed the sense that the timing of the developing product's arrival in the marketplace was dependent on investments as well as technology breakthroughs, such as with larger-scale manufacturing.

Some of the caveats to the technology developer interview process (outlined in Section 3.2) also represent lessons learned. For example, within a technology area with multiple developing products, the level of readiness and maturity of individual technology products can and does vary.

4.1.3.2 Technology Overlap

There is clearly some overlap between capabilities of certain technology areas. Photonic technology underlies plastic thin-film organic solar cells as well as photonic/fiber-optic sensors. Advanced seals and locks may use RFID to communicate a non-standard condition, and RFID systems may communicate with each other in sensor networking. Fiber-optics is used as a sensor to detect chemicals in one technology area and as a seal in another. Nanowire technology is used to detect chemical, biological, and radiological threats as well as being an underlying technology of nanopiezoelectronics.

4.1.3.3 Far Horizon

No developing technologies were identified that appear to be maturing in the 11–15 year horizon. This perhaps indicates the motivation that developmental organizations, especially companies, have to bring technologies to maturity in a timely manner. It could also indicate that in today's world of rapid technology change, planning too far in the future may simply be too risky. Many modern technologies were not planned 11–15 years in advance and external risks abound, including being overtaken by more agile competitors.

4.1.3.4 Technology Interaction

The interaction of the most promising emerging technologies with other technologies is markedly positive. The alternative power generation technology group is the most prominent example, because it involves working with other technologies and may even be the reason those technologies can be used for certain applications. The representative technologies of wireless power, nanopiezoelectronics and plastic thin-film solar cells will be able to supply power to sensors, communications, and other devices. That supply promises to enable electronic devices for safety and security to exist in places and under conditions that would not have been feasible before. Working in conjunction with ongoing miniaturization developments (e.g., MEMS/NEMS), alternative power generation can make possible more remote monitoring, whether on non-powered vehicles such as railcars and barges, or with infrastructure such as pipelines. Batteries can be smaller and their replacement much less frequent or even unnecessary.

One of the advanced locks and seals technologies is the best illustration of the flexibility of systems to work together. Its secure platform concept provides for integration of sensors such as magnetic, glass break, passive IR, IR breakbeam, balance magnetic switch, fiber-optic receiver, fiber-optic loop, vibration, and microwave, with a communications protocol that can support hardwire and RF.

The only potentially negative interaction among the technologies that came to the team's attention is with RFID. A variety of RFID technologies are available, differing in the frequencies at which they operate and the type of tag which is queried. These characteristics, in turn, affect power requirements, read range, and suitability for various environments. Because RFID systems operate in shared frequency bands, they are susceptible to interference generated by other wireless systems. Most systems operate at one of the following frequencies: 125 kHz (LF), 13.56 MHz (HF), 900 MHz (UHF), or 2.4 GHz. Active tags contain a power source (e.g., battery) and permit higher read ranges and lower reader power. Passive tags, on the other hand, draw power from the incident electromagnetic waves of the reader and consequently are lower in cost. RFID systems operating at 900 MHz UHF with passive tags are commonly used (*43*). Use of RFID devices can be limited in some types of facilities such as nuclear plants.

Plastic thin-film organic solar cells need to be adhered or laminated to other technologies, so development efforts are required in most cases to incorporate the product into other technologies. Also, the product must have an electrical connection which may require development efforts depending on the application. These are not impediments to reaching the marketplace, but rather an additional step in commercializing the product.

4.1.4 Where and How Could the Most Promising Emerging Technologies in the Monitoring and Surveillance Group Be Used?

Some sensors such as RFID can be networked; active RFID chips enable networking because they have two-way communications capability. The concept of ubiquitous sensors is that of a networked system in which sensors in proximity can transmit information about their environment to one another. Ubiquitous RFID would involve the combination of tags, readers, communications, and processing capability. Mesh networking is a type of local area network (LAN) that allows information to be independently routed to reach a destination.

In an example of a system with **networked RFID, ubiquitous sensors and cargo monitoring,** a truck with Hazmat cargo could have the condition of its cargo (perhaps even its bill of lading information) remotely and automatically monitored when it passes by a roadside transponder. An out-of-normal condition detected with the Hazmat cargo would generate an alert. Mesh networking with ubiquitous sensing could allow an abnormal condition with cargo on a certain truck to be detected and reported by other trucks at a rest area. Mesh networking with ubiquitous sensing offers advantages in reliability and redundancy but at greater cost. There are also privacy issues; the transportation industry tends to closely hold proprietary information such as customer bases.

RFID has limited range. The railroads' Automatic Equipment Identification (AEI) system reads RFID tags on virtually every railcar and locomotive from a few feet away to provide Car Location Messaging (CLM) data. In other applications, RFID tags can use battery power to boost read ranges out to 100 meters and beyond. For long-range communication of information detected by RFID, information is usually reported via the terrestrial or satellite communications associated with GPS/GLS systems on trucks, railcars, or barges.

Pressure gauges and chemical detection sensors are increasingly able to detect leaks of specific transported Hazmat such as chlorine as well as out-of-normal temperature and pressure readings that can signify problems for many types of cargo. In the future, these sensors will be able to determine chemical composition of Hazmat, chemical agents, and even biological agents. This category of sensors can be used with any of the transportation modes, whether for tanks, casks, smaller containers, or pipelines. Recently, it was announced that a port city in the northeastern United States plans to install a new chemical detection sensor system to enhance safety in the area by alerting emergency responders to and providing critical information on chemicals detected. This system is intended to be integrated with a Port Area Waterside Video Surveillance System (PAWVSS) that provides live camera feeds from a large, well-known bay leading to the port (*44*).

One concern with this technology area is false positive readings, which are often a problem with any new sensing technology. For example, if a sensor on a TIH railcar falsely reports a leak or other dangerous condition, the financial cost of stopping the train with all its in-transit cargo to check the problem can be substantial. Depending on the train's location, it could even prompt an unnecessary evacuation. Advances are moving this technology area toward better performance.

Fiber-optic/photonic sensors and optical scanners have a range of capabilities and promise for not only vehicle and cargo monitoring, but also infrastructure, such as identifying the type and concentration of toxic gas in a tunnel or the degree of movement of bridge support structures. Fiber-optic sensors and the more expensive optical scanners can read a variety of conditions. Fiber-optic line is recognized for the quantity and quality of data transmitted, and fiber-optic sensors can also work with wireless transmission. These have particular value in tunnels where neither satellite nor terrestrial communications associated with GPL/GLS may work. This technology area shares the same concern with false positive readings as noted in the pressure gauges and chemical detection sensors technology area.

Advanced locks and seals are examples of some of the most flexible integration of different technologies found in the research. A wide range of technologies can work together to provide automated monitoring and alerting for high value cargo, which may be passing through remote sites. Implementation of the most advanced systems in this technology area, used for nuclear material management, is currently expensive although less expensive components can sometimes suffice. However, the concept has promise for offering some of the most secure access protection using sophisticated encryption techniques with low life cycle cost sealing materials.

Intelligent video tracking and surveillance builds on the proliferation of CCTV and other cameras. The development is not so much in the cameras as in the software that can work with legacy cameras to detect objects left on a scene or removed, detect certain behaviors, and track people or vehicles. The technology can be used for any mode in which security and access control are needed. In a more advanced version, cameras along highways or Interstates in a HTUA could track a Hazmat vehicle of interest; for example, its image could be handed off from camera to camera as it moves along a beltway equipped with traffic cameras. The PAWVSS mentioned in the pressure gauges and chemical detection sensors technology area would appear to be a candidate for a potential maritime implementation. Privacy issues are always present when people's images are captured and biometric techniques are used to do more than verify identity. However, security concerns since 9/11 have brought about the proliferation of video systems, and their uses are being expanded through this type of technology advance.

4.1.5 Where and How Could the Most Promising Emerging Technologies in the Alternative Power Generation Group Be Used?

Of the three different approaches to alternative power generation, **wireless power** is perhaps closest to the marketplace, with products capable of maturing in the next 2 years. Unlike the other two alternative power source technologies, wireless power does not create electricity but rather receives it from another source where it is needed. This can be a considerable advantage for powering sensors, communications, and other devices applicable to Hazmat transportation. One of its other advantages is the ability to design out power cords and cable runs.

The question about how soon it can play a major role appears to be determined by the power requirements, efficiency of transmission, and regulations concerning power outputs. Products are already on the market to wirelessly charge cell phones and laptops; the day may soon be approaching when a traveler may not have to bring power cords, batteries, or chargers on a trip. In terms of Hazmat transportation, distance is a concern for this technology type. That can be overcome by techniques such as the conceptual capability to have a receiving device relay power. In this concept, power could be "daisy chained" from a locomotive along a series of Hazmat railcars to operate GPS/GLS devices with terrestrial or satellite communication, integrated with sensors such as hatch open or chemical leak detectors.

Plastic thin-film organic solar cells may be equally close to the marketplace in terms of power levels likely to be useful (some have already reached product status but most are 2–5 years out). Their form-factor is a real positive, as their great flexibility allows them to be used on curved or angled surfaces, and their relative transparency allows them to be applied to vehicle surfaces or even windows. Conceptually, it might be possible to have a vehicle's painted surfaces coated with a transparent, organic thin-film solar cell to generate additional power. The challenge appears to be mainly the matter of continuing development to make cells larger and at volume. Solar cell manufacturers must work with device manufacturers to ensure that the solar cell design provides an appropriate power supply matched to the device needs and a battery or capacitor for holding the charge during periods when there is no light. Plastic thin-film organic solar cells could play a significant role within 2–5 years, powering sensors, communications, or other devices on stand-alone vehicles (e.g., railcars or untethered trailers) or pipelines in remote locations that are hard to monitor. The ability to provide capability for safety and security without having to change batteries is significant, and these devices are made of common, non-toxic materials.

Nanopiezoelectronics will take longer to reach the marketplace. Whereas solar cells depend on the sun for power generation, nanopiezoelectronics technology generates power from motion such as bending wires. This technology is gradually developing to the point at which power levels will be sufficient for practical use. So far this power has been able to light an LED. It is at an earlier stage of development than the other alternative power generating technologies, but its progress is rapid and products based on this technology are likely to be very affordable.

4.1.6 Where and How Could the Most Promising Emerging Technologies in the Infrastructure Group Be Used?

The two technologies researched, **self-sealing materials** and **sandwich structures,** are representative developments but by no means the only designs being considered for improved container integrity. The greatest concern driving these designs is the release of bulk TIH from rail tank cars. The chemical and rail industries working together have been leading the way in this area, and research by U.S. DOT and others is continuing. As a hallmark of the perceived importance of this area, millions of dollars are expected to be invested over the next few years directed at strengthening containers. These are primarily large tanks such as on railcars, but the same designs can benefit smaller containers and even pipeline design to an extent. For containers on vehicles, one concern in the tradeoffs involved in stronger designs is additional weight (as well as size) that not only reduces fuel efficiency, but must also be considered for its effect on railway and roadway design limits.

4.2 Recommendations

The team examined all the information gathered during the project to determine how the findings would have greatest benefits to the Hazmat transportation community. The resulting observations and recommendations are made both on a technical and a temporal basis and with regard to what is known of funding needs and availability. Table 4-1 shows the relative maturity comparisons of technologies for which interviews were conducted by technology areas and maturity timeframes.

Table 4-1. Technology maturity comparison.

	Short Term	2-5 Years	6-10 Years	Category Totals
Networked RFID, ubiquitous sensors and cargo monitoring	3	2		5
Pressure gauges and chemical detection sensors	2		3	5
Fiber-optic/photonic sensors and optical scanners			1	1
Advanced locks and seals	1	1		2
Intelligent video tracking and surveillance	1	1		2
Wireless power	2			2
Nanopiezoelectronics		1		1
Plastic thin-film organic solar cells	1	2		3
Container integrity	1		1	2
Numbers of technology interviews	**11**	**7**	**5**	**23**

4.2.1 Technologies on the Verge of the Marketplace

Most (7 of 9) of the technology areas, representing 11 of 23 developing technology interviews, have one or more products expected to reach the marketplace in the short term (i.e., less than 2 years). These include the following technology areas:

- Networked RFID, ubiquitous sensors and cargo monitoring
- Pressure gauges and chemical detection sensors
- Advanced locks and seals
- Intelligent video tracking and surveillance
- Wireless power
- Plastic thin-film organic solar cells
- Container integrity

These technology products have momentum and appear to be getting the level of private investment or public sector funding that they need to continue moving forward. Four of these seven technology areas maturing in the short term also have products maturing in the 2–5 year timeframe. One of these seven technology areas (wireless power) has products maturing only in the short term.

4.2.2 Technologies Recommended for Operational Test When Ready

A lower number (5 of 9) of the technology areas, representing 7 of 23 developing technology interviews, have one or more products expected to reach the marketplace within 2–5 years. This includes the following technology areas:

- Networked RFID, ubiquitous sensors and cargo monitoring
- Advanced locks and seals
- Intelligent video tracking and surveillance
- Nanopiezoelectronics
- Plastic thin-film organic solar cells

Four of these five technology areas have other products that are expected to enter the marketplace in the short term, which is an indication that the products emerging in the 2–5 year timeframe would also have some developmental momentum. The one remaining technology area (nanopiezoelectronics) only has a product maturing in the 2–5 year timeframe.

The lowest number of the technology areas, representing 3 of 9 developing technology interviews, has one or more products maturing in the 6–10 year timeframe. Two of the three technology areas have products maturing in the short term, which suggests a technology gap within a similar area that has to be bridged in one case (the pressure gauges and chemical detection sensors technology area), and the variety of different solutions to strengthening tanks in the other (container integrity technology area). One technology area (fiber-optic/photonic sensors and optical scanners) only has a product maturing in the 6–10 year timeframe, which seems to correlate to the products with similar technology in the pressure gauges and chemical detection sensors technology area that are maturing in the 6–10 year timeframe.

4.2.3 Technologies Recommended for Assistance

One of the technologies cross-cutting in its usefulness is chemical detection sensors. These devices can be used to monitor leaks or releases in tanks and pipelines as well as conditions at critical fixed locations. They can provide not only detection and alerting, but can also measure concentrations. The most sophisticated—and thus the most challenging to develop—are those that can sample the environment and determine what substance of concern is present and in what concentration. Those sensors can be very useful for monitoring key infrastructure such as tunnels or strategic chokepoints. Where possible, their portability will greatly assist emergency responders.

The technical challenges in creating advanced chemical detection sensor and analysis systems that are accurate, rugged, affordable, and with a low false alarm rate are considerable. This technology capability is represented by the **pressure gauges and chemical detection sensors** and **fiber-optic/photonic sensors and optical scanners.** Two developing chemical detection systems from the pressure gauges and chemical detection sensors technology area are identified as Level 4-5 and projected to mature in the short term. Three of the pressure gauges and chemical detection sensors technologies—involving nanowire technology, color metric barcodes, and gas chromatography—are at Level 2 and projected to mature in the 6–10 year timeframe. The sole representative of the fiber-optic/photonic sensors and optical scanners technology area is identified as Level 1–2 and projected to mature in the 6–10 year timeframe. These related products maturing in the 6–10 year timeframe in both technology areas are perceived to be more advanced and sophisticated developments involving higher development risk. The ability for the output of these sensing and analysis systems to be transmitted by both wireless and wired/fiber-optic means is evident from the associated systems discussed in this report. On balance, the payoff for realizing the great potential from this technology area makes it a candidate for assistance.

Nanopiezoelectronics is another technology at an early development stage (Level 1–2), but which is believed capable of transitioning to adoption relatively quickly (2–5 years) given adequate funding. It is important for developers to continue increasing the amount of power that can be generated through this means. The ability to generate power from small motions, even flow turbulence, should make this a valuable cross-cutting technology for the future for all modes in conjunction with miniaturization trends.

4.2.4 Technologies to Monitor for Progress

One **container integrity** technology—the sandwich structure—is projected to mature in the 6–10 year timeframe. It appears to have usefulness beyond Hazmat transportation, including military applications. Because of its relatively long development cycle, and in view of other related container strengthening initiatives underway, it is a technology to monitor.

4.2.5 Use of This Report

The size of any investment in leading-edge technologies can be quite large and the ROI cannot be assured. With the knowledge gained from the conduct of this project, the HMCRP and its stakeholders will gain knowledge of which technologies can be expected to have the greatest impact or promise when applied to Hazmat transportation safety and security.

Consequently, the HMCRP will be able to share information from the project's findings that will help both the public and private sectors make informed decisions about emerging technologies that they may wish to deploy. The findings will help them better understand how technologies can be made to work together effectively, as well as how technology gaps can keep systems from performing at a higher level. Moreover, it is conceivable that the information from the project could help accelerate development of certain technologies if the common interest among groups is recognized.

Perhaps, one of the best ways to determine the success of this project is to measure the number of government transportation officials, shippers and carriers, emergency responders, and other stakeholders seeking the results of this study. A secondary means is to gauge the number of organizations that access and subsequently use the project's findings to inform their plans to incorporate technologies for Hazmat transportation safety and security. Whether these data are captured through uploaded "success stories" or some other means is beyond the scope of this project.

Making determinations about the maturity timelines and usefulness of technologies that are in development is not an exact science. Therefore, going forward, it is recommended that a program of retrospective case studies be undertaken to examine success or failure of new technologies as applied to Hazmat transportation safety and security.

APPENDIX A

Acronyms

AA&E	Arms, Ammunition, and Explosives
AAR	Association of American Railroads
ACC	Adaptive Cruise Control or American Chemistry Council
ACE	Automated Cargo Environment
AEI	Automatic Equipment Identification
AES	Advanced Encryption Standard
AGPS	Assisted Global Positioning System
AIS	Automatic Identification System
ALPA	Air Line Pilots Association, International
ANGEL	Airborne Natural Gas Emission LIDAR
APA	Airline Pilots Association
API RP	American Petroleum Institute Recommended Practice
ATRI	American Transportation Research Institute
ATSI	Advanced Technology Safety Initiative
AVI	Automatic Vehicle Identification
BCA	Benefit-Cost Analysis
BOL	Bill of Lading
CAPEX	Capital Expenditures(s)
CBP	U.S. Customs and Border Protection
CBRN	Chemical, Biological, Radiological, and Nuclear
CCTV	Closed-Circuit Television
CDC	Certain Dangerous Cargo
CDL	Commercial Drivers License
CFATS	Chemical Facility Anti-Terrorism Standards
CFR	Code of Federal Regulations
CFS	Commodity Flow Survey
CHEMTREC	Chemical Transportation Emergency Center
CLM	(Rail) Car Location Messaging
COTS	Commercial-off-the-Shelf
CPM	Computational Pipeline Monitoring
CVSA	Commercial Vehicle Safety Alliance
DC	Direct Current
DGPS	Differential Global Positioning System
DHS	Department of Homeland Security
DIOD	Differential Impedance Obstacle Detection
DOD	U.S. Department of Defense
DOE	U.S. Department of Energy

DSRC	Distributed Short Range Communications
DTTS	Defense Transportation Tracking System
ECM	Engine Control Module
ECP	Electronically Controlled Pneumatic (train brakes)
EDI	Electronic Data Interchange
EGPS	Enhanced Global Positioning System
EHC	Especially Hazardous Cargo
EMS	Energy Management System
EPA	Environmental Protection Agency
ERA	European Research Area
EV	Electric Vehicle
FAA	Federal Aviation Administration
FCC	Federal Communications Commission
FEMA	Federal Emergency Management Agency
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FRSGP	Freight Rail Security Grant Program
GCOR	General Code of Operating Rules
GHG	Greenhouse Gas
GHz	Gigahertz
GIS	Geographic Information System
GLS	Global Locating System
GPR	Ground Penetrating Radar
GPRS	General Packet Radio Service
GPS	Global Positioning System
GSM	Global System for Mobile Communications
GSM-R	Global System for Mobile Communications-Railway
Hazmat	Hazardous Materials
HF	High Frequency
HM-ACCESS	Hazardous Materials-Automated Cargo Communications for Efficient and Safe Shipments
HMCRP	Hazardous Materials Cooperative Research Program
HRCQ	Highway Route Controlled Quantities
HSSM	Highway Security-Sensitive Materials
HTUA	High-Threat Urban Area
HVAC	Heating, Ventilation, and Air Conditioning
IAEA	International Atomic Energy Agency
IAPA	International Airline Pilots Association
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
ID	Identification or Identification Number
IED	Improvised Explosive Device
IEEE	Institute for Electrical and Electronic Engineering
IFF	Identification Friend or Foe
InteRRIS®	Integrated Railway Remote Information Service
IR	Infrared
IRRIS	Intelligent Road/Rail Information Service
ISIS	Integrated Surveillance Intelligent Systems
ISD	Inherently Safer Design
IST	Inherently Safer Technologies
IT	Information Technology
ITS	Intelligent Transportation Systems

KTC	Kentucky Transportation Center
LAN	Local Area Network
LED	Light-Emitting Diode
LF	Low Frequency
LIDAR	Light Detection and Ranging
LLIS	Lessons Learned Information Sharing
LORAN	Long-Range Navigation
LRIT	Long-Range Identification and Tracking
LTL	Less-than-Truckload
MEMS	Microelectromechanical Systems
MHz	Megahertz
MIRA	Motor Vehicle Research Association
MIT	Massachusetts Institute of Technology
NAIS	Nationwide Automatic Identification System
NARMO	North American Rail Mechanical Operations
NASA	National Aeronautics and Space Administration
NDGPS	Nationwide Differential Global Positioning System
NEMS	Nanoelectromechanical Systems
NFPA	National Fire Protection Association
NGRTC	Next Generation Railroad Tank Car (Program)
NIHS	National Institute of Hometown Security
NIST	National Institute of Standards and Technology
NNSA	National Nuclear Security Administration
NOAA	National Oceanic and Atmospheric Administration
NORAC	Northeast Operating Rules Advisory Committee
NOW	Network Operating Workstation
NRC	National Response Center or Nuclear Regulatory Commission
NTIS	National Technical Information Service
NTSB	National Transportation Safety Board
OFM	Operator Fatigue Management
OMB	Office of Management and Budget
OPEX	Operating Expenditure(s)
OPS	Office of Pipeline Safety (U.S. DOT)
OREIS	Operation Respond Emergency Information System
OSM	Other Sensitive Material
PAWVSS	Port Area Waterside Video Surveillance System
PHMSA	Pipeline and Hazardous Materials Safety Administration
PIG	Pipeline Inspection Gauge
PIH	Poison Inhalation Hazard
PSAP	Public Safety Answering Point
PSI	Pounds per Square Inch
PTC	Positive Train Control
R&D	Research & Development
RF	Radio Frequency
RFID	Radio Frequency Identification
RMSA	Remotely Monitored Sealing Array
ROI	Return on Investment
RSIA	Rail Safety Improvement Act
RSSI	Received Signal Strength Indication
RVSS	Remote Video Surveillance Systems
RWIS	Road Weather Information System
SAI	Security Action Item(s)

SCADA	Supervisory Control and Data Acquisition
SCC	Stress Corrosion Cracking
SME	Subject Matter Expert
SOLAS	International Convention for the Safety of Life at Sea
SoOP	Signals of Opportunity
SSP	Secure Sensor Platform
TAD	Trackside Acoustic Detector
TIH	Toxic Inhalation Hazard
TPD	Truck Performance Detector
TRANSCOM	U.S. Transportation Command
TRB	Transportation Research Board
TRIS	Transportation Research Information Services
TRKC	Transport Research Knowledge Centre
TRL	Technology Readiness Level
TSA	Transportation Security Administration
TSNM	TSA Transportation Sector Network Management
TTCI	Transportation Technology Center, Inc.
TWIC	Transportation Worker Identification Credential
UAV	Unmanned Aerial Vehicle
UCI	Universal Communication Interface
UHF	Ultra High Frequency
UL	Underwriters Laboratories
UN	United Nations
U.S. DOT	United States Department of Transportation
VDT	Vehicle Disabling Technology
VHF	Very High Frequency
VIDS	Visual Identification System
VST	Vehicle Shutdown Technology
WAN	Wide-Area Network
WAVE	Wireless Access in Vehicular Environment
WILD	Wheel Impact Load Detector
WMD	Weapon of Mass Destruction
XML	Extended Markup Language

APPENDIX B

Initial Research Interview Summary and Guideline

Overview

A total of 34 interviews were conducted, involving 49 interviewees representing 24 types of organizations such as regulators, security agencies, academics, national laboratories, research consulting organizations, carriers, manufacturers, shippers, technology providers, environmental protection agencies, and emergency responders. Interview responses are displayed by organizational type grouping in Table B-1.

The Interview Guide used by the team is provided in this appendix. In the interview summaries that follow the Interview Guide, some of the thoughts captured have been paraphrased or structured in a way that is meant to best convey the perceived point of the interviewee. It should be noted that the interview record does not preclude the possibility that an interviewee's message was not recorded exactly as intended, that some point significant to the interviewee may not have been captured, or that references to time (i.e., something current) are necessarily still valid. For the purpose of maintaining anonymity, certain responses such as organizational identity may have been intentionally recorded in more generic terms than information provided by the respondent.

In addition to needs and potential solutions tied to emerging technologies, responses include information on prior technology initiatives as well as the status quo (i.e., current state-of-the-art technology in use for Hazmat safety and security). While this information is not about emerging technologies per se, these responses provide perspective. When respondents provided other references, these were appreciated but have not been included in the following record unless there was a particular perspective that needed to be captured by the reference. Finally, not all respondents addressed emerging technologies to a degree sufficient for their remarks to be included.

Interview Guideline for Emerging Technologies Applicable to Safe and Secure Hazmat Transportation HMCRP Project 04

Purpose:

This guideline is to verify the lists of functional requirements and the gaps in them that have been developed by the Emerging Technologies team. It is for understanding the users' viewpoints on the technologies available to fill the gaps and their perceptions of obstacles to wider deployment. The information from this interview supports Tasks 1 and 2 of the HMCRP Project 04. This discussion may yield information on existing plans to develop or deploy technologies, but that is not its primary purpose as that activity is for Task 4.

Intended respondents:

This guideline is for interviewing those who experience the functional requirements and could directly benefit from filling the gaps. It is for those who deal with the Hazmat itself on a regular basis—shippers, carriers, consignees, and emergency responders—either in their individual companies or through their trade associations. It is also for government officials who have a perspective on the needs of the systems they regulate. This guideline is not optimized for interviewing vendors or manufacturers of products that implement the technologies.

Format:

Regular type: instructions to the interviewer
Bold type: words or suggestions for the interviewer to say
HEADINGS: broad topics of the conversation

Introduction

Thank the respondent for taking time to meet with you.

Table B-1. Characterization of interview respondents.

Type of Organization	Total Number of Organizations	Total Number of Respondents
Marine Shipper	1	1
Level 1 First Responder Organization*	4	4
Level 2 First Responder Organization*	5	5
First Responder Training Organization	1	2
Academic	3	3
Government Security Agency	1	4
Emergency Responder Association	1	1
Motor Carrier Association	2	4
Chemical Manufacturer Association	1	1
Supply Chain Tracking Technology Provider	1	2
Class I Railroad	1	2
Environmental Protection Agency (state)	1	2
Air Carrier Association	1	2
Environmental Remediation Company	1	1
Modal Regulatory Agency	1	2
Motor Carrier – Truckload	1	2
Motor Carrier – Specialized	1	3
Emergency Response Technology Provider	1	1
National Laboratory	1	2
Rail Tank Car Technology Provider	1	1
Multi-Modal Regulatory Agency	1	1
University Technology Developer	1	1
Chemical Manufacturer/Shipper	1	1
Railroad Trade Association	1	1
Total 24 Types	**34 Organizations**	**49 Respondents**

*These descriptions were taken from the five levels recognized by the National Fire Protection Association (NFPA) Publication 472: Standard for Competence of Responders to Hazardous Materials/Weapons of Mass Destruction Incidents.

Explain the purpose of the project

- Identify needs in the safe and secure transportation of hazardous materials
- Identify emerging technologies that can meet those needs.

Assure the respondent that they will not be identified by name or affiliation. They will be identified as "a manager at a major railroad" or "a shipper of corrosives."

For those in industry: **Please speak for the entire industry, not for your own company. We are looking for common problems faced by everybody, and not for any private details of your own operation.**

For those in government: **Please tell us your thoughts from your own perspective. I want you to be free to say what's on your mind without worrying if you are misrepresenting agency positions. If you want to tell me official agency policy, that's OK, but I will report your words as official policy only if you specifically identify it as such.**

Do, however, be sure you have the complete identity, affiliation, and contact information for the person with whom you are speaking.

Needs

We'll talk about the needs first and then get to your perspectives on new technologies.

Begin with an open-ended question: **What phone call at 3 o'clock in the morning do you dread the most? What do you see are the biggest needs in transporting Hazmat safely and securely?**

If the interviewee begins with safety, make sure you turn the conversation to security before leaving the topic of needs. Keep a list of the needs that are mentioned.

Refer to the project's Functional Requirements for the mode at hand. If there are any requirements that have not been mentioned, ask "**How important is it to ___________?**" The answer will likely fall in one of three forms:

1. No, it's not really a big need. If so, leave that topic.
2. Yes, it's a need, but it's being met. If so, ask how it's being met or if there's room for improvement.
3. Yes, I forgot to mention it. If so, have the respondent elaborate on the gaps if necessary.

Technologies

When you have a complete list of needs, go back through and ask what technologies the respondent is aware of to meet those needs. For each technology (and there may be more than one per need), ask "**What are the shortcomings in capability, what are the obstacles to adoption?**" A technology might be a specific product on the market, it might be a research project they have vaguely heard about, or it might be just a wish, "somebody ought to invent _______." Can the respondent name any specific products they use?

And then ask if they are familiar with the technologies (people in operations will probably know the products more than the technologies) on our list. Ask what are the capabilities and shortcomings of those technologies. What are the barriers to wider adoption of the technologies? Without leading the respondent, try to find out whether the barriers are technical (e.g., technology is unproven, technology still leaves an unacceptable gap, technology needs another supporting technology) or economic (e.g., product is too expensive, risk of a loss is too remote). (This question is more for Task 4 than for Task 1, but it is beneficial to ask for the users' perspective as well as the suppliers'). **Can you think of any examples in recent history of well-executed deployment of new technology?** Ask how it came quickly and rapidly gained acceptance and provided its intended benefit. **Can you think of any examples of poorly introduced or marketed technologies? What went right? What went wrong?**

Date of Interview:
Name and Organization of Interviewer(s):
Name of Interviewee(s):
Title or Position and Organization:
Other Hazmat Affiliation(s):
Contact Information
 Phone number:
 E-mail address:
 Address:
Place of Interview (or teleconference):
Specialty:
Biggest Concern with Hazmat:
Need(s) and Gaps Identified:
Emergency Technologies Identified:
Forecasts:
Obstacles:
Referrals:
Other Remarks:

APPENDIX C

Summary of Key Results from Initial Research Interviews

Marine Carrier

A major improvement in navigation technology has been the advent of the Automatic Identification System (AIS). This system provides a means for boats to electronically exchange vessel identification, position, course, and speed with other nearby ships and Vessel Traffic Services (VTS) stations. AIS is now operational in major maritime traffic areas and is a required installation on vessels moving through these areas.

AIS information is integrated into electronic navigation system software provided to the industry by commercial vendors. AIS and other geographic information can be overlaid on GIS-based navigation charts to provide both a visual reference and to support calculations indicating the proximity of oncoming hazards. The ability to send and receive safety related messages are also supported.

Examples of integrated electronic navigation system functionality include

Collision avoidance functionality that shows both the closest point of approach and provides a prediction of where and when the vessel will make contact. Customized alarms can be set accordingly.

Use of GPS to set up "virtual buoys," a form of geofencing that triggers alarms if vessels deviate from these areas. An important application is avoidance of what have been historically high grounding areas.

A recent technology development is the ability to predict outdraft (cross-current), which can be a serious navigational problem around locks, bridges, and other major structures. Sensors submerged at these locations determine the direction and velocity of the outdraft, and the information is transmitted to the AIS for dissemination.

To deal with allisions (vessels striking stationary objects rather than other moving vessels), the U.S. Army Corps of Engineers and the U.S. Coast Guard have established standards at bridges and locks to assist with safe vessel maneuverability. A technology being adopted by the industry is the ability to read a signal emitted at these locations which will enable a boat to determine its distance from the structure in question.

From an institutional standpoint, mariners have had a high acceptance of and reliance on these new technologies, particularly compared with 3 to 4 years ago. It has reached a point where mariners are reluctant to navigate without having access to electronic information.

Boat pilots have an opportunity to train on simulators owned and operators by Seaman's Church Organization. Seaman's has four simulated wheelhouses, each of which contains a representation of the entire bridge of the boat. The simulator provides a 180 degree visual and contains a full set of controls. A wide range of scenarios that a vessel operator is likely to encounter on the waterways can be simulated.

By September 2008, all mariners and support personnel were required to have a Transportation Worker Identification Credential (TWIC). The TWIC has biometric features, including fingerprints and eye scans.

Around docks, some companies have installed underwater sensors, used to detect any foreign objects that may have been accidentally or purposely placed, with the potential to cause harm to the docking vessel. The oil industry is known to be deploying this technology.

A technology is currently being tested to detect pressure changes of container contents, with the readings sent via satellite. One safety concern is how to make these systems spark resistant.

Many boats are outfitted with a panic button which transmits an alarm to a centralized location. When an incident has occurred that requires an emergency response, a single call to the National Response Center (NRC) initiates the response process. Interestingly, the industry has yet to leverage GIS information technology to identify the nearest response assets in proximity (e.g., police, medical personnel, recovery resources, etc.) to the incident site.

Dock navigation is still an issue. Presently, dock operations are performed using hardcopy reference documents that are available on computers in pdf form.

Level 2 Emergency Responder Organization: Chief of Fire Department

The worst nightmare would be a phone call about a major wreck involving multiple vehicles (i.e., rail and truck Hazmat) and catastrophic release of a flammable compressed toxic substance in a congested area. Pipeline leaks are usually localized, although they can happen in congested areas. Waterways seldom have these types of catastrophes.

There is a move to route Hazmat shipments so as to bypass major cities. But this can mean routing it through areas whose response capabilities are less able to handle this type of emergency.

Evacuation in response to a catastrophic Hazmat release can be extraordinarily difficult to orchestrate. Sheltering in place may be the better solution.

The capability for standardization of Hazmat response training is present but implementation is not, particularly among volunteer fire departments. An emerging issue is the need for capable Hazmat response equipment such as detection systems released with their capabilities validated and the knowledge with which to use them.

Decision support systems such as those that detect and alert in response to patterns can be put to good use at a high level. However, it is disconcerting to respond to false alarms.

We are going to see more alternative fuels being shipped, similar to how ethanol shipments rapidly ramped up. This will affect both rail and trucking equally. For example, we should expect to see more future shipments of hydrogen, which requires specialized firefighting techniques. Technologies for this can be "high gap—low market adoptability."

There will be more emphasis for emergency responders on biological agents. New equipment and countermeasures such as germicidal foams will be needed along with the techniques for using them.

Some small percentage of shipping containers at ports (perhaps 3 to 5 percent) do not contain what their markings say they contain. This is a problem.

Level 1 Emergency Responder: Company Emergency Manager

First responders need technologies that are simple and straightforward. There are many cases in which funding has been made available for emergency responders to procure sophisticated instruments, but they have found that those instruments are harder to understand, interpret, and use.

As a Hazmat shipment crosses (boundaries such as) county lines, politics can come into play and cause response not to be as smooth as it could be.

The first 15 minutes following an incident is a critical period in which real-time information needs to flow on the hazardous substance(s) being faced.

Security Agency Officials

There is a need to facilitate the ability to have continuous on-demand locating of the truck tracking trailer element.

With rail, the biggest need is to protect the conveyance. This starts with deterrence, but if deterrence fails, it is important to be able to detect the problem so the threat can be mitigated. There is need for improved security mechanisms. Some dangerous chemicals shipped by railcar are subject to theft.

Shippers install a security seal, which can be a heavier cable wire seal for more dangerous cargo.

The current design of hatches is more than 30 years old and is mostly for physical protection. Railroads are working to make access to valves more difficult. Better security from locking mechanisms is needed, but when something on a railcar malfunctions mechanically, emergency responders need to get access. Who will pay for improved locking mechanisms? What is the balance between more difficult general access to valves for security needs and rapid access to valves by emergency responders?

Railroads are moving to improve the survivability of pressurized tank cars through designs such as self-sealing technologies. There is greater emphasis on product security and anti-tampering systems. It is possible to manufacture some chemicals in a safer form for transportation.

From both a security and an emergency response perspective, there is much value in early detection of product release. Early warning systems such as chlorine sensors are needed for loss of container integrity. However, electro-chemical sensors are largely not yet up to the environmental rigors of rail transport.

Levels 2 and 5 Emergency Responder Organization: National Emergency Responder Association

It is very important for emergency responders to be able to determine contents (at the site of a Hazmat incident). They need to verify contents from placards and get their hands on the shipping documents. Chemicals may be shipped by trade names or chemical names. Part of the emergency responder's job is to eliminate "what it is not," facilitated by having information about the commodity and its chemical properties. If shipping papers are destroyed, a placard helps eliminate more than it helps identify.

Chemical and biological hand-held assays that can sample a product are needed. Not knowing what a commodity is soon enough can cause a major transportation tie-up. Detection devices can help determine what (dangerous substances) you have within a certain range. Other devices can help indicate how much you have that is a problem and warrants evacuation.

The work that has been done on railcar (GPS) tracking such as that conducted by Dow Chemical is important.

Automatic crash notification is a good idea. For example, if a Hazmat truck overturns, notification of that event and its location would be automatically sent to a PSAP (Public Safety Answering Point: a call center responsible for answering calls to an emergency telephone number). Even better would be (PSAP) notification of the chemical cargo so that after 911 is called, responders will know what substance is involved with minimal delays.

Containers with unique identifiers would help during emergency response, such as a 3-D barcode like the railroads' Automatic Equipment Identification (AEI) system. Class I railroads have improved (their awareness of commodities being shipped) by leaps and bounds. What the railroads face is low frequency, high risk events.

It is currently hard to justify technology expenditures based on safety and response alone.

Motor Carrier Association

The capability to remotely disable a commercial vehicle exists. Current safety features work. So do security features, and they are robust enough (to resist malicious intent). Technology improvements must have a return on investment and pay for themselves.

An electronic manifest would improve efficiency. However, its value is only as good as the information entered, and the weak link is that someone has to key in the information. The driver realizes what is onboard but the system does not until the shipment reaches the terminal. What is the best way to get information on what is in the truck into the system? Have the shipper enter information into a master database?

Another weak link is emergency response. Getting information to emergency responders in a rural area can be a real challenge. If there were the capability for all involved to have smart phones, that would help, but it is not feasible to equip all (Hazmat) trucks with that capability.

Diverting or routing Hazmat around highly populated areas translates to more miles driven and more time on the road during which an incident can occur. It also can mean there will be bigger delays (in getting adequate response to the scene because of more rural or remote locations).

How can technologies be made more efficient so that industry embraces them?

On international shipments, brokers as well as carriers are involved in the U.S. Customs and Border Protection's (CBP's) Automated Cargo Environment (ACE) (the commercial trade processing system being developed by CBP to facilitate legitimate trade and strengthen border security). An Electronic Truck Manifest (e-manifest) is part of the ACE process.

A package in a Less-than-Truckload (LTL) shipment may need to be handed off (to other vehicles). Which truck it may go on depends on (criteria such as) fullness, capacity, and compatibility.

There is a need for a security credential that is universally accepted. What hasn't received traction is that there are a lot of private facilities that need to provide security for their assets, but (a carrier) doesn't want to have to deal with 30 different credentialing systems. TWIC is available and is a good idea but there is a hidden cost from aspects such as the time it takes to get (a driver) enrolled.

Rollover prevention technologies are helpful. Non-intrusive (screening) technologies such as radiation portal monitors have their place.

The possibility of a PIH Zone A accident when you do not know what caused it is an example of something that is worrisome. (NOTE: PIH Zone A materials are relatively small quantities of PIH that require additional specialized packaging when transported via highway. The final packaged material can be very bulky and consequently can also be quite expensive to ship.) It is not feasible to dedicate trucks with sensors that transport only Zone A PIH.

Incentives or deductibles are possibilities for encouraging the use of technologies (for safety and security).

Level 1 Emergency Responder Organization

This organization maintains a list of contractors to respond on-scene and facilitates Level 2 and 3 response through mutual agreements.

Previously, the Dow Chemical Company implemented a "Track and Trace" program that integrates GPS, GIS, and radio frequency identification (RFID) to improve the safety and security of its Hazmat shipments. Dow and the Chemical Transportation Emergency Center (CHEMTREC) expanded the concept to Dow's Railcar Shipment Visibility Program, an initiative for using tracking and sensing technologies for surveillance of TIH being transported by rail, and improved communications between the two organizations as well as with emergency responders should an incident occur with Hazmat in transit.

In addition to GPS-based tracking with satellite communications, this initiative includes tank car sensors such as load indicators, external sniffers, dome open/close indicators, temperature indicators, and pressure gages (NOTE: while not all sensors had been be activated at the time of the interview, the system was in use). Geofencing at locations such as customer docks or in High-Threat Urban Areas (HTUAs) is also involved. Signals can be automatically generated when an instrumented tank car enters or exits a HTUA. Railroad and DHS alerts can be tied to the system and railcar GPS devices can be queried. The system helps determine whether a (safety and/or security) event has occurred. When an alert is generated by this system, CHEMTREC is notified and is charged with implementing protocols.

There is no such thing as a "typical" incident.

The telephone is the most valuable tool (for Hazmat response). Nothing will replace someone picking up the phone and calling to say they need help and someone to help solve the problem.

In responding to an emergency, it is desirable to have three (sources of information) that say the same thing (since initial information is so often wrong).

Previously, deciphering a train consist was difficult. But now, cooperation between CSX Railroad and CHEMTREC has greatly streamlined the process with CSX's Network Operating Workstation (NOW). If there is notification or a derailment, using NOW, the train number, tank car number, and approximate location (integrated with Google Earth) can be pulled up on a computer screen within about 1 minute. A graphic portraying the railcars is shown along with Hazmat shipping description information such as shipper, consignee, and status.

Hapag-Lloyd, a global container shipping line, has a system with which shipper and container content information can be determined from the container number.

There is conflict between proprietary information and an open architecture. The issue is information exchange, not technology exchange.

If (technology) is not necessary to the business bottom line, it is harder for it to be adopted. Technologies are (relatively) easy to understand and adopt. Standards become the issue. Ideally (to be adopted), technologies need to have a self-sustaining component and more than one benefit.

Rail Hazmat Technology Academic SME

Micro-Electromechanical devices have promise for a smart apparatus on railcars that can detect hunting, hot bearings, and acceleration. (NOTE: "hunting" is a railcar motion phenomenon in which severe, low frequency, lateral accelerations are experienced. Typically, this is caused by wheel and track wear, track conditions, and speed. The phenomenon can be severe enough to damage rail shipments or even raise the risk of derailment.)

When emergency responders arrive at the scene of a Hazmat railcar derailment or truck crash, it would be desirable to have a hand-held device capable of remotely getting information from the affected vehicles concerning their contents, such as what is on the placard. These devices themselves would not have to be expensive, but instrument cost is not the only factor. Many personnel would have to be trained on how to use it and how to gain access to the Hazmat information. Carriers would have to make shipment information available, and that has a security aspect to it.

Achieving a safely distant stand-off range with the hand-held devices would be a problem. The greater the range required, the greater the reason for the vehicle to have active technology, thus the greater the cost (compared to passive technology). And the farther away from the scene the emergency responders are, the greater the challenges for them to manage the information. Railcar devices (e.g., RFID) would need to have a relatively sophisticated programming capability. There must be universal compatibility with devices. The information would have to be updated whenever the Hazmat contents change, or more harm can be done than good could by the misinformation. The driver will not have the capability to certify the load. Thus, you lose control unless you have strong verification that the Hazmat you are told a vehicle is carrying (or not carrying) is actually so.

Barcodes can get very dirty and hard to read, especially on trucks in the winter. If the interest is primarily in the substance, the placard gives that.

Hazmat Emergency Response Technology Provider

The Intelligent Road and Rail Information System (IRRIS) is a powerful tool (and existing technology product) that has been developed with capabilities for visibility and tracking of assets. IRRIS was originally developed for the U.S. Military to track, manage, and document the movement of surface cargo transported throughout the world. It is designed to integrate data for the customer's use and has the capability to be tied into the systems of various government and military organizations. It works with the Defense Transportation Tracking System (DTTS), which provides satellite tracking capability for truck shipments of sensitive conventional Arms, Ammunition, and Explosives (AA&E) shipments, and Other Sensitive Material (OSM). It is capable of tracking cargo on a "parent-child" relationship and can look at data on trends such as malicious acts. It provides the ability to drill down to the contents of pallets and containers. Shipments being tracked can be managed by exception alerting.

Class I Railroad Officials

This rail carrier's Network Operating Workstation (NOW) is a proprietary development that allows point-and-click functionality to access railcar and rail traffic databases through a mainframe computer. Extracting information is done through different screen lookups. Through NOW, it is possible to get information that includes a train's consist, crew, origin and destination, and route points. NOW facilitates train, railcar, and locomotive management. It can be used for situational awareness for homeland security and incident response. There is an internal version and an external version, the latter of which can be used with fusion centers. NOW doesn't provide an insider's view such as whether a train is running late. Five agencies (four states and the Transportation Security Operations Center) and CHEMTREC have access to NOW data.

When a railcar's information is pulled onto a screen, it displays the railcar's placard. An icon of the car was added as a feature. Information can be obtained four different ways: (1) GPS on the locomotive, which "knows" and displays the consist, (2) a computer-aided dispatch (CAD) system, (3) the Automatic Equipment Identification (AEI) system of RFID railcar tags and railside readers, and (4) updates made by certain personnel. At the time of the interview, approximately 50 percent of locomotives were thought to have GPS (NOTE: do not know whether that figure was for all Class I railroads or only this one).

This rail carrier operates in 31 HTUAs (more than any other Class I railroad). With NOW, alerting parameters such as geofencing can be set. Alerts can be test or e-mail. NOW is a great tool for derailment response and security planning. Local communities want an advance consist. When NOW started to deal with states and fusion centers, they thought having a central, well-trained point of contact was the best concept. They could communicate with free access and were able to get critical information out. If a third party logistics (3PL) firm is vetted by NOW, they can get the latest database information on location.

What hasn't changed is the need for emergency responders to seek out locomotive conductors who will have paperwork such as the train's consist. With NOW, it is possible to identify what is in the schematic within seconds. This railroad sees a day when a sensor can automatically notify the closes dispatch center if an event occurs. Also, there may be telemetry devices communicating the locations of both the front and back ends of the train.

There is also the concept of a radio broadcast in which, if there were an undetermined emergency, a message could be generated and sent to an emergency services band that includes the railroad's identity and the train's identification. A device on the train would make the broadcast. Through encryption, emergency responders could get useful status information on certain commodities such as whether the cargo is upright or overturned or a chemical has been released.

Protecting information on the customer base will continue to be paramount, and railroads may never agree to have the same system. But having a common platform is vitally important. There needs to be a uniform system that offers consistency and ease of use. The focus needs to be on what can be done to help emergency responders and federal and state homeland security organizations.

Environmental Protection Agency (EPA)

Someday there may be embedded technology in the roadways to guide robotic Hazmat response modules. Many of the Hazmat problems are associated with specific routes.

This state EPA sees driver behavior as a major cause of Hazmat incidents. Medical devices that monitor the driver and other sensors that monitor outside status such as ground surface conditions or following too closely would be helpful. Diabetic and cardiac emergencies could be detected by medical monitoring devices. Certain conditions might preclude the driver from starting the vehicle.

With the highway mode, danger from Hazmat events is lower per mile on Interstate freeways than on rural roads. It is more likely that a Hazmat shipment will run into trouble in a rural area. In metropolitan areas, accidents tend to be "fender benders" that frequently do not involve other vehicles, or even if they do, there is little cargo damage. In contrast, there is more likelihood that a Hazmat shipment will run into trouble in a rural area, such as running off the shoulder of the road and overturning. With the rail mode, tank cars experience a reduced rate of incidents.

It is hard for rural fire departments to afford specialized training. There normally is training on a quarterly basis on the types of railcars that come through a certain area. Some firefighter training is not useful because it is not geared to the level of protection, danger zone, and equipment (required). Training in the "20-second evaluation" is important (i.e., if you get a certain reading, here's what you do).

Many times, shipping papers are not in the door pocket (of a truck cab) where they should be.

First responders can find themselves dealing with a mixed consignment. It is sometimes hard to know what is leaking. Better definitions are needed. A brand name is always useful.

When fire departments buy meters, it is desirable that the meters clearly indicate what they are responding to, such as numbers that show concentration.

Many big companies have response teams. Rural fire departments are well-trained (for Hazmat emergencies). Metro fire departments can be over-specialized. People are less likely to panic (over a Hazmat release) if they know something about the hazard rather than a total unknown.

Sensors along rail beds may someday be able to provide information such as identity of railcars, whether they are moving, and unauthorized access.

Diesel fuel and gasoline account for about 80 percent of this state EPA's (incident) activities.

Hazmat Environmental Response and Information Organization

In the near term (i.e., from the present out 5 years), informational technologies will reign. More traditional technologies can be made to work in new ways for remediation, packaging standards, safety, and keeping the most dangerous materials away from population centers while enabling better efficiencies.

In the mid-range (i.e., 6–9 years out), technologies that capture information will reign. They will more easily compile data and seamlessly collect and integrate information. This information can include items such as protective equipment and response planning needed.

In the longest range (i.e., 10–15 years), technologies will answer questions not yet asked. Response technologies and information and communications technologies will move to a predictive nature such as predicting the characteristics of a Hazmat release, what equipment will be needed, and where and how it needs to be used. In the longest range, neural networks will assist with predictive modeling.

Activities of shippers are growing into the predictive nature of things. Information currently available (e.g., through GPS-based tracking) is good, but given the right information, communication can be made more predictive. There is a vast amount of location-related data. Intelligent agent software can be designed to "chew" through these data to identify patterns associated with risk.

The (generic) functional requirements (selected by the HMCRP Project 04 team) sound appropriate.

There is a difference between building a better mousetrap and something that has never been deployed before.

The ability to get bill of lading information from a vehicle (remotely) will be important. There is a concept for a "memory stick on a truck" that ties into a truck's 9-pin connector. It can be loaded remotely with bill of lading (BOL) data, and the BOL data can be read remotely by an emergency vehicle using shortwave communications.

The insurance industry will seek technologies that can manage claims and litigation, pushing the process back to an operational setting such as going back in time to dispatch. If they know what it takes to win a claim and then design that into a (data collection) system, they increase their chances of prevailing in court. Avoiding the need for regulation, response, and cleanup (are incentives). Regulatory processes are usually not technology-based.

Shortcomings (in the Hazmat transportation industry) include (1) business operating systems, load management, and accounting that are antiquated. For example, motor carriers make investments but do not learn how to use the full capabilities. (2) Online, on-demand training is needed on systems, including automated information gathering. How does a firm bill costs, get paid, and assign a driver? The industry will be hamstrung until the back office improves. But Hazmat may be the best way to justify the expense and provide the best incentive to change. There are costs to cleanup, injury, etc.

How hard would it be to place a macro on an onboard (truck) system that says "this is who I am, where I am, what I spilled, and what I need?"

Marketing of new technologies is very important. Good marketing can cause good deployment. A technology can get a lot of R&D and work but not be well-sold. (Consequently) it does not get well-rounded feedback or the best critiques. (It is helpful) to have a website—this gives (users) a way to determine whether something should work for them. Conversely, there has been over-marketing of incremental improvements. Great examples of technology deployments are few and far between.

Lack of deployment is sometimes used as a reason why new technology is not as good as "lower" technology. Big integrators go with big technology providers, but it is sometimes better to go with a smaller solution. It is always important to get the right people on the team (when deploying new technology). And it is helpful to showcase (a technology's) problem-solving abilities for first responders, consignees, carriers, etc. What is the problem we need to solve? Transportation treats technologies as an end in themselves.

Some (carriers) are reluctant to invest in technologies because of perceived liability. But they should absolutely want an emergency response/spill alert system, which would help mitigation, regulatory, and compliance so third-party liability can be much less. Technology has to tell (its information to) someone. Tell who needs to know on an exception basis.

Officials of Air Transport Association

There is a link between safety and security. The biggest difference between air transport (of Hazmat) and the surface modes is individual package volumes (i.e., 400 Kg/450 Liters or less), which pose significantly lower risks. The Hazmat commodities that can be moved (by air) are a subset (of what can be moved by other modes). Some substances are forbidden. This association has a field guide reflecting technical instructions. The basis for both the field guide and the ICAO model is the United Nations (UN) model (but not commodity limits).

Air transport has lower risk of accidents. There are few occurrences of Hazmat delivery from rail or ship to aircraft.

Security for air transport has been in place a long time and is well-established. Another area in which (air transport of Hazmat) is ahead of other modes is in mandatory dangerous goods training for all who touch Hazmat cargo.

Concerning technologies, packaging is under constant review. If incident reporting suggests a problem with packaging, use of packaging gets scrutiny. Most technologies fall on the safety, not security, side.

Use of RFID (in air transport) is still emerging. It becomes a matter of cost-benefit analysis. The need to know (Hazmat cargo) location constantly is not yet in-place. If a technology drives a competitive advantage, it can even drive the industry to get it adopted. If a technology saves $10,000 in fuel costs, it probably has a reason (to be adopted). RFID is probably the same – if it can prevent theft, minimize cost, and guarantee product integrity, it will have an advantage. RFID is a technology that people can see minimizing loss and guaranteeing integrity.

Flammable and toxic substances are generally not transported, although perfume and gasoline samples for analysis are exceptions. Infectious substances are something that needs to move quickly. Radio-pharmaceuticals, corrosives, and dry ice are some examples of other substances that can be transported by air.

With the regulations, shippers want to have as much flexibility as possible. The pharmaceutical industry is using smart tags to ensure substances do not get out of their temperature range. They also use holograms, visible to consignees, to reduce the use of counterfeit drugs. They are in the process of tracking these goods better.

The biggest challenge to Hazmat air transport safety and security are people who do not know the rules. The problem is the things that can be on the plane that you do not realize are there because the rules were circumvented. Education needs to get out.

Vendors' goods do not pose the highest risk, but rather illegal trade such as arms and drugs. The amounts of Hazmat put on a plane (legally) represent a minimum level of threat. Other transportation modes are easier to hit, with greater volumes in a single container or package.

It is desirable to ensure the security of the full supply chain. All secure programs by country come under ICAO, but countries have differences (in their implementation). Also, each airline has different levels of security. It is a goal to try to harmonize these differences and bring in best practices from the countries that are doing best.

First Responder Training Organization

The challenge in responding to Hazmat incidents is not a gadget problem, it is a people problem. It is difficult to get personnel to learn, use, and maintain equipment. They cannot practice with the equipment every day. Officers sometimes get the training when responders do not always. It is important to take the correct action right away so (the problems from) a spill do not get bigger. For unification to responses, a standard operational guideline is needed for the country. (Certain) alerts need to be sent to NOAA, DOD, DOT, or DHS.

The quintessential question is "given the same emergency/Hazmat release/time, would anyone respond differently? Everyone teaches to the standard but we respond in chaos. (In a Hazmat incident first response scenario), a person who has authority but no knowledge is dangerous.

Ohio Hazmat Teams Conference

In a case study of a certain train derailment involving Hazmat, it was noted that the railroad's emergency response and the assets they bought to bear were impressive. However, it took 5 hours to get the train's consist and responders had to use the fax at a Home Depot store to get the consist. Cell phones had to be used, although their drawback was that not everyone could hear what was being discussed, so that had to be separately relayed. During the early part of the Hazmat derailment incident, news helicopters were the emergency responders' eyes and ears. Their video feed was invaluable, and, in fact, helped the emergency response team realize they had a butane car in proximity to burning railcars that were in a jumble.

There is no good list of how many Hazmat teams there are nationwide, much less their competence levels.

A flammable atmosphere is what is most dangerous to firefighters. An assessment needs to be done in minutes, not hours.

Corrosives account for about 20 percent of spills.

Marine Regulatory Agency Hazmat Officials

Stability of ships must be calculated, and there is need for new technologies. This is more of a "blue water" (open ocean) concern (as opposed to a "brown water," or inland concern).

The worst nightmare is a major near-shore collision that both damages critical infrastructure and releases large quantities of poisonous Hazmat in the vicinity of a populated area.

There is a need to make distress calls in English. Linguistic tools are being developed for that use.

There is a push toward full maritime domain awareness. The AIS system is like IFF (Identification Friend or Foe) in aviation in that it provides a vessel's identity. It is being required nationally as Nationwide Automatic Identification System (NAIS). An international body is looking at tracking a ship 500 miles before making port using satellite-based tracking.

AIS for the brown water fleet is different than for the blue water fleet with regard to their announcements of position.

There is much work going into cargo status, including RFID tags on each package and interrogators with cargo ships. Some ships have large containers stacked 8 to 10 deep, and the ship may have 4,000 containers. This makes networked sensors important.

There is aging infrastructure at some ports, and some are relatively shallow. However, ships are getting bigger with deeper draft, increasingly forcing them to come in at high tide.

Ports currently only track ships headed to them (i.e., to that specific port). Receivers need to go out beyond 200 miles, which they cannot do now.

Routing of ships in response to a storm is changing.

Within recent years, there have been regulations requiring more hazardous substances to be further away from the skin of the ship (now ¾ meter).

Lashing systems keep containers from being washed overboard. There are improvements being made to these systems involving many companies.

Motor Carrier Safety Official

The biggest concern is a truck on its side and not knowing whether the driver is all right.

After 9/11, selection of drivers became very important. Background checks revealed problems that did not show up on motor vehicle registration checks. If you hire right, you can train a vehicle operator well.

This company's fuel trucks now have a lower center of gravity, a wider wheelbase, and roll stability. Retrofitting with newer technologies is desirable, but it is not practical to take older trailers costing $80,000 to $90,000 out of service.

Technologies in use include a black box providing location over the web, remote door locking, installed security switches with panic buttons, and some remote shutdown capability.

Owner-operators are hesitant at first to try new technologies. From a safety and security standpoint, technologies need to be improved. Information can be corrupted, and vehicles can be in a dead zone where no information is flowing. Millions of dollars have been put into technology, and the government should hold vendors to higher standards.

There are new technologies needed for product integrity such as chemical analyzers and barcodes that must agree before fuel can be pumped. Gasoline and kerosene when mixed can explode in a heater.

Cell phones are good technology but are locked down when in transit so they are not used while on the road.

Motor Carrier Security Official

Hiring the right person is the most important aspect of security.

The industry needs a single security credential assigned to a Hazmat driver; a common identification card recognized universally, simple to use with a single standardized reader. Updating databases to remove access for departing personnel is important.

Integrity of the package and risk exposure is typically better on short-haul transport.

There is a move to take things away from the driver and instead provide technology to lessen risk. Dynamic security profiling is an example of risk reduction.

There is a requirement for Hazmat haulers to immediately locate Hazmat containers through GPS-based tracking. However, there is no access to a government database that provides PSAP information. If there should be a criminal (or terrorist) incident involving Hazmat, there should be a way for the carrier to push information to the PSAP without having to rely on the government for that. Owner-operators might not want the government watching their shipments.

Flow sensors are a technology that could help Hazmat truck transport.

Specialty Motor Carrier Representatives

Hazmat accounts for about 10 to 15 percent of their shipments. They rely on customers accurately telling them what is being shipped, for placarding, and on the driver checking. They do not transport Hazmat waste. They have 24-hour operations and do not want drivers to mix potentially dangerous materials such as organic peroxides with other substances.

There are computers on their trucks and GPS tracking with two-way communication. There are certain "white glove" vehicles that have a panic button with emergency alert. These vehicles carry high value or dangerous substances such as PIH, explosives, and radioactive and infectious materials.

There is always a security concern when drivers stop. In certain security circumstances, two drivers will be required.

One of the technologies needed is a better way to determine what infrastructure like bridges and tunnels will not allow Hazmat shipments, at least during certain times of the day. It is important to provide the driver with that information; otherwise there can be a fine or delay from rerouting over additional miles, and this is not just with more dangerous materials. There is some software for this now, but it is piecemeal (i.e., not a unified system).

Emergency Response Technology Provider

The biggest challenge for emergency response equipment is identification: decreasing the time needed to come up with a survey and come up with an answer.

Radiation detection devices should be set up for exposure rates, not activity. First responders are not the biggest customers for radiation devices, but those devices can be calibrated to be accurate for specific isotopes.

Standard alarm level settings need to be developed. Hazmat incidents are dynamic. They need to be identified in minutes, then mitigated and remediated. If that happens in a rural area, the capability may be much less (than in a metro area). Knowing the response distance and having a game plan developed are important.

Technology Research Consultant

There is great strength in wireless technologies. There are lots of communications available with huge potential and value: roadside-to-roadside, vehicle-to-vehicle, and DSRC.

With technologies, everyone wants to be a "close follower." However, technologies need leaders to take charge.

Mobile phones with GPS and navigation capabilities are currently providing useful results. In the range of 5–10 years out, people are increasingly looking at behavior, especially risk perception. Gain sometimes means loss: people may drive faster since they know they have protection from seat belts or automatic braking.

There are clever algorithms that could be used to determine whether a driver is driving safely. It is possible to set out a baseline of "normal" and so determine a risk profile.

Impulse radar has been used in missile scoring. It is very good for measuring distance and tracking. An "infiltrator" vehicle moving into the line of view can be recognized and tracked. A predictive algorithm can determine whether two vehicles are on a collision path. Impulse radar can constantly pick up an object in a cone and do (collision) predictions using probabilistic calculations.

Decision support tools have been developed to deal with lower-level decisions like subway service recovery (following an emergency shutdown). Situational awareness still resides with the operator, but technology could be applied in a clever way to deal with higher-level challenges.

Technology should not be confined due to legacy systems. People who are willing to think outside of the box and try out things may find that algorithms and expert systems can solve new problems.

National Laboratory Scientists

It is possible to penetrate containers without going through the usual seals and access doors. Detecting that is a difficult challenge. A number of technologies have been considered for this problem, but until now all have been too expensive. Volumetric sensors include IR, ultrasonic, and bi-static radar. Effectiveness can be impacted by the type of contents in the container.

This national lab is a proponent of ubiquitous sensing: clusters of sensors on an active network detecting status of cargo contents and transmitting results that can be picked up by other sensors. Costs to make this happen are going down. These can be in a sleep mode most of the time, but constantly "sniffing" for substances that can trigger an alert condition, such as chemical or radiological detection. One such sensor could be a fiber-optic seal with radio frequency communications that could monitor cargo condition and attitude. There are now plastic fiber-optics that are very inexpensive.

But input could be from many different types of sensors performing continuous monitoring. Sensor thresholds can be set with alarm levels. An external seal could have such an alarm. Sensor information could be picked up for multiple containers, and alerts could be collected by a receiver talking to the world via cell phone, satellite, or GSM-R.

There could also be state of health sensors. And if a transmission is not made when expected, the reason can be determined on the next transmission. All monitors can have substantial memory and storage information. All messages would be stored at the data collection point, with a series of redundancies to recover from malfunctions.

Authentication encryption can be made very tamper-resistant. There is an application to develop a low-cost, long-life fiber-optic seal that incorporates this. It is called the remotely monitored sealing array (RMSA). It contains public key authentication, with messages cryptographically authenticated with very strong security.

National Motor Carrier Association Official

Some food products are Hazmat. Having harmful substances get into food products is a concern. Another worry is having someone follow a truck with flammable cargo to a fuel station and blow it up (a greater concern to this respondent than a chlorine leak). Fuel doesn't go far, usually less than 50 miles, but up to 100 miles in some cases.

Grant incentives for safety and security may not be right. If a safety or security step is important enough, do not make it voluntary—require it.

A lot of things are going on in safety and security. Of all of these, measures to provide frequent or instant communication are among the most impressive. It used to be said that "trucking is the largest unsupervised workforce." Now trucks are monitored frequently.

How much can you put into a driver's environment without affecting the driver?

Worker identification and credentialing is a mess. Worker verification is an area that begs to be addressed, a single system that everyone will accept. Military bases ask for drivers' social security numbers, which bothers the drivers.

Remote sleep apnea monitoring is being tested by a certain large motor carrier.

Needs to be addressed include cross-deliveries (i.e., gasoline is put into a diesel tank). Technology could help this problem. Chips on hoses could be made to "talk" to a tank when the wrong fuel is about to be pumped. People die every year from chemical reactions resulting from the cross-delivery problem. Nitrogen in cargo tanks also kills people every year.

Rail Tank Car Designer

The Next Generation Railcar is underway. The design involves balancing competing issues. Physics and deformation models are well-developed and can be used to evaluate new models. Engineered metal structure (corrugate) provides strength and absorption and a means to allow a structure to have deformation over a relatively long period.

Industry wants a compliant container with a strong puncture-resistant layer; that is an area that needs more research. Anything impinging can deform the container. Fiberglass is a strong but affordable material.

Performance has been increased 2 to 3 times but that is only one aspect of the solution. There can be added benefits if we understand the needs better. Metals and structures need more work.

Regulator Agency Representative: Pipeline

Safety and environmental protection are the primary focus. There is some gray area in security, but security improvement is highly relevant as a secondary effect of technology improvements. One big culprit in pipeline damage is third-party digging.

Where a pipeline comes out of the ground is a vulnerability. Pipeline location data includes some vulnerabilities. Knowledge of interconnections is well-guarded.

In rulemaking, the U.S. Office of Management and Budget (OMB) requires regulatory agencies to conduct a burden analysis. Having a safe, efficient, and secure pipeline is a cost element.

Pipeline corrosion is one area that needs more research.

Leak detection at altitude can be made by fixed-wing, helicopter aircraft, or unmanned aerial vehicles (UAV).

A number of specific research areas were provided including the following:

DTRS56-02-T-0005, "Digital Mapping of Buried Pipelines with a Dual Array System"

DTRS56-02-T-0006, "Pipeline Damage Prevention Through the Use of Locatable Magnetic Plastic Pipe and a Universal Locator"

DTRS56-04-T-0006, "Effectiveness of Prevention Methods for Excavation Damage"

DTRS56-04-T-0007, "Infrasonic Frequency Seismic Sensor System for Preventing Third-Party Damage to Gas Pipelines"

DTPH56-06-T-000005, "Differential Impedance Obstacle Detection Sensor (DIOD)—Phase 2"

DTRS57-05-C-10110, "Infrasonic Frequency Seismic Sensor System for Pipeline Integrity Management"

DTPH56-07-P-000046, "Determine the Requirements for Existing Pipeline, Tank and Terminal Systems to Transport Ethanol without Cracking"

DTRS56-04-T-0012, "Hazardous Liquids Airborne LIDAR Observation Study (HALOS)"

DTPH56-05-T-0004, "Use of Unmanned Air Vehicle (UAV) for Pipeline Surveillance to Improve Safety and Lower Cost"

DTPH56-08-T-000017, "GPS-Based Excavation Encroachment Notification"

DTPH56-08-T-000019, "Advanced Development of Proactive Infrasonic Gas Pipeline Evaluation Network"

DTRS56-01-X-0023, "Airborne LIDAR Pipeline Inspection System (ALPIS) Mapping Tests"

DTRS57-04-C-10002, "Infrasonic Frequency Seismic Sensor System for Pipeline Integrity Management"

DTRS57-04-C-10012, "Intrinsic Distributed Fiber Optic Leak Detection"

DTRS57-04-C-10016, "Piezo Structural Acoustic Pipeline Leak Detection System"

First Responder Information Provider

The interviewee's top technology thrust areas include (1) dependable (rail) infrastructure and inspection, (2) rail tank car puncture resistance, and (3) improved emergency response techniques.

It is baffling that there is so much "dark" (unsignalled) territory. There is a huge amount of available technology (that could alleviate that).

Rail tank car puncture resistance has improved but has not gotten to where it needs to be if infrastructure inspection techniques and positive train control are not there. The backup plan is a better package. The goal is to achieve improvement somewhere around 5 to 10 times that of current designs. Structural foams are another area for improvement. It would be good to get to a point where there would be no puncture (for collisions) at or below 50 mph. An industry research program has been formulated (for tank integrity).

There needs to be better infrastructure inspection techniques. There have been Hazmat rail incidents resulting from failure of a rail.

One technology area that is important to more rapid Hazmat incident remediation, is how to better transfer a commodity from a breached railcar. Suction (a slight vacuum to pull off vapors) and liquid transfer pumps provide that capability, although there are not many of these pumps around. With such a pump, Hazmat commodity from a breached tank car may be capable of being transferred within a day. There have been noted Hazmat incidents in which transfer took many days due to circumstances. If an incident remediation can be safely sped up, people (who were evacuated) can return to their homes more quickly.

There is need for improvements in other remediation technologies.

There has been work in the United States looking at railcar valve and fitting designs that will not release product if sheared off in an accident. Similar work has taken place in Europe. Other approaches have included recessed valves and fittings, but these have not been adopted. Older steel can be brittle.

(In terms of collateral benefits from technology improvements), puncture resistance provides a security bonus from better resistance to an IED (Improvised Explosive Device) or projectile. However, outside of tank truck or (other) motor carrier shipments, it is hard to justify (the cost of) GPS (tracking) for security alone.

Level 1 First Responder: Incident Command Consulting Service

There is concern over intentional damage directed at rail tank cars. One counter is to make tank cars as slick as possible, so that a glancing blow from another object will be deflected. There can also be crumple zones to help absorb energy. There have been looks at foam spray-on protection for the commodity. Rock wool and fiberglass are little protection to the shell.

From the emergency response side, the biggest question is "if we prove something can be built, what is done with the tools available?" There needs to be more vision for implementing and executing (helpful technologies). There needs to be a long-term plan to design and market (improvements) to industry.

Air monitoring for CBRN (chemical, biological, radiological, and nuclear) agents is needed.

There are some chlorine tank cars that have what is called "enhanced fittings" or "next generation fittings" (associated with the Next Generation Railroad Tank Car Program). These fitting designs require some different techniques when using the "Chlorine C" and "Midland" kits (two frequently-used chlorine emergency response products).

When a general service car is on its side and the bottom outlet valve is sheared off, there is no way to shut off (the flow). It is difficult to get access (to fix this problem). However, PIH or TIH substances are not shipped in that type of tank car.

Lots of tools could be developed (to help in Hazmat response and mitigation). The truck tank car industry has pretty good tools.

Fire services and the municipal side have gotten a lot of funding, and much of it has gone toward elaborate rigs that are difficult to know how to operate. It is possible to have the best of the best equipment but not know how to make it work.

When it comes to Hazmat incidents, it is possible to get "hidebound" by rules. That can result in "paralysis by analysis," and lead to (over reactions such as) evacuating for excessive distances. With all of the technology that is out there, we are still in our infancy. Truckers are better-versed in Hazmat (response) best practices and have protective clothing.

Rail engineers have hours of service also (like on the trucking side).

In the Graniteville (South Carolina rail tank car) chlorine release, (some) chlorine was absorbed by foliage and trees. (Depending on circumstances), sheltering in place can be a better response than evacuation.

The Next Generation (Railroad Tank) Car has lots of improvements but is focused just on North America. Europe designs different valving with no external valves to shear off.

An affordable protective clothing suit with air packs for more than short-duration use is needed. So is monitoring equipment that is easy to be trained how to use, for a wide range of commonly carried materials.

(Updated) modeling of chlorine incidents is needed. Some real-world incidents have turned out differently than expected.

Offload of product using pumps and hoses (e.g., from a breached tank car) is now down to hours.

Official of Chemical Manufacturer: Shipper

A number of solutions (in rail tank car integrity) have not been high-tech but rather (improvements in) materials performance. Those can be looked at as emerging technologies too. It requires finding the "sweet spot" balancing weight issues and cost vs. performance. Industry has only scratched the surface (of improvements that could be made) and could achieve more.

Two things should be noted. First, in North America, we are heavily dependent on the railroads for shipping TIH (90 percent goes by rail). There have been some well-known incidents, and cities are taking steps to ban (Hazmat rail) movement. What can be done to reduce risk? Safer railcars, better working arrangements with railroads, improved containers and emergency response (can all play a part). Second, small cylinders of TIH are shipped around the world. These can be stolen, diverted, and used as weapons of mass destruction because they have passed out of (responsible) control. Track and trace technology should be able to help this challenge.

Railcars are in the third generation of technologies. Many improvements come from power management and delivery systems. There is some pain from being on the leading edge (of emerging technology implementation). GPS devices on railcars (can be programmed to) wake up every 15 minutes and also wake up if an event triggers (an alert). GPS devices can be recharged through solar power. Industry is looking at new concepts such as processing in the (GPS) unit itself.

Technologies do not always live up to what they are touted to be.

The Next Generation Railcar did a lot of material characterization. (The program sought to know) how to achieve performance without sacrificing weight and cost. Some government agencies looked at the use of engineered metal structures. Industry looked at corrugated structures that could absorb energy with much less weight. Thought has been given to introducing oblique angles, so a projectile like a high caliber bullet would be deflected and not penetrate a tank car. (It would be ideal to have) a single design concept that can implement crashworthiness as well as ballistics protection with one technology.

Rail tank cars have three functions: (1) contain the (Hazmat) commodity, (2) manage train loads, and (3) protect the commodity from insults (e.g., derailment). One protective measure is the tank within a tank concept. Another is to take weight out of the tank but still contain the commodity. Approaches to that include composites and fiber-reinforced plastics. The tank can be “skinnied down” and wrapped in composite materials. The weight can be taken to the external shell.

Increasing crashworthiness will help mitigate damage from an external explosion. A low profile design with all closures below or within a pressure plate offers protection since leaks would not result even if the valves were sheared.

Emergency responders are willing to try new things. Two-way communications technology can help when emergency responders have to stand off (at an incident like the derailment of a Hazmat tank car). The right people with the right tools and authorization can get access (to critical information). But we must ensure we do not make it easier for the “bad guys” to also get access.

A certain chemical manufacturer/shipper is actively involved with Railinc to assess how the existing CLM system can be more fully integrated and used for railroad and emergency response communications. With a stand-alone system, it is difficult to bring the two together.

There are significant differences between European and North American tank cars, not the least of which are differences that reduce head-to-head damage. For example, in a European derailment, the tank car may be intact although on its side, whereas in the United States, there may be accordion stacking.

Union Pacific railroad has taken a leading role in the development and implementation of Positive Train Control.

Many of the initiatives to better protect rail tank cars can be applied to other transport modes as well.

Improvements in cargo screening and inspection technologies are needed.

National Laboratory Scientist

The Federal Motor Carrier Safety Administration has implemented the Safety Status Measurement System (SafeStat), an automated analysis system that combines current and historical safety performance data to measure the relative safety fitness of interstate commercial motor carriers. With SafeStat, a carrier has a score that can change monthly based on a culmination of Level I/II/III inspection findings and a carrier’s ability to adhere to safety standards.

After 9/11, radiation detection introduced security. Now there is interest in certain freight configurations, materials, and the legitimacy of the carrier. On the safety side, there is interest in radiation as Hazmat. A certain national lab that pioneered radiation detection as a safety measure found that it could also be used for security. At first, some substances found in common products can trigger radiation detectors. Now there can be a high degree of certainty that a material with naturally occurring radiation is not from a threat category.

Ubiquitous sensing is a technology that offers much promise. A hybrid battery-powered RFID tag that is activated by an actuator has shown positive testing results. Data can be analyzed and provided through trade data exchange, which involves getting the commercial sector to share data with trusted agents. Social networking and digitizing will play a role in ubiquitous sensing.

The Smartfreight initiative could be tied in. Technologies for ubiquitous sensing are there but policies complicate their potential use.

Rail Trade Association Representative

The greatest concern is the release of bulk TIH (from rail tank cars) such as has been seen in the past few years.

There has been good collaboration among several industry partners such as Dow Chemical, Union Tank Car Company, and Union Pacific Railroad to improve tank car design. Research by the U.S. DOT and others is continuing.

Spent nuclear fuel casks are different from tank cars.

Improving the package (is a logical step). Also evaluate safety and security. Not all are convinced that preventing release of Hazmat is the best use of resources. For example, passenger trains can also be attacked.

The highway mode is different (when it comes to use of technologies). With a railcar, there is no power supply, so technologies depend on the life of the battery. Dow Chemical has taken the lead on an initiative concerned with a common system of common reporting to the railroad so a determination can be made whether there is an issue (such as an incident).

What action does the railroad take? Technology reliability is a big concern. (It is not feasible to) stop trains for too many false alarms.

Axle generators are being looked at. Electronically Controlled Pneumatic (ECP) brakes are showing up—some coal trains now have ECP brakes. Current pneumatic brakes can take up to a mile to stop a freight train. ECP brakes (1) stop the train more quickly, (2) are a conduit for railcar information, and (3) are a power source for items on a train.

It is possible for a train consist to be transmitted electronically. Lots of paper is currently being shuffled. Emergency responders may not have the manifest, which messes up communications, and indeed crews can be impaired (by an accident).

Railroads have implemented shelf couplers, head shields (the part of a tank car most likely to get punctured) and pressure relief valves. Thermal protection has gone a long way toward eliminating boiling liquid expanding vapor explosions (BLEVEs) and flame impingement.

When railroads have accidents, they do not make money and it costs them. So they have high motivation to be safe.

APPENDIX D

Modal Screening Process

Modal Screening Process

This section provides each of the transportation modes' specific functional requirements. It portrays the application of their functional requirement development priorities to the project's initial screened technologies as a key step leading to the eventual selection of the most promising technologies.

For each mode, the screened research list was reviewed and from it the team extracted technologies that applied to the functional requirements shown in the modal-specific technology development needs graphic. A technology selected for a mode was associated with one or more functional requirements in the cells that are classified as high, medium, or low priority needs in the technology development needs graphic for that mode. The selected technologies were then summarized in the extracted screened technologies table for that mode. Each extracted technology row in the table is characterized by technology need (referenced to one or more functional requirements), description, and potential solution(s). If the selected technology was associated with a high priority need functional requirement, it is in bold type. That is important for understanding the development of the technology selection criteria (described in Section 2.4) and the subsequent application of the methodology to select the most promising technologies (described in Section 2.5).

The subsection titled Technology Development Priority that follows for each mode has a graphic called functional requirement technology development priority.

1.1 Highway (Truck) Mode

Functional Requirements—Highway Mode

NOTE: The highway mode has 11 functional requirements: 8 generic and 3 additional functional requirements, more than any other mode.

A. Package Integrity—Package is robust such that material contents are not breached during normal transport operations and typical accident conditions. Capability exists to sense/detect pressure build-up and/or material release.

Technical capability rating: **9** (High capability = **Low technical capability need**)

Rationale for technical capability rating: Motor carriers transport bulk (non-divisible) Hazmat shipments in specially designed tanker trailers that comply with stringent construction standards. These standards are designed to minimize the potential for cargo releases in the event of a traffic incident. Tankers also feature cargo pressure gauges for drivers to monitor internal pressure. Divisible Hazmat shipments typically hauled in barrels or on pallets rarely have monitoring devices. Drivers may be unable to inspect these shipments prior to travel if a Hazmat shipment is loaded in the nose of the trailer or the shipper has sealed the trailer. Though Hazmat shipments must be properly packaged or transported in special tanker trailers, the integrity of divisible and non-divisible packaging/containers may be compromised by load shift, mechanical failure or if the vehicle is involved in a severe traffic incident.

Emerging technologies that address capability gap: Tanker status and pressure gauge readings are typically available only to the driver by reading gauges, located on the tanker trailer for pressure, volume, temperature, etc. Emerging technologies that provide constant tanker status monitoring include data that are transmitted via terrestrial or satellite technology. These readings may be sent directly from a device on the tanker or via in-cab communication systems. Other emerging technologies for divisible Hazmat shipments include trailer tracking and trailer status devices that monitor different aspects of trailer status.

Market adoptability rating: **6** (Medium adoptability = **Medium market adoptability need**)

Rationale for market adoptability rating: Due to stringent regulations governing the transport of Hazmat on highways, many carriers have already deployed in-cab communication systems. Also, tanker trailers are significantly more expensive that van trailers, prompting carriers to maximize tanker trailer utilization. Use of trailer monitoring devices is becoming more commonplace.

Challenges/obstacles to market adoption: Due to the capital costs and support systems required for in-cab communication systems as well as trailer tracking devices, these systems are typically used by only larger carriers.

B. Equipment Reliability—Vehicle and cargo equipment are structurally sound and properly maintained. Capability exists to sense/detect problems such as engine failure or loss of steering. Vehicle is able to protect its crew from serious injury under most accident circumstances.

Technical capability rating: **8** (High capability = **Low technical capability need**)*

Rationale for technical capability rating: Truck drivers are required to inspect their tractor and trailer at least once per day and many carriers require both a pre-trip and post-trip vehicle inspection. Large trucks and trailers are subject to routine vehicle inspections by enforcement personnel at weigh stations or roadside. In addition, motor carriers must document that any vehicle deficiencies have been repaired. Carriers are also required to maintain vehicle preventive maintenance records. However, vehicle inspections, preventive maintenance programs, and equipment sensors may not detect all possible mechanical failures.

**NOTE: Radioactive Materials shipments such as Highway Route Controlled Quantities (HRCQ) require a Commercial Vehicle Safety Alliance (CVSA) Level VI Inspection at the point of origin.*

Emerging technologies that address capability gap: Newer large trucks display vehicle faults, namely engine fault codes, on a display located on the truck's dashboard. Some in-cab communication systems transmit real-time engine fault codes to back office systems.

Market adoptability rating: **8** (High adoptability = **Low market adoptability need**)

Rationale for market adoptability rating: Older vehicles do not provide a dashboard display of vehicle faults. Though newer vehicles provide more information to the driver on engine/vehicle status, engine faults are available to back office personnel on an irregular basis if the data are not transmitted real time and downloaded either at the end of each day or when the vehicle is serviced. In-cab communication systems are more frequently used by larger and medium-sized carriers.

Challenges/obstacles to market adoption: The cost of new vehicles prevents many carriers and owner-operators from replacing older vehicles. In addition, the costs of in-cab communication systems and resources needed to support these systems impede further industry adoption.

C. Operator Performance—Operator is able to successfully maneuver vehicle under normal and off-normal conditions. Capability also exists to sense operator performance degradation due to fatigue, acute health problem, substance abuse, and so forth, and to alert the operator and back office to this situation.

Technical capability rating: **8** (High capability = **Low technical capability need**)

Rationale for technical capability rating: Before a driver can operate a commercial motor vehicle transporting Hazmat shipments, the driver must demonstrate the ability to operate a vehicle under normal and, to some extent, off-normal conditions. Drivers must obtain a medical certificate, a commercial driver's license (CDL) and a Hazmat endorsement.

Emerging technologies that address capability gap: Several new technologies can indirectly alert drivers and back office personnel of driver performance degradation by measuring vehicle operating characteristics. Examples include roll stability systems, collision warning systems and lane departure warning systems. In addition, some measure of driver performance may be available via the Engine Control Module (ECM) readings (for example, top speed, the number of hard brakes, etc.). Additionally, in-cab communication systems oftentimes have a driver distress feature that allows a driver to send a distress alert. Providers monitor these systems 24/7 for driver alerts.

Market adoptability rating: **4** (Medium adoptability = **Medium market adoptability need**)

Rationale for market adoptability rating: Though the first generation of these systems has been on the market for several years, certain sectors of the trucking industry have been slow to adopt these technologies.

Challenges/obstacles to market adoption: High capital costs and driver attitudinal issues with some of these systems have played a role in relatively low industry adoption rates. In addition, motor carriers may lack the safety data necessary to identify which of these technologies best meet their needs.

D. Hazmat Commodity Identification and Awareness—Ability to identify the cargo being shipped either in person or via remote access.

Technical capability rating: **9** (High capability = **Low technical capability need**)

Rationale for technical capability rating: There is a clear need to know/confirm the type of Hazmat being transported, and the primary methods for doing so include vehicle placarding and Hazmat information on the bills of lading. There is limited use of advance transmittal of Hazmat information to the carrier, shipper, or consignee, although some of the concepts seem promising. Trailers consisting of less-than-truckload (LTL) shipments may have several shipping documents that could get lost or destroyed in the event of a severe accident.

Emerging technologies that address capability gap: Electronic transmission of Hazmat information, via Electronic Data Interchange (EDI) or Extensible Markup Language (XML), by the shipper to the motor carrier and the consignee. Transmission of data must occur at the time of pickup.

Market adoptability rating: **4** (Medium adoptability = **Medium market adoptability need**)

Rationale for market adoptability rating: Shippers of certain types of Hazmat already transmit, or could easily begin transmitting, electronic Hazmat shipment data.

Challenges/obstacles to market adoption: The transmission of data can be costly and time-consuming. In addition, all senders and receivers of data must have standards and processes in place to know when bad data have been received or data are missing. In addition, system maintenance and data transmission can be a significant, ongoing cost.

E. **Communication**—Vehicle operator and back office have two-way communication capability at all times.

Technical capability rating: **9** (High capability = **Low technical capability need**)

Rationale for technical capability rating: Most truck drivers have either personal or company-provided cell phones. In addition, many fleets have equipped their vehicles with in-cab communication systems that provide cellular and/or satellite communication.

Emerging technologies that address capability gap: In rural areas with sporadic cellular coverage, satellite phones could improve two-communication capability.

Market adoptability rating: **6** (Medium adoptability = **Medium market adoptability need**)

Rationale for market adoptability rating: Motor carriers desiring satellite coverage would likely choose an in-cab communication system.

Challenges/obstacles to market adoption: In-cab communication systems have not been adopted by all segments of the industry.

F. **Tracking**—Vehicle and cargo location are known at all times.

Technical capability rating: **6** (Medium capability = **Medium technical capability need**)*

Rationale for technical capability rating: In-cab communication and satellite tracking devices typically track truck locations. Use of these systems continues to grow, especially among larger carriers, followed by medium-sized carriers. Owner-operators and small fleets are less likely to use these systems. In addition, some of these systems are terrestrial-based systems, providing more limited communications (although the GPS signal has the same effectiveness as satellite systems). Integrated satellite and terrestrial technologies provide more coverage, especially in rural areas, though mountains or tall buildings (i.e., urban canyon) may inhibit real-time data transmission.

**NOTE: transport of HRCQ shipments and transuranic waste under the DOE shipping program would have a higher score due to more stringent requirements.*

Emerging technologies that address capability gap: Tethered and untethered trailer tracking devices provide the ability to track trailers. RFID tags and electronic seals can provide a certain level of cargo tracking. Some of these technologies provide automatic real-time location updates.

Market adoptability rating: **6** (Medium adoptability = **Medium market adoptability need**)

Rationale for market adoptability rating: Several of these technologies have costs that are higher than the market is willing to bear. In addition, the challenges and expense of RFID tag deployment in other industries has stymied use of this technology.

Challenges/obstacles to market adoption: Carriers must be presented credible cost/benefit analyses for each of these technologies. In addition, these technologies may offer benefits to certain segments within the industry. Lastly, more research and design work is needed to standardize and augment the hardware and software for systems such as RFID.

G. **Security**—Vehicle, cargo, and operator are resistant to theft, diversion, sabotage and other intentional acts.

Trucking capability rating: **6** (Medium capability = **Medium technical capability need**)

Rationale for technical capability rating: Protecting the vehicle, cargo, and operator from security-related risks requires technology solutions specific to each. Drivers are restricted to specific routes and must comply with regulations dictating where a driver can take a break and how often the driver must be in contact with back office personnel.

Emerging technologies that address capability gap: Driver authentication technologies, such as biometrics and smart cards, may reduce the risk of vehicle/trailer theft. Hazmat route geofencing ensures Hazmat loads are not diverted from planned routes. Electronic seals provide trailer seal status and an indication whether any efforts are or were being made to tamper with the device.

Market adoptability rating: **3** (Low adoptability = **High market adoptability need**)

Rationale for market adoptability rating: The initial and ongoing costs of these systems have impeded more widespread use.

Challenges/obstacles to market adoption: Since no comprehensive solution exists to protect the vehicle, cargo, and operator, carriers must vet each technology independently by cost/benefit analysis and ease of integration into existing operations.

H. **Emergency Response**—Qualified emergency response is delivered to incident site in a timely manner wherever it may occur.

Technical capability rating: **8** (High capability = **Low technical capability need**)

Rationale for technical capability rating: It is critical that first responders are fully prepared for addressing Hazmat spills and events. The present system is relatively low-tech and usually requires first responders to arrive on the scene to determine the Hazmat involved and the appropriate response, procedures, and protocols.

Emerging technologies that address capability gap: There are technical systems in place that could send each vehicle's Hazmat load information to first responders in advance of their dispatch. These "Mayday plus" systems are relatively simple but require other technologies such as communication and GPS technologies.

Market adoptability rating: **3** (Low adoptability = **High market adoptability need**)

Rationale for market adoptability rating: These systems must be used in conjunction with other technologies.

Challenges/obstacles to market adoption: Based on the origin of the shipment, either from a customer location or a terminal, multiple parties would need to produce the advance information. In addition, carriers may perceive a low benefit-cost ratio for a program that requires data transmission on every Hazmat shipment.

I. **Vehicle Identification**—Vehicles can be quickly identified by first responders as well as back office personnel.

Technical capability rating: **8** (High capability = **Low technical capability need**)

Rationale for technical capability rating: Vehicles must display the name of the carrier, the city and state of domicile, the U.S. DOT number, a tractor number, and a trailer number. However, carriers may use rental trailers or tractors that have no identifiable carrier specific markings.

Emerging technologies that address capability gap: None identified.

Market adoptability rating: **9** (High adoptability = **Low market adoptability need**)

Rationale for market adoptability rating: Motor carriers must comply with these regulations.

Challenges/obstacles to market adoption: None identified.

J. **Hazmat Route Restrictions**—Some roadways, bridges, and tunnels prohibit trucks with Hazmat shipments. Additionally, motor carriers may impose further route restrictions on trucks hauling Hazmat shipments.

Technical capability rating: **8** (High capability = **Low technical capability need**)

Rationale for technical capability rating: Capability exists to determine whether a truck is traveling on the designated route.

Emerging technologies that address capability gap: GPS-based vehicle tracking systems for both tractors and trailers must be integrated with GIS mapping software to create geofences on specified routes.

Market adoptability rating: **4** (Medium adoptability = **Medium market adoptability need**)

Rationale for market adoptability rating: Similar to in-cab communication systems, these technologies are used mostly by medium to large carriers.

Challenges/obstacles to market adoption: Financial constraints and the need for technically sophisticated support staff.

K. **Driver ID Known**—The present system used for identifying drivers is the Commercial Drivers License (CDL). Operators of vehicles hauling hazardous materials are required to possess both a valid CDL and a Hazmat Endorsement. Capability exists to quickly verify that a driver is credentialed to operate a commercial motor vehicle and certified to haul Hazmat.

Technical capability rating: **8** (High capability = **Low technical capability need**)

Rationale for technical capability rating: In the past, CDL fraud was viewed as relatively commonplace (*45*).

Emerging technologies that address capability gap: Attempts to strengthen the program have included proposals to use biometrics and smart cards. Other systems have tested biometric devices on the truck for confirming driver ID.

Market adoptability rating: **1** (Low adoptability = **High market adoptability need**)

Rationale for market adoptability rating: As an emerging technology, these systems must be supported by substantial financial resources and back office personnel.

Challenges/obstacles to market adoption: Financial and institutional issues have typically interfered with these efforts.

Technology Development Priority—Highway Mode

Table D-1 is a recap of the functional requirement gap rating—highway.

Table D-2 is a recap of the mode importance rating.

Based on Tables D-1 and D-2, Table D-3 provides the development priorities for the highway mode functional requirements.

Extracted Screened Technologies—Highway Mode

Table D-4 contains technologies the modal lead selected from the screened research list as being most applicable for the highway mode. Technologies considered high priority development needs are in bold type.

1.2 Rail Mode

Functional Requirements—Rail Mode

NOTE: The rail mode has 10 functional requirements: 8 generic and 2 additional functional requirements.

Table D-1. Functional requirement gap rating—highway.

Market Adoptability Need Rating	Technical Capability Need Rating: Low	Technical Capability Need Rating: Medium	Technical Capability Need Rating: High
High	**Medium** H. Emergency Response K. Driver ID Known	**High** G. Security	**High**
Medium	**Low** A. Package Integrity C. Operator Performance D. HM Commodity ID E. Communication J. HM Route Restrictions	**Medium** F. Tracking	**High**
Low	**Low** B. Equipment Reliability I. Vehicle ID	**Low**	**Medium**

Table D-2. Mode importance rating.

	Modal Activity Level (Ton-Miles): Low	Modal Activity Level (Ton-Miles): Medium	Modal Activity Level (Ton-Miles): High
High	**Medium** Air	**High** Rail Barge	**High**
Medium	**Low**	**Medium**	**High** Truck Pipeline
Low	**Low**	**Low**	**Medium**

A. Package Integrity—Package is robust such that material contents are not breached during normal transport operations and typical accident conditions.

Technical capability rating: **6** (Medium capability = **Medium technical capability need**)

Rationale for technical capability rating: Existing rail tank cars have a proven record of survivability for typical accident/derailment conditions. Other types of railcars do not generally survive typical accidents without significant damage and loss of cargo, although they are sometimes used to transport potentially hazardous materials of many kinds. Spent nuclear fuel/waste from nuclear facilities is transported in highly developed, crash survivable casks developed per the Nuclear Regulatory Commission (NRC) and other federal requirements. The railcar on which the cask is carried does not provide any substantial additional protection against hazards. Rail tank cars

Table D-3. Functional requirement technology development priority—highway.

Mode Importance Rating	Functional Requirement Gap Rating: Low	Functional Requirement Gap Rating: Medium	Functional Requirement Gap Rating: High
High	**Medium** A. Package Integrity B. Equipment Reliability C. Operator Performance D. HM Commodity ID E. Communication I. Vehicle ID J. HM Route Restrictions	**High** F. Tracking H. Emergency Response K. Driver ID Known	**High** G. Security
Medium	**Low**	**Medium**	**High**
Low	**Low**	**Low**	**Medium**

Table D-4. Extracted screened technologies—highway.

Technology Need	Description	Potential Solution(s)
HIGH PRIORITY **Cargo container status sensors** ***(Tracking, Emergency Response)***	Sensors that document the presence, and potentially the amount, of cargo or other aspects of the container/trailer status. These sensors may detect the integrity, temperature, or the position of the door hatch.	Improvements to current sensors that can detect the existence of cargo include ultrasonic and IR sensors; pressure gauges and/or chemical detection sensors; fiber-optic sensors and photonic sensor integrated wireless systems; and container vibration patterns gathered from wireless RF sensor tags.
HIGH PRIORITY **Cargo/facility sensors** ***(Tracking, Emergency Response, Commodity Identification)***	Sensors to detect different types of cargo/substances.	Photonic or fiber-optic sensors are fixed point monitoring and mobile tracking. In fixed point monitoring, sensors monitor bridge and tunnel structural health and environment problems such as toxic gases in a tunnel. Mobile tracking sensor systems designed to track shipboard cargo containers and trucks have multifunctional sensor requirements including intrusion (tampering), biochemical, radiation, and explosives detection. May also include non-intrusive radiation portal monitors. These sensors may be used to detect accidental or malicious releases of hazardous materials.
HIGH PRIORITY **Innovative power sources for vehicle components** ***(Tracking)***	Battery charging, flexible batteries that never need to be recharged, electronics that can power themselves.	Wireless electrical or motion-powered technology; plastic thin-film organic solar cells with flexible polymer batteries; nanogenerators harnessing power from movement of flexible wires; very fast storage for solar power or a flash charge for cell phones and laptops.
HIGH PRIORITY **Improved area access control** ***(Security, Driver ID Known)***	Technologies that prevent unauthorized personnel from accessing restricted areas or identify behaviors indicating a security threat.	Improvements to current biometric authentication technologies including fingerprint, voice recognition, iris/optical scans and finger-vein recognition. A finger-vein identification system that could be used to allow a door to be opened simply by gripping the handle. Behavioral monitoring technologies. Trucks equipped with RFID tags. Directive antenna with middleware and received signal strength indication (RSSI) feature that makes the system more accurate and robust and avoids conventional problems.
HIGH PRIORITY **Advanced cargo locks & seals** ***(Security)***	Cargo locks and seals that can transmit cargo or trailer/container status to back office systems.	Improvements to positive locking mechanisms that can disarm and disable conveyance hatches and locks using low cost, plastic indicative seals with RF communications running on single battery with 4 years of life to support continuous monitoring; the external seals would have status and alarm notifications sent to a receiver with all messages stored at a data collection point, and using a remotely monitored sealing array (RMSA) with cryptographically authenticated messages (highly resistant to defeat). Electronic seals and other anti-theft monitoring devices.
HIGH PRIORITY **Vehicle security** ***(Driver ID Known, Security)***	Vehicle may be started and or operated by authorized operators once predetermined protocols are met.	Improvements to current Vehicle Disabling Technology (VDT) and Vehicle Shutdown Technology (VST). VDT does not allow vehicle restart while VST shuts down a vehicle that may be in motion.
HIGH PRIORITY **Operator Credentials** ***(Driver ID Known)***	Universally accepted security identification credential.	Credential should be simple and universally read and could include biometric authentication using smart card technologies.
HIGH PRIORITY **Vehicle/Trailer Tracking and Monitoring** ***(Tracking)***	Real-time vehicle or trailer tracking and visualization. Also used by geofencing technology.	Improvements to a current GPS-based instrument; cellular or satellite based tracking; Internet-delivered, remote asset telemetry Asset Management Platform using GSM communications; GSM-based GPS device with built-in RF receiver (for sensor reception), camera, and impact detector; and the use of geofencing to monitor vehicle or trailer movements.
HIGH PRIORITY **Intelligent Video Surveillance/Tracking** ***(Tracking)***	Capability to visually track Hazmat vehicles of interest (mainly trucks but possibly railcars and barges) along their passage in critical areas.	Intelligent video surveillance system capable of tracking Hazmat vehicle through high-threat urban area in real time using automated handoff from camera to camera; networked RFID combined with GPS and cargo monitoring.
HIGH PRIORITY **Alert/incident notification systems** ***(Security, Emergency Response)***	Hazmat safety monitoring software/applications.	Event data including Hazmat information received by sensor technology is transmitted to appropriate parties when an event occurs. In addition, exception-based notifications can be generated when events do not occur when scheduled. System also includes the ability to inventory vulnerable targets (e.g., critical infrastructure) and generate customized alerts of criminal incidents to appropriate officials. Digital photograph (using an IR flash for conditions of darkness) can also be included in the report.

will not survive all accident conditions. They have the potential to be punctured (by couplings from adjacent cars, displaced rail, ballistics, etc.). Other types of standard railcars are not highly suited to protecting potentially hazardous material from damage in an accident or derailment, and limitations on their use may vary by interpretation of rules or regulations by the shipper or the railroad.

There is a significant effort to further improve tank car survivability. These efforts involve both a retrofit of existing tank cars and new tank car designs. The FRA now requires that any new hazardous material tank cars built after March 16, 2009 must conform to new interim design specifications. These interim designs specify a stronger container which usually means a thicker tank. There is also an effort to improve survivability of the service connections on these tank-cars. New product loading and unloading valves that incorporate inner tank check-valve systems can now survive a top shearing event or rollovers without leaking. Because of these research efforts the technical capability of future designs will likely exceed the current interim designs.

Emerging technologies that address capability gap: Several technologies are being designed to improve tank car package integrity and survivability. The Federal Railroad Administration (FRA) is expected to require Hazmat tank cars to meet the resulting more stringent design specifications. There are 3 emerging redesigns of Hazmat tank cars.

Volpe Design—Specifications and a design from FRA for a super-tanker (nothing built yet). This specification was issued for comment April 1, 2008 (*46*). As a result of the comments and because no prototype car was built that could meet this specification, the FRA has delayed the issuance of a final specification. Instead the FRA has required that new cars built after March 16, 2009, must meet a new set of "interim" car specifications.

Advanced Tank Car Collaborative Research Program (*47*)—The roots of this effort began with a prototype design led by Dow Chemical and the AAR. Their design preceded the release of FRA specifications. The initial prototype car could not meet head-on impact specifications in the Volpe design. Currently this research program and the Next Generation Railroad Tank Car Program (NGRTC) have participation from both industry and government. It is expected that their work focused on improving the integrity of Hazmat tank cars will last several years and could drive a final specification from the FRA.

Trinity Car—The prototype car built by Trinity also preceded the FRA Volpe design specification. Currently, it will not meet head-on or side impact specifications in the Volpe design. The car does meet the FRA "interim" specifications. This car was available for purchase in early 2008 but was not readily adopted until the interim specification was made by the FRA allowing its use.

An FRA specification for a new super tank car design was released for comments in April 2008 (Volpe design). Because there were no proven prototypes that could meet the design, the FRA ruled in November 2008 that an interim car design is acceptable. The cost of fleet replacement is very significant so a phased-in approach is expected. In the interim rule, the FRA only requires that tank cars constructed of non-normalized steel must be retired before cars constructed of normalized steel. No changes were made to shorten an existing tank cars' lifespan. Because this is an FRA rule there will be 100 percent market adoption. However, it is expected that due to the research efforts led by the Advanced Tank Car Collaborative Research Program and the FRA, additional rule changes will likely occur as technology develops.

Enhanced tank car valves and fittings are also emerging as part of the technology packages that improve package integrity. For example, there is a new chlorine angle valve design whose primary seals are actually check valves located beneath the pressure plate which should survive without leaking even if the protective housing is sheared off. The newer designs include locating the pressure relief valves underneath the pressure plate also reducing the chances of a product release.

Market adoptability rating: **6** (Medium adoptability = **Medium market adoptability need**)

Rationale for market adoptability rating: Existing rail Hazmat transport packaging is regulated (Specifications for Railroad Tank Cars Used to Transport Hazardous Materials, 49 CFR (Code of Federal Regulations) 3468;3473 January 27, 1984). Shippers must use the approved container for the material transported. A rule was issued in November 2008 that requires chlorine car retirements to be replaced with an improved interim car designed to better withstand derailments. Even though an improved design is currently mandated by the FRA for replacement Hazmat tank cars, the market adoptability rating is discounted to 6 because there are only a few improved interim car designs currently deployed and no prototype cars exist that meet the FRA Volpe design specification. It is also likely that the existing interim design specifications will change as new package integrity improvements are made.

In addition to the tank car design, ancillary equipment, such as product loading/unloading valves, is also being improved to better survive shearing and rollovers. These new valve designs are just beginning to gain market adoptability.

Challenges/obstacles to market adoption: When designs and specifications are being adjusted and prototypes have not been proven, there is a tendency for a car owner to postpone adoption until final designs are approved. Currently, all new Hazmat tank cars built must be an improved interim design. These cars are more expensive than existing fleet designs and may not be the final design issued by the FRA. Car owners will likely postpone purchases of the new interim design as long as possible. It is also possible that replacements with the newer interim designed cars will be by attrition and only if there is no existing used stock available.

B. Equipment Reliability—Vehicle and cargo equipment are structurally sound and properly maintained.

Technical capability rating: **6** (Medium capability = **Medium technical capability need**)

Rationale for technical capability rating: There are several systems that have been pioneered by the railroads to detect mechanical problems associated with cargo transport. The AAR developed a program named Advanced Technology Safety Initiative (ATSI). One of the goals of ATSI is the detection and reporting of faulty equipment. This initiative incorporates three primary detection technologies.

The railroads currently have a limited number of wayside "Wheel Impact Load Detectors" (WILDs) in operation. A WILD senses wheel impacts generated by a passing railcar, for example, those caused by wheel defects such as flat spots or divots. If the impact caused by the wheel is deemed to be excessive, the train will be directed to reduce its speed and stop at the nearest railcar shop to uncouple the railcar with the wheel damage. The railroads also have a small number of "Truck Performance Detectors" (TPDs) in operation. (NOTE: a "truck" in this context refers to the structures underneath a railcar at both ends containing the wheels, axles, bearings, springs, and brakes). TPDs work by sensing sway stress on the rail and are used to detect truck hunting. (NOTE: "truck hunting" refers to a phenomenon in which wheels of a railcar truck begin to oscillate from side to side between the rails of the track, causing eventual damage to both the rail and the railcar.) The railroads are also testing "Trackside Acoustic Detectors" (TADs). TADs "listen" for abnormal sounds from passing trains and are designed to detect bad wheel bearings. The data from these detectors are compiled, maintained, and analyzed in the AAR Integrated Remote Railway Information Service (InteRRIS®) database. Notifications to the car owners are generated based on this analysis.

There are existing FRA regulations requiring preventative railcar, track, and roadbed maintenance. These rules specify how long certain equipment parts can operate without inspection. Regulatory maintenance information is required to be stenciled on certain railcar types. Regular inspection and maintenance of the infrastructure is required by regulation for safe train movement, and movements are restricted by railroad rules when infrastructure deficiencies are found. In addition, freight railroads have operating rules for train "consists" which isolate hazardous cargo and reduce the consequences of a train accident involving such material.

Significant advancement in detecting faulty rolling stock has occurred in the last decade. Despite the advancement in technology used by Class I railroads, there are rail corridors (short lines, regional) where ATSI technologies have not been applied. Access to data is not free to the car owners and many owners depend solely upon notification from the AAR concerning faults detected. There is consensus that the railroads benefit from this technology much more than do the car owners. The car owners incur costs associated with maintenance required before the specified regulatory due dates. Most fault detection efforts have been focused on rolling stock and the damage it does to the rails.

There is not a good system that has been widely deployed for detecting broken rails or damaged track switches in non-signaled territories. Currently, track integrity and condition is maintained primarily as a result of automated track flaw detection vehicles or manual maintainer inspections for un-signaled territories. In signaled territories of the railroads, the track circuits and switch controllers provide vital protection against some broken rail and track switch failure conditions. The rest are found by the manual inspection method.

Restrictions on Hazmat cargo placement in train consists are variable and determined by each railroad, even though the best practice could be codified as part of the General Code of Operating Rules (GCOR) or the Northeast Operating Rules Advisory Committee (NORAC) standard Operating Rulebooks. The current content of these rulebooks only provides general guidance as to being aware of and vigilant about identified hazardous cargo (*48, 49*).

Emerging technologies that address capability gap: There are several emerging technologies designed to improve defect detection in rolling stock. Advances in machine vision systems will permit wheel profile defect detection. Thermal sensing devices are being tested to determine wheel bearing health. Recent advances in accelerometer technology sensors can differentiate between impacts and sway allowing truck hunting and bad track detection. Wireless sensor technology could also allow easier installation on railcars and data communication between rolling stocks sensors and wayside readers. There are a couple of technologies being considered for detection of rail breaks. One uses acoustic wave transmission/sensing and was tested on a short span of track in the New York City transit system in 2006. The other uses electric current flow analysis. Both techniques offer a potential additional benefit of detecting vehicle presence within their monitoring zones.

Market adoptability rating: **6** (Medium adoptability = **Medium market adoptability need**)

Rationale for market adoptability rating: Preventative maintenance of rolling stock is regulated by the FRA. The AAR ATSI program is sponsored and promoted by its Class I railroad membership. ATSI detection systems are typically not deployed on short or regional rail lines because of the lack of infrastructure and costs. The AAR issued rules providing for on-site repair of conditions found by their detectors with car owners bearing the repair costs. Shippers and car owners typically do not implement fault detection systems within their domain due to a lack of infrastructure and costs. Instead they rely on regulatory preventative maintenance and manual inspections.

Challenges/obstacles to market adoption: The Automatic Equipment Identification/Car Location Messaging (AEI/CLM) system along with the WILD wheel detector, TPDs, and TADs must communicate their alerts back to a central database at Railinc. The cost of these new wayside sensor systems impedes their growth on Class I railroads and prohibits adoption by most short-line railroads. In addition, these systems must have infrastructure to do that communication and properly power these detectors. The costs of the infrastructure required to support these sensor systems are very large. Finding a lower cost support infrastructure such as low power and wireless capable could improve adoptability.

C. Operator Performance—Operator performance is being able to successfully maneuver vehicle under normal and off-normal conditions. Capability also exists to sense operator performance degradation due to fatigue, acute health problem, substance abuse, and so forth, and to alert operator and back office to this situation. Additional capability to control train movement in a safe manner in absence of proper operator vigilance has been deployed in some areas, and is under development for others.

Technical capability rating: **7** (High capability = **Low technical capability need**)

Rationale for technical capability rating: Operator fatigue, particularly involving the engineer and train conductor, can have dramatic consequences. Accidents have happened within the last 5 years where operator fatigue was listed as a primary root cause. Solutions to operator fatigue have remained on the NTSB Most Wanted list since 1990. Currently, operator fatigue has been addressed by a series of implemented crew scheduling practice recommendations. FRA Regulations provide mandatory hours of service limitations on railroad workers, and are very specific and tightly enforced. These regulations have been in effect since 1907 (*50*). Most railroads have advanced software packages that generate crew scheduling which attempts to comply with the hours of service rules or flag any exceptions for crew management action.

A limited number of high-density or high-speed railroad lines are protected from many unsafe crew errors by systems generally referred to as "Cab Signal" systems. These systems use failsafe means of conveying train speeds to the cab and displaying the required speed to the operator, and provide warning and alarms to the train operator for unsafe conditions in real time. In some of these applications, braking is automatically enforced if the train operator does not respond to the warning in an appropriate manner. Cab signal systems have been in use for many years, and in combination with "dead-man" control, prevent operator inattention from causing some accidents.

The majority of Class I U.S. railroads are currently developing, testing, or demonstrating radio-based Positive Train Control (PTC) systems in compliance with upcoming FRA regulations in 49 CFR Part 236, Subpart I. These systems protect against human errors in complying with signals, speed limits, switch positions, etc. by sensing train location and speed, comparing them with the current railroad conditions and infrastructure, and automatically applying brakes as needed for safety. One of the additional capabilities of PTC systems is to monitor the crew's timely response to restrictions, work authorities, track authorities, and signal aspects. Failure to comply with the rules to allow the PTC system to provide protection is an indication (in near real time) that the train is not being controlled safely. Therefore, central dispatchers can observe crew behavior and take appropriate action.

Gaps: The current fatigue prevention system relies on mandatory scheduling of adequate off-hour rest periods and by having human redundancy in the cab. These approaches are not totally effective, and cab signal or PTC train controls are not widely applied at this time. Several versions of PTC are being tested but there is no agreement as to which system is preferred. An accident involving a freight and passenger train in Chatsworth, California, on September 12, 2008, resulted in multiple deaths and has resulted in pressure to adopt a standard PTC system.

The conductor should notice micro-sleep or macro-sleep episodes and alert the engineer. This is facilitated by current railroad rules requiring verbal confirmation of all switch positions and signal aspects among the crew and with the central dispatcher by radio. In addition, the train engineer and conductor communicate with each other at frequent intervals.

There is some thought that emerging technologies such as positive train control and remote control locomotive systems will reduce vigilance by removing the human redundancy. The counter-assertion is that a properly applied failsafe PTC or cab signal system is more likely to safely respond to unsafe conditions than a second person. In addition, many AMTRAK trains already operate with a single crew member in the cab.

Emerging technologies that address capability gap: Engineman Vigilance Monitoring is an FRA project to explore new technology to monitor real-time locomotive engineer alertness. The same technologies applied to monitor truck driver alertness can be applied here.

PTC can also be considered an emerging technology as various systems are being offered, and standardization of PTC for inter-line operation of trains is just now under development by AAR and the individual railroads. Fully failsafe PTC systems require substantial testing to ensure safety and reliability.

Market adoptability rating: **6** (Medium adoptability = **Medium market adoptability need**)

Rationale for market adoptability rating: The AAR has recognized and promoted research in fatigue management since 1992. The AAR "Work Rest Task Force" along with the "North American Rail Alertness Partnership" identified key principles of an effective fatigue countermeasures program. Class I railroads do employ work schedule policies and these countermeasures to manage operator fatigue. There are some that use the Operator Fatigue Management (OFM) tools to manage this. Many railroads have policies that allow operators to nap under controlled conditions. Some of the non-vital real-time alertness monitoring devices are still considered experimental and have not been deployed on board locomotives.

The NTSB has listed PTC as one of its top 10 needed transport safety improvements for over a decade. The Class I railroads are presently investing significant resources in developing and applying PTC systems for capacity improvement, which will also provide the noted significant benefits for safe train control in both signaled and non-signaled (dark) territory.

Challenges/obstacles to market adoption: The cost of PTC is estimated to be $10 billion U.S. dollars to the Class I railroads. Since it is now mandated by Rail Safety Improvement Act (RSIA) 2008, some federal monies (stimulus funds) have been made available to support this implementation. However, these systems are very complex and will require extensive verification and validation. PTC systems are not mature technology. There is a significant development effort required to make the individual PTC implementations interoperable as a standard such that locomotives can interchange on PTC lines. It will be a challenge to develop and implement an interoperable PTC by the 2015 deadline.

D. Hazmat Commodity Identification and Awareness—Ability to identify the cargo being shipped either in person or via remote access.

Technical capability rating: **7** (High capability = **Low technical capability need**)

Rationale for technical capability rating: All Hazmat shipments by rail are required to be placarded and listed on the train's construct manifest (consist). Information is also maintained by the railroads management systems. A uniform set of hazardous material identification methods, handling, and definitions is required to be understood and carried by every rail crewmember (*51*). There is an express need by emergency responders to quickly retrieve this information without risking life in an attempt to read a placard or locate the engineer.

Emerging technologies that address capability gap: There is a desire for devices such as a transponder broadcasting content information triggered by irregular impacts or axis modification. Deployment of RFID technologies and satellite-radio identification (ID) tags with GPS or GLS for cargo module identification and localization on a continuous or frequent intermittent basis has begun, with several vendor products on the market. These technologies have the ability to identify the exact contents of Hazmat cargo, the responsible party for the cargo, and even the proper means of hazard containment and hazard mitigation, accessible to the authorized personnel for the public safety forces, federal authorities, shippers, and railroads affected.

Market adoptability rating: **9** (High adoptability = **Low market adoptability need**)

Rationale for market adoptability rating: All Hazmat shipments must be placarded and recorded on the train's consist. Shippers and railroads are adopting radiolocation and RFID tagging for Hazmat cargo as the technology is deployed.

Challenges/obstacles to market adoption: Not applicable—all Hazmat shipments are placarded.

E. Communication—Vehicle operator and back office have two-way communication capability at all times. This may take the form of verbal communication or data communication, preferably both are available.

Technical capability rating: **6** (Medium capability = **Medium technical capability need**)

Rationale for technical capability rating: Current technologies are through a variety of radio, cellular, microwave, and satellite wireless technologies that are used for voice, text, and data transmissions. No one communication technology is 100 percent capable. Satellite technologies depend on view (i.e., tunnels, subway, overpasses, and canyons cause problems). The other technologies depend on sufficient coverage and transmission/reception range. Combination communication technologies can provide nearly 100 percent capable systems but, unfortunately, application of redundant communication technologies is not widespread. Class I railroads are now using multiple radio systems on trains for voice (Very High Frequency or VHF, cellular) and data (VHF, Ultra High Frequency or UHF, and satellite). Many regional and shortline railroads depend solely on VHF voice technology which can fail due to available coverage and/or range. Deployment of additional radio devices is regulated by the FCC, which is faced with frequency and bandwidth allocation issues, complicated by international spectrum allocation rules as well.

Emerging technologies that address capability gap: GSM-R is now being combined with the General Packet Radio Service (GPRS) to form the basis for an Intelligent Transport System in Europe. GSM is expected to be combined with satellite and radio to provide near 100 percent capable communications. In the United States, 802.11 short range communication standards are expected to include "Wireless Access in Vehicular Environment" (WAVE). The concept is to exchange data between high speed vehicles and other vehicles or wayside readers. The FCC has mandated a VHF Frequency Re-farming into 12.5 kHz channels (vs. 25 kHz) in the Railroad Radio services (*52*). This provides the opportunity for additional channels to be applied for improved coverage.

The AAR is sponsoring development of a high-performance Software Defined Radio, which will allow much more flexible transmission options for both voice and data for railroad purposes, improving overall communication success. The railroads are also permitted under FCC rules to add various forms of UHF and/or Microwave links for PTC data purposes. These options, and the ability of PTC to require fewer voice radio conversations with trains (e.g., sending of track authority digitally), will also improve communications. Cellular telephone service is now in service as supplemental communications for train crews and field personnel of the railroads.

In addition, "smart" locomotive radio equipment could be used as a repeater from another locomotive to a base station radio to increase coverage. This could be incorporated in the new AAR High-Performance Radio development.

Market adoptability rating: **8** (High adoptability = **Low market adoptability need**)

Rationale for market adoptability rating: 100 percent communication capability and reliability to the rail crew is important to the railroads. It improves safety (dark regions) and efficiency. Adoptability is primarily affected by lack of, and the cost of, supporting communication infrastructure. Capacity improvements offered by PTC systems may serve as a way to justify and implement additional infrastructure.

Challenges/obstacles to market adoption: The RSIA 2008 requires implementation of PTC by 2015. It is expected that this implementation will upgrade communications capabilities. Costs of the infrastructure upgrades are the biggest obstacle.

F. Tracking—Vehicle and cargo location are known at all times, and can be monitored remotely.

Technical capability rating: **6** (Medium capability = **Medium technical capability need**)

Rationale for technical capability rating: Current technology is a mix of techniques. It includes passive reads of low-frequency RFID tags on all railcars and locomotives from wayside readers. This provides intermittent location. GPS tracking devices are implemented on many train power units (i.e., locomotives) for the primary purpose of unit health reporting, but this also provides low resolution location reporting. PTC systems allow high resolution tracking of trains and their associated cargo consists. The AAR provides a computerized shipment tracking service that originated in the 1950s that currently identifies which train, known to be traveling between two major stations, contains the Hazmat cargo on a certain railcar.

All railcars are required to have Automatic Vehicle Identification (AVI) or AEI tags on them but the wayside, RFID readers are geographically sparse, and are not often on low-volume tracks. GPS coverage requires a good view of at least two GPS satellites at frequent intervals. Some locomotives have tracking capability such as GPS but individual non-powered railcars do not. Those few railcars that do have GPS and radio report only periodically to conserve on-board power. The current shipment tracking services are neither highly precise as to location, nor are they in real time. In 2009, DHS and the Federal Emergency Management Agency (FEMA) recognized tracking as a gap and have targeted a part of the FY 2009 Freight Rail Security Grant Program (FRSGP) to fund TIH car owners to equip a portion of their cars with GPS devices.

Emerging technologies that address capability gap: Nationwide Differential Global Positioning System (NDGPS) or Differential Global Positioning System (DGPS) provides more accuracy (~5m resolution) compared with (~15m) of standard GPS. Higher accuracy could provide enough resolution to provide track specific location in dense rail yards and may facilitate adoption as a cost saving measure. Assisted GPS (AGPS) or enhanced GPS (EGPS) allows use of GPS in "bad view" areas by assisting GPS with Wireless Cell Site location using various techniques. New battery designs and more efficient solar charging units can improve availability of these tracking devices.

Some PTC systems have, as part of their database for each train, the "consist" which includes information on Hazmat cars. Conceptually, these trains can be identified very precisely on the track in real time for cargo location and tracking purposes.

Market adoptability rating: **3** (Low adoptability = **High market adoptability need**)

Rationale for market adoptability rating: Increasing the number of wayside readers and the infrastructure required is costly. Some railroads have as much as 60 percent dark territory (i.e., no signaling). The AVI wayside readers are independent of the signal system, but the communications to a central location is often through the signal system infrastructure. GPS tracking technologies on Hazmat rail tank cars are being tested by a few shippers but less than 1 percent of the Hazmat tank car fleet has been equipped. Shippers have cited a lack of logistic benefit as one reason. Shippers also believe that responsibility for safety and security of the Hazmat asset lies with the custodian of the asset. There are also liability concerns around response to alarms from sensor equipped GPS devices. AAR is considering an interchange rule to require private car owners to share tracking data with the railroads to supplement the wayside tracking system. If such an interchange rule were to occur, then the adoptability would increase to 100 percent. Current battery and charger technologies will not permit continuous radiolocation tracking on non-power tank cars due to power requirements of the devices. Continuous tracking on powered units is possible and is enabled by emerging technologies such as PTC. Emerging communication technologies such as WAVE would certainly play an important role in PTC.

Grant programs such as FY 2009 FRSGP could dramatically improve adoptability.

Challenges/obstacles to market adoption: Because of the low costs associated with the current CLM technology there is not a good business case for investing in GPS technology independent of the safety and security benefits. TSA and FEMA recognized this and implemented a grant program (Freight Rail Security Grant 2009) for Hazmat car owners to equip their tank cars with GPS. This program is expected to equip approximately 20 percent of the U.S. Hazmat fleet in 2010.

G. Security—Vehicle, cargo, and operator are resistant to theft, diversion, sabotage, and intentional acts.

Technical capability rating: **3** (Low capability = **High technical capability need**)

Rationale for technical capability rating: As of June 16, 2008, PHMSA adopted interim rules that reiterate the rail carriers' obligation to address in their security plans issues related to en-route storage and delays in transit. Moreover, it adopts a new requirement mandating that rail carriers inspect placarded Hazmat railcars for signs of tampering or suspicious items, including improvised explosive devices. The rulemaking was developed by PHMSA in consultation with the FRA (*53*). Existing railroad policy is to not leave loaded Hazmat railcars unattended in unmanaged yards. Most managed yards have 24-hour security presence in the yards. Some large managed yards are equipped with video surveillance. The U.S. Coast Guard has initiated a mandate requiring a new credential for transportation workers. A Transportation Workers Identification Credential (TWIC) will be required for unescorted workers entering secured areas. The TWIC technology involves an extensive background search and deep sensing biometric fingerprint reading. Marine ports have taken the lead in adopting this ID system. The FAQ section of TSA's TWIC website states "At this time, the TWIC program is focused on the maritime mode, specifically MTSA-regulated facilities and vessels." (Note: MTSA stands for Maritime Transportation Security Act.) And while the U.S. Coast Guard would prefer that all crew members of a train entering a secured port area possess a TWIC, that has not been made an absolute requirement (i.e., there are approved equivalent entry processes that train crews can follow).

Equipment tampering technologies exist but are not readily used. An example is an open door or dome sensor on a tank car. Sensors must be coupled with a GPS tracking device to do near real-time alerting. The railroads do not own the Hazmat railcars they transport so the car owners would have to provide asset tampering detection solutions. The AAR is considering an interchange rule to require sharing GPS tracking data and alerts received by the private equipment owners with the railroad of custody.

One only has to look at the presence of graffiti on railcars to see evidence of the gaps in security associated with rail freight transportation. The U.S. rail system has 140,000 miles of track. It is cost prohibitive to fence or frequently patrol this entire system. The current capability is primarily a rail security policy enforcement designed to keep loaded Hazmat moving or in a secure yard. The upcoming rule for more secure Hazmat routing is only intended to minimize the risk from attack, not to prevent it.

Emerging technologies that address capability gap: One current approach taken by TSA involves periodic rail corridor assessments for Hazmat transport through high threat urban areas. Some high value corridors have been identified and pilot projects to enhance security using technology is currently underway. These technologies involve installing virtual fence that detects moving objects and perimeter breaches. Some wayside readers were modified to use sensor technologies such as gas or explosives detection. One such corridor is a 7-mile corridor through Washington, DC. New technologies are being tested by the FRA and AAR at TTCI that would permit covert remote control operations of rail locomotives including an emergency stop.

Cooperative arrangements between shippers and carriers to share tracking and sensor data would improve situational awareness and response. Emerging security related sensor technology includes smart impact detection, event triggered site image capture, leak detection, smart locking, and tamper detection. The AAR, CHEMTREC, and shippers are currently working on a communication standard to permit tracking and sensor data sharing. The AAR began a pilot test of this data transfer with 2 shippers in August 2008.

Market adoptability rating: **4** (Medium adoptability = **Medium market adoptability need**)

Rationale for market adoptability rating: Much of the funding related to rail security has been applied to passenger rail (mass transit) through TSA priorities on protection of the general public. Because of the size and numbers of rail yards in the United States, the installation of video surveillance is costly. The railroads are adding their own video yard monitoring capabilities selectively. The Class I railroads have their own police and train their employees annually on security. Private rail car owners have not been able to justify the costs of implementing GPS sensor technologies from a logistics benefit. Many see the primary responsibility for security once consigned to the railroad as the carrier's since they have custody of the asset. Cost sharing between the government, carriers, and the car owners for such technologies has not yet materialized.

Challenges/obstacles to market adoption: It is a monumental task to secure 140,000 miles of track in the United States. It is difficult to determine where to apply limited resources. TSA and FEMA recognized this and implemented a grant program (Freight Rail Security Grant 2009) to help fund efforts to support security awareness and emergency response training for frontline Class I employees. Class II and III railroads can also apply for funds supporting vulnerability assessments and security plan development. Car owners can use funds to equip their tank cars with GPS from this program. It remains a challenge to properly secure that much territory using limited resources.

H. Emergency Response—Qualified emergency response is delivered to the incident site in a timely manner wherever it may occur.

Technical capability rating: **6** (Medium capability = **Medium technical capability need**)

Rationale for technical capability rating: Under federal law, notification of emergencies involving releases of reportable quantities of hazardous materials must be made to the National Response Center. Local emergency response organizations are also notified. The Occupational Safety and Health Administration (OSHA) requires the implementation of the Incident Command System (ICS). An ICS is a combination of personnel, policies, procedures, and equipment working together within a common organizational structure with responsibility for management of assigned resources to effectively accomplish stated objectives at the scene of an accident. Hazmat shipments are identified by placards and stenciling on the railcars. Industry services such as the ACC's "Chemical Transportation Emergency Center" (CHEMTREC) provide a 24-hour response hotline. They will provide information and assist in contacting the manufacturer, carrier, and shippers.

Member companies often have trained response teams that can be deployed to the accident scene to assist local responders. To receive financial and technical assistance under FEMA's grant programs, state governments must develop and update a 4-year exercise program for validating emergency preparedness and response. FEMA, shippers, community responders and major carriers conduct regular cooperative response exercises. At its Pueblo, Colorado, facility, TTCI provides training to responders on Hazmat accident mitigation and methods for prevention and containment of hazardous emissions. Automated detection and notification of release information could speed up response but is considered experimental and not currently deployed. Costs, reliability, and false triggers hinder deployment of such systems. Rail accident sites are often difficult to access by road thus delaying response.

Smart GPS devices with sensors are being developed and tested. Such systems could detect spills or leaks and notify responders with information such as location, materials, and quantities. Together with GIS data systems, responders can quickly access information such as access routes, weather conditions, and population density and produce a more complete threat assessment. Sophisticated railroad dispatch systems include databases of hazards, local public safety contacts, and shipper contacts related to Hazmat. Even more precise information would be available from PTC systems as they are deployed.

Market adoptability rating: **9** (High adoptability = **Low market adoptability need**)

Rationale for market adoptability rating: The rail industry must implement emergency response as an essential part of operating their business. Maximizing response while minimizing response time is a primary goal of emergency management. Technology to speed emergency response must be reliable and properly filtered with no false alarms. The liability caused by responding to false alarms must be reduced or eliminated.

Challenges/obstacles to market adoption: The rail industry and Hazmat manufacturing industry recognize the importance of effective emergency response. Automated systems that do early detection and alerting can also provide false indications which could result in liabilities to the message receiver and costs associated with responding. Such systems must be adequately filtered and validated before there will be significant acceptance. Emergency first responders need rapid identification and relevant information on the hazardous materials they are required to mitigate. Emergency responders, outside of industry, are community based local fire fighters and emergency workers. They are often first on the scene but often have the least amount of information initially.

I. Vehicle Identification—Vehicles can be quickly identified by first responders as well as back office personnel.

Technical capability rating: **8** (High capability = **Low technical capability need**)

Rationale for technical capability rating: Tank cars must display their unique identification mark. These must be stenciled in particular locations which typically include both sides and the top. The Hazmat material and hazard associated with that material is also stenciled on the side of the car. The technical rating is an 8 instead of a 9 because of the need expressed by emergency responders to identify a tank car and its contents from a distance. There is some discussion in the emergency response functional requirement concerning this.

Emerging technologies that address capability gap: Not applicable.

Market adoptability rating: **9** (High adoptability = **Low market adoptability need**)

Rationale for market adoptability rating: Tank car owners must comply with these regulations.

Challenges/obstacles to market adoption: Not applicable.

J. Hazmat Route Restrictions—Routes are selected in part based on minimizing risk to people and the environment.

Technical capability rating: **8** (High capability = **Low technical capability need**)

Table D-5. Functional requirement gap rating—rail.

Market Adoptability Need Rating	Low	Medium	High
High	**Medium**	**High** F. Tracking	**High**
Medium	**Low** C. Operator Performance	**Medium** A. Package Integrity B. Equipment Reliability	**High** G. Security
Low	**Low** D. HM Commodity ID I. Vehicle ID J. HM Route Restrictions	**Low** E. Communication H. Emergency Response	**Medium**

Technical Capability Need Rating

Rationale for technical capability rating: As of June 16, 2008, PHMSA adopted interim rules for routing of trains transporting the most toxic and dangerous hazardous materials in rail tank cars. Under the interim rule, rail carriers must complete a comprehensive safety and security risk assessment of their primary routes and any practicable alternative routes, beginning June 1, 2008. This is intended to promote improved security of trains against malicious attacks that would endanger larger than necessary populations. The AAR is doing work on generating routing algorithms that use the required factors and produce routes which are approved by PHMSA.

***Market adoptability rating:* 9** (High adoptability = **Low market adoptability need**)

Rationale for market adoptability rating: The rail industry must implement this required route analysis as an essential part of operating its business. Because this is a requirement for all railroads by the end of 2010, the market adoptability is high.

Challenges/obstacles to market adoption: Not applicable. Hazmat routing will be a requirement.

Technology Development Priority—Rail Mode

Table D-5 is a recap of the functional requirement gap rating—rail.

Table D-6 is a recap of the mode importance rating.

Based on Tables D-5 and D-6, Table D-7 provides the development priorities for the rail mode functional requirements.

Extracted Screened Technologies—Rail Mode

Table D-8 contains technologies the modal lead selected from the screened research list as being most applicable for the rail mode. Technologies considered high priority development needs are in bold type.

1.3 Marine Mode

Functional Requirements—Marine Mode

NOTE: The marine mode has the eight generic functional requirements.

Table D-6. Mode importance rating.

Serious Consequence Potential (Volume Per Shipment)	Low	Medium	High
High	**Medium** Air	**High** Rail Barge	**High**
Medium	**Low**	**Medium**	**High** Truck Pipeline
Low	**Low**	**Low**	**Medium**

Modal Activity Level (Ton-Miles)

Table D-7. Functional requirement technology development priority—rail.

Mode Importance Rating	Low	Medium	High
High	**Medium** C. Operator Performance D. HM Commodity ID E. Communication H. Emergency Response I. Vehicle ID J. HM Route Restrictions	**High** A. Package Integrity B. Equipment Reliability	**High** F. Tracking G. Security
Medium	**Low**	**Medium**	**High**
Low	**Low**	**Low**	**Medium**

Functional Requirement Gap Rating

Table D-8. Extracted screened technologies—rail.

Technology Need	Description	Potential Solution(s)
HIGH PRIORITY **Materials to Improve Equipment Crashworthiness** *(Package Integrity, Equipment Reliability)*	Derailments will occur and Hazmat containers need to survive these events. New materials and container designs are needed.	Specialty and treated steels, engineered metal structures such as corrugated crumple energy absorbing designs, structural foams and composites are needed. Self sealing technologies, impact resistant coatings, protected recessed valves and fittings. Hazmat tank car design specification is regulated.
HIGH PRIORITY **Rail Infrastructure and Equipment Defect Detection** *(Equipment Reliability)*	Most derailments are due to either defects in rail infrastructure or rolling stock.	Improved infrastructure material such as concrete or composite ties. More defect detection technologies such as GPS-based truck hunting detectors, acoustical bad bearing detectors, wild wheel detectors, automated rail defect survey equipment, and track integrity sensor systems.
HIGH PRIORITY **Cargo Content Identification** *(Cargo Identity, Tracking)*	Wireless identification of Hazmat contents detectable by locomotive and emergency responders.	Networked RFID tag on each railcar with interrogators on locomotive and emergency responders; load contents and macro data via memory stick on tank cars; data could be networked via wireless repeaters or electronic brake wiring on cars to front and end of trains.
HIGH PRIORITY **Cargo Condition Sensors** *(Tracking, Emergency Response)*	Sensors to detect diminished container integrity, loss of material, temperature, hatch open/close, penetration by other than hatch opening.	Pressure gauges and chemical detection sensors combined with other sensors such as Impact could alert via GPS devices of security and derailment events. Embedding image collecting could provide visual information and evidence concerning the event.
Anti-Collision Systems *(Operator Performance)*	Anti-collision systems such as Positive Train Control (available but not widely adopted) and driver assistive systems.	Several versions of a positive train control system are currently available but are not widely adopted due to costs and lack of a standards technology. A technology standard is required because locomotives often move on different Class I railroads and incompatibility issues could occur. Other technologies could also help prevent collisions due to inattentiveness or sleeping such as mini-cameras to monitor driver's eye and eyelid movements; devices that record heart rate, blood pressure, respiration, and brain waves; the use of risk perception algorithms to determine whether the locomotive is being operated safely.
HIGH PRIORITY	Standard GPS requires a good view of the sky and is not functional in tunnels and ravines. Enhanced GPS uses additional techniques to continue to acquire tracking data even under these conditions.	Fusion of imaging and inertial sensors (including the use of LIDAR and Doppler) that result in GPS-level navigation precision; beacon-based navigation (including pseudolites); signals of opportunity (SoOP).

(continued on next page)

Table D-8. (Continued).

Technology Need	Description	Potential Solution(s)
HIGH PRIORITY **Innovative GPS and Sensor Power for Non-powered Vehicles** *(Tracking)*	Tank cars do not have a power source available to supply GPS and sensor devices. Frequent reporting requirements mandate a reliable power source. Battery recharging, flexible batteries that never need to be recharged, electronics that can power themselves are needed.	Bearing or axle generator recharging capability on rolling stock. Wireless electrical or motion-powered technology; plastic thin-film organic solar cells with flexible polymer batteries; nanogenerators harnessing power from movement of flexible wires; very fast storage for solar power or a flash charge for cell phones and laptops.
HIGH PRIORITY **Universal Security ID for Transportation Industry** *(Security)*	Almost every organization interviewed expressed a strong desire for a single universal security ID system. Many Hazmat shippers use DHS CFATS IDs and U.S. Coast Guard ports require TWIC IDs. The railroads require their own ID systems. There is a need for a single system.	There are several advanced security ID systems available. Chemical factory workers IDs (CFATS) and transportation worker IDs (TWIC) systems are new and use biometric + PIN technologies to verify a person's identity. Standardizing IDs for Rail, Truck, Barge, and AIR would reduce costs and allow for these ID technologies to be leveraged with other technologies such as smart locking or sealing systems.
HIGH PRIORITY **Advanced Cargo Locks & Seals** *(Security)*	Conveyance hatch seals today are simple mechanical cables that are easily cut by pliers or cutters. They are designed to alert the receiver that someone tampered with the cargo but do not hinder the tampering or generate an alert in real time.	Improved positive locking mechanisms that can disarm and disable conveyance hatches. Smart locking mechanisms could be combined with smart card ID recognition such as TWIC and only open when a properly credentialed person attempts to access it. It could also be programmed to differentiate geofenced behaviors. Seals could be equipped with break wire technology and provide alerts via GPS concerning seal breakage when not within a shipper or customer geofence.
HIGH PRIORITY	Improved detection of foreign devices and defects on shipping stock.	High resolution camera systems triggered by AEI reader technology can auto capture images of tank cars. Analysis systems could be applied based on that tank car's profile to identify foreign devices and potentially defects in the equipment. Such systems when applied to tank cars' exiting facilities could supply additional documentation for Chain-of-Custody transfer.
HIGH PRIORITY **Tank car tracking** *(Tracking)*	Real-time visual vessel tracking, including vessel name, speed, course, etc.	Intelligent video surveillance system capable of tracking Hazmat tank cars through high-threat urban area in real time using handoff from camera to camera; Networked RFID (AEI) combined with GPS and cargo monitoring; Internet-delivered, remote asset telemetry Asset Management Platform using GSM or satellite communications; GSM-based GPS device with built-in RF receiver (for sensor reception), camera, and impact detector; and the use of geofencing. Redundant communication techniques (GSM failover to satellite) could be combined to improve message delivery in dark cellular areas.
HIGH PRIORITY **Alert/incident notification systems** *(Security, Tracking)*	False alarms from sensor systems are barriers to adoptability. They are costly and generate liabilities. Technology is needed to provide alarm filtering such that confidence in sensor data is enhanced. Such systems will combine multiple sensors with infrastructure information to decide how to treat an alert. Systems could automatically notify the proper agencies based on this assessment.	Event data received by sensor technology is compared with programmed values in data tables to identify matches indicating an actual/emerging problem. When such patterns are identified, alert messages are automatically sent via fax, email, pager, text message, and/or voice message. System also includes the ability to inventory vulnerable targets (e.g., critical infrastructure) and generate customized alerts to appropriate officials. Digital photograph (using an IR flash for conditions of darkness) can also be included in the report.
HIGH PRIORITY **Universal communications interface standard** *(Security, Tracking, Emergency Response)*	There is a strong desire by government, railroads, shippers and Hazmat responders to use a standard universal communication interface for communicating credible threats, tracking, and alert information to the proper agencies. Currently, there is no standard definition for such an interface.	XML definitions and secure data protocols for communicating credible threat information, tracking data, sensor data and alert notifications between stake holders. A central secure data-repository for such information where business proprietary data is protected but stake holders can access needed tracking, content, and response information.

A. Package Integrity—Package is robust such that material contents are not breached during normal transport operations and typical accident conditions. Capability exists to sense/detect pressure build-up and/or material release.

Technical capability rating: **8** (High capability = **Low technical capability need**)

Rationale for technical capability rating: Hazmat cargo carried by the marine mode is typically in bulk using specialized barges, open sea tankers, or containers. While these may be breached due to collision, allision, or grounding, such events are relatively rare (although the consequences can be significant). Tankers are being converted to double hulls in an effort to reduce spill likelihood. Note, however, that an unintended consequence of double-hulled vessels can be that if flammable materials seep from the inner hull, these fumes may ignite if exposed to a spark caused by a grounding, allision, or collision that punctures the outer shell; in such instances, the entire cargo could explode and burn. Technologies to sense/detect pressure build-up and/or material release are not in wide commercial use at this time.

Emerging technologies that address capability gap: Being tested today are technologies to detect and send an alarm for pressure changes of container contents, spills/leaks, and hatch status (open or closed), with readings to be sent by satellite. Coupled with these systems is the ability to send photo images of the impact area. One important concern is to provide sufficient power such that safe (i.e., spark resistant) and frequent readings can be made and transmitted (see discussion under "F. Tracking").

Market adoptability rating: **8** (High adoptability = **Low market adoptability need**)

Rationale for market adoptability rating: Most of the industry uses the same type of packaging, although the extent to which various sensors are utilized will depend on the nature of the cargo and the availability of resources to invest in this technology.

Challenges/obstacles to market adoption: As technology is implemented to provide sensing/detection capability, depending on installation and operating cost, it may be that only the larger, more financially secure carriers will opt to use this capability. The remainder of the industry may follow, however, if required to do so by regulation or if the cost of implementation is affordable.

B. Equipment Reliability—Vehicle and cargo equipment are structurally sound and properly maintained. Capability exists to sense/detect problems such as engine failure or loss of steering. Vehicle is able to protect its crew from serious injury under most accident circumstances.

Technical capability rating: **8** (High capability = **Low technical capability need**)

Rationale for technical capability rating: It appears that the industry is keeping its equipment properly maintained and that equipment and procedures are in place to protect the crew. The capability to sense/detect problems, such as engine failure and loss of steering, should be similar to other transport vehicles. There is some concern that improvements need to be made to vessel stability. A vessel's stability is the measure of its ability to withstand high winds, waves, and other forces resulting from its operations (lifting, trawling, towing, etc.) and resist capsizing by returning to an upright position after being heeled over.

Emerging technologies that address capability gap: Improved lashing systems for marine containers; automated stability systems for ships.

Market adoptability rating: **8** (High adoptability = **Low market adoptability need**)

Rationale for market adoptability rating: Most of the industry uses similar equipment and maintenance practices.

Challenges/obstacles to market adoption: None specified.

C. Operator Performance—Operator is able to successfully maneuver vehicle under normal and off-normal conditions. Capability also exists to sense operator performance degradation due to fatigue, acute health problem, substance abuse, etc., and alert the operator and back office to this situation.

Technical capability rating: **7** (High capability = **Low technical capability need**)

Rationale for technical capability rating: Major improvements have been made in navigation technology with the advent of the Automatic Identification System (AIS). AIS technology and communication protocol has been adopted by the International Maritime Organization as an international standard for ship-to-ship, ship-to-shore, and shore-to ship communication of navigation information, including vessel position, speed, and course information. AIS users operating in proximity to each other automatically create a virtual network. Shore stations can join these virtual networks and receive shipboard AIS signals, perform network and frequency management, and send additional broadcast or individual informational messages to AIS equipped vessels. Most major U.S. ports have AIS capability. Inland waterway AIS installations only cover the Mississippi River below Baton Rouge, although boats traveling through this area are required to have AIS capability. Also, AIS range is limited to VHF radio range. The major inland waterway carriers, representing roughly 70 percent of the industry, have AIS installed on their power boats. Many carriers use electronic navigation systems that identify channels and currents, along with AIS capability, integrating these technologies to identify potential conflicts with boats, infrastructure, and other obstructions. Boat pilots are also trained on high-end simulators that represent the wheelhouse/bridge, present a full set of controls and offer a wide range of scenarios that may be encountered. Note that dock navigation remains an issue, however, as most of these operations are still performed using hardcopy reference documents that are available on computers in pdf form.

Systems that sense operator performance degradation as a result of fatigue, acute health problem, substance abuse, etc., and alert the operator and back office to this situation are not in commercial use at this time.

Emerging technologies that address capability gap: Plans call for land-based AIS to be implemented throughout the entire inland waterway system. Capability to sense/alert performance degradation from boats deviating off course or coming too close to another boat is possible and being tested. Another emerging technology is a system mounted on the power vessel that records radar images, VHS radio, and video images. Also, the U.S. Army Corps of Engineers has successfully prototyped "Smartlock," a system that can measure and communicate outdraft (cross-currents) that creates upstream navigation problems around locks, bridges, and other major structures; sensors submerged at these locations determine the direction and velocity of the outdraft, and the information is transmitted to the AIS for dissemination. The Corps has also been asked by waterway operators to develop a means of controlling drift wood that builds up around locks. Among the technologies being considered that can detect and report physical conditions and operator behavior are mini-cameras and IR lights mounted above the steering wheel to monitor driver's eye and eyelid movements; devices that record heart rate, blood pressure, respiration, and brain waves; and the use of risk perception algorithms to determine whether the vessel is being operated safely.

Market adoptability rating: **6** (Medium adoptability = **Medium market adoptability need**)

Rationale for market adoptability rating: Only about 70 percent of the inland waterway industry has invested in AIS capability. Also, not all operators have integrated AIS with other navigation technologies to the full extent.

Challenges/obstacles to market adoption: Both market adoption of existing technology (AIS, electronic navigation charts) and emerging technology will be highly dependent on deployment cost and the carrier's ability to pay. While the major carriers have a strong interest in developing and using more advanced technologies, some of the others may not follow unless required to do so.

D. Hazmat Commodity Identification and Awareness—Ability to identify the cargo being shipped either in person or via remote access.

Technical capability rating: **8** (High capability = **Low technical capability need**)

Rationale for technical capability rating: Nearly all marine Hazmat shipments are in bulk and relatively easy to identify. Moreover, the shipments are placarded and the material is listed on the shipment manifest, which is stored on the bridge. Furthermore, AIS broadcasts include the vessel identification number and the type of ship and cargo. Some concern has been expressed with stacked container ships in terms of difficulties reading RFID tags on containers that are located under layers of other containers.

Emerging technologies that address capability gap: Under consideration/development are IR spectroscopy to analyze for potentially hazardous chemicals, with chemical signatures stored that can be rapidly matched; networked RFID tags on each package with interrogators on container ships (to read from deepest containers stacked on ships); and load assignment and shipping paper transcription via memory stick on conveyance, wireless transmittal, and broadband user enrollment.

Market adoptability rating: **8** (High adoptability = **Low market adoptability need**)

Rationale for market adoptability rating: The industry is fairly uniform in how it deals with Hazmat commodity identification and awareness.

Challenges/obstacles to market adoption: Again, market adoption will come down to whether the industry can justify investment in new technology for safety, security, and economic reasons. Otherwise, wholesale adoption will only occur if required by regulation.

E. Communication—Vehicle operator and back office have two-way communication capability at all times.

Technical capability rating: **7** (High capability = **Low technical capability need**)

Rationale for technical capability rating: The advent of AIS also provides a means for boats (and back offices) to electronically exchange information on boat identification, position, course and speed. Use of satellite communication is also prevalent in the industry, as are cell phone technology, walkie-talkies, and text messaging. Communication dead spots and the fact that AIS is not operational everywhere impact complete coverage. In deep sea operations, there is often a communication problem because many foreign vessels are operated by individuals who are not fluent in the English language. This can lead to confusion in terms of how to navigate in U.S. waters, jeopardizing safety and security.

Emerging technologies that address capability gap: Plans call for land-based AIS to be implemented throughout the entire inland waterway system. Among the technologies under development to resolve GPS "dark spots" are fusion of imaging and inertial sensors, including the use of LIDAR and Doppler, that result in GPS-level navigation precision; beacon-based navigation (including pseudolites: small transceivers that are used to create a local, ground-based GPS alternative); and signals of opportunity (SoOP; e.g., time beacons and radio broadcasts). To combat foreign language communication problems, it has been suggested that development of a linguistic tool, one that could translate typical marine navigation terminology into several foreign languages (and vice versa), would provide added safety and security. In response to the Maritime Transportation Security Act of 2002, the Coast Guard is developing a two-way maritime data communication system based on AIS technology, referred to as the Nationwide Automatic Identification System (NAIS). AIS data (e.g., vessel location, course, and speed) collected by NAIS will be combined with other government intelligence and surveillance data to form a holistic, overarching view of maritime traffic within or near U.S. and territorial waters. NAIS is expected to consist of a system of AIS receivers, transmitters, transceivers, repeaters and other equipment located on shoreside installations and remote platforms, potentially including buoys, offshore platforms, aircraft, and spacecraft, to receive, distribute, and use information transmitted by vessels that operate AIS equipment. Message data will be transported between system components over a wide-area network (WAN) and diverse, remote site connectivity (e.g., leased analog circuits, microwave). Implementation of the NAIS involves installing AIS equipment and related support systems on and around communications towers or other structures along 95,000 miles of coastline and inland waterways. The system is expected to be fully implemented and operational by 2014.

Market adoptability rating: **7** (High adoptability = **Low market adoptability need**)

Rationale for market adoptability rating: Only about 70 percent of the waterway operators have invested in AIS capability on their boats, perhaps an indication of the extent to which the industry is embracing the availability of advanced communication technologies.

Challenges/obstacles to market adoption: Both market adoption of existing and emerging technology will depend on deployment cost and the carrier's ability to pay. While the major carriers are likely to leverage these technologies where it can be proven to be cost-effective, the remainder of the industry may not follow suit unless it is a regulatory requirement.

F. Tracking—Vehicle and cargo location are known at all times.

Technical capability rating: **6** (Medium capability = **Medium technical capability rating**)

Rationale for technical capability rating: Many boats have GPS (Global Positioning System) or DGPS (Differential GPS) capability while others use LORAN-C (LOng RAnge Navigation)-C to identify their location. Intermittent coverage and lack of positional accuracy can be problematic for navigational purposes, although the lapses in readings may be less of a concern relative to other modes because of the travel speed of the boat. Barges assigned to a consist are typically tracked based on the boat that is powering it, rather than on a separate GPS transponder tagged to the barge. This creates a potential problem if the association between barge and power boat is not made properly. For deep sea operations, the International Convention for the Safety of Life at Sea (SOLAS) enables the U.S. Coast Guard to correlate Long Range Identification and Tracking (LRIT) data with data from other sources so that it can be received by flag states, port states, and coastal states to detect anomalies and heighten overall maritime domain awareness. Passenger ships, cargo ships of 300 gross tonnage or more, and mobile offshore drilling units while in transit are required to transmit LRIT information.

Conditions vary in terms of the locations under which U.S. and foreign flag vessels must report. Some exemptions also apply. Transmissions are to occur with a frequency of 2 to 4 times per day to reduce the communications cost to be in line with the demand of states requiring LRIT information. The LRIT system is expected to be operational by December 31, 2008. The LRIT system consists of the ship borne transmitting equipment; communications service providers; application service providers; and an LRIT data center, data distribution plan, and international data exchange. The Coast Guard does not envision LRIT and AIS interfacing with each other, however. Although the position, identification, and time of position information will be similar in both systems, the method of transmission is distinct. AIS is a VHF-based system that is limited to line-of-sight, but is able to transmit broader data content than LRIT. In contrast, LRIT uses satellite technology to identify and track ships in a larger geographic area than shore-based AIS. Because AIS data is open broadcast and is easily obtainable, the Coast Guard may not need LRIT information while a ship is in port. However, the process to stop and re-start LRIT transmissions is not cost-effective unless the ship will not be transmitting for an extended period of time.

Emerging technologies that address capability gap: NDGPS or DGPS provide more accuracy compared with standard GPS. AGPS or EGPS allow use of GPS in "bad view" areas by assisting GPS with wireless cell site location. Among the technologies being proposed or under development are an intelligent video surveillance system capable of tracking Hazmat vehicles through high-threat urban areas in real time using handoff from camera to camera; networked RFID combined with GPS and cargo monitoring; the GT Freight Data Collector system, a GPS-based instrument; E-Transport River Information Services (RIS) vessel tracking and tracing telematics; satellite-based tracking out beyond 200 miles in conjunction with NAIS; Internet-delivered, remote asset telemetry Asset Management Platform using GSM communications; GSM-based GPS device with built-in RF receiver (for sensor reception), camera, and impact detector; and the use of geofencing. New battery designs and more efficient solar charging units offer potential for improving tracking of individual barges. Among these are wireless electrical or motion-powered technology; plastic thin-film organic solar cells with flexible polymer batteries; nanogenerators harnessing power from movement of flexible wires; and very fast storage for solar power or a flash charge for cell phones and laptops.

Market adoptability rating: **6** (Medium adoptability = **Medium market adoptability need**)

Rationale for market adoptability rating: The major waterway operators are financially stable and routinely invest in hardware and software upgrades to support operations, including tracking. On the other hand, smaller operators with limited financial resources are constrained in their ability to acquire these capabilities. LRIT is envisioned to be backward compatible with existing equipment onboard vessels. Consequently it is estimated that approximately 15 percent of U.S. flag vessels (about 70 of 450) may need some type of equipment enhancement; in such cases, the costs are expected to be nominal (i.e., under $5,000 apiece).

Challenges/obstacles to market adoption: A decrease in the acquisition cost of these technologies and/or justification that the operating cost savings of improved logistics management outweigh the technology acquisition cost will help to improve overall industry adoption.

G. Security—Vehicle, cargo, and operator are resistant to theft, diversion, sabotage, and other intentional acts.

Technical capability rating: **6** (Medium capability = **Medium technical capability need**)

Rationale for technical capability rating: From a security standpoint, it is extremely difficult to maintain a closed marine transportation system due to the number of parties involved, the culture of port operations, international linkages, etc. However, progress is being made. By September 2008, all mariners and support personnel will be required to have a TWIC. The TWIC has biometric features including fingerprints and eye scans. Hulls are generally locked and electronic seals are sometimes used. Around docks, some companies have installed underwater sensors to detect any foreign objects that could cause potential harm to the docking vessel. Ports are using x-ray and gamma machines, as well as radiation detection devices to screen cargo. However, where these systems have been implemented, only a small percentage of cargo is observed. Integrated surveillance intelligent systems (ISIS), unmanned aerial vehicles (UAVs), and remote video surveillance systems (RVSS) are also being used as security tools. Many boats are outfitted with a panic button which transmits an alarm to a centralized location. Also, piracy remains a problem in the open seas.

Emerging technologies that address capability gap: The extent to which ISIS, UAVs, and RVSS have matured is unknown. It is possible that more advanced versions of these systems are under development, such as the use of underwater imaging technology to map hulls of ships. Another area of security technology development is in the use of advanced cargo locks and seals. Systems under consideration/development include improved positive locking mechanisms that can disarm and disable conveyance hatches and locks using low life cycle cost plastic fiber-optic seals with RF communications running on a single battery with 4 of years life to support continuous monitoring. The external seals would have entry and state-of-health alarms sent to a receiver talking to "the world," with all messages stored at a data collection point, and using a remotely monitored sealing array (RMSA) with cryptographically authenticated messages (much more resistant to defeat).

Market adoptability rating: **6** (Medium adoptability = **Medium market adoptability need**)

Rationale for market adoptability rating: At this time, most ports and docks do not have sophisticated surveillance and detection technologies installed.

Challenges/obstacles to market adoption: The resources required to implement advanced security technology will require either investment by the DHS and/or ports/vessels that are considered prime terrorist targets. The extent to which these resources will be made available is unknown. An additional challenge will be how to screen a greater percentage of cargo without creating an excessive burden to commerce.

H. Emergency Response—Qualified emergency response is delivered to an incident site in a timely manner wherever it may occur.

Technical capability rating: **6** (Medium capability = **Medium technical capability need**)

Rationale for technical capability rating: When an incident occurs that requires an emergency response, a single call to the National Response Center initiates the response process. Subsequent Center interactions with the carrier and the U.S. Coast Guard provide a means for identifying the accident location, cargo involved, and other pertinent information (through back office and AIS communications, respectively). Even so, response can be problematic, as access to a dock and the time to reach an incident site can be difficult. The industry has yet to leverage GIS technology to identify the nearest response assets in proximity (e.g., police, medical personnel, recovery resources) to the incident site. Fortunately, crews are well trained in handling fires and other onboard incidents, with drills run once a week.

Emerging technologies that address capability gap: The U.S. Coast Guard and waterway operators are working collaboratively to develop Waterway Action Plans, identifying trigger points and actions taken by towboat captains and companies to mitigate risk. Technologies to support improved emergency response include systems where event data received by sensors is compared with programmed values in data tables to identify matches indicating an actual/emerging problem. When such patterns are identified, alert messages are automatically sent via fax, email, pager, text message, and/or voice

Table D-9. Functional requirement gap rating—marine.

Market Adoptability Need Rating	Technical Capability Need Rating: Low	Medium	High
High	**Medium**	**High**	**High**
Medium	**Low** C. Operator Performance	**Medium** F. Tracking G. Security	**High**
Low	**Low** A. Package Integrity B. Equipment Reliability D. HM Commodity ID E. Communication	**Low** H. Emergency Response	**Medium**

message. The system also includes the ability to inventory vulnerable targets (e.g., critical infrastructure) and generate customized alerts to appropriate officials. Digital photograph (using an IR flash for conditions of darkness) can also be included in the report.

***Market adoptability rating:* 8** (High adoptability = **Low market adoptability need**)

Rationale for market adoptability rating: Most of the industry recognizes its emergency response role and has appropriate operating practices in place.

Challenges/obstacles to market adoption: The extent to which new technologies will be adopted to enhance existing operations will depend on whether such implementation is considered cost-effective.

Technology Development Priority—Marine Mode

Table D-9 is a recap of the functional requirement gap rating—marine.

Table D-10 is a recap of the mode importance rating.

Based on Tables D-9 and D-10, Table D-11 provides the development priorities for the marine mode functional requirements.

Extracted Screened Technologies—Marine Mode

Table D-12 contains technologies the modal lead selected from the screened research list as being applicable for the marine mode. Technologies considered high priority development needs are in bold type.

1.4 Air Mode

Functional Requirements—Air Mode

NOTE: The air mode has the eight generic functional requirements.

A. Package Integrity—Package is robust such that material contents are not breached during normal transport operations and typical accident conditions. Capability exists to sense/detect pressure build-up and/or material release.

***Technical capability rating:* 7** (High capability = **Low technical capability need**)

Rationale for technical capability rating*:* Aircraft are categorized as Passenger, Cargo, and Combination aircraft. The probability of transporting large containers of dangerous goods is small in the total number of flights. The majority of

Table D-10. Mode importance rating.

Serious Consequence Potential (Volume Per Shipment)	Modal Activity Level (Ton-Miles): Low	Medium	High
High	**Medium** Air	**High** Rail Barge	**High**
Medium	**Low**	**Medium**	**High** Truck Pipeline
Low	**Low**	**Low**	**Medium**

Table D-11. Functional requirement technology development priority—marine.

Mode Importance Rating	Functional Requirement Gap Rating: Low	Functional Requirement Gap Rating: Medium	Functional Requirement Gap Rating: High
High	**Medium** A. Package Integrity B. Equipment Reliability C. Operator Performance D. HM Commodity ID E. Communication H. Emergency Response	**High** F. Tracking G. Security	**High**
Medium	**Low**	**Medium**	**High**
Low	**Low**	**Low**	**Medium**

air shipments involve either limited quantities or small quantities which are flown during the daytime, and cargo shipments that are usually flown during the evening or early morning hours. Containers for bulk shipment usually involve palletized drums or cylinders that are certified as meeting the container requirements for UN/ICAO (United Nations/International Civil Aviation Organization) standards. These standards are enforced domestically by the U.S. DOT. The primary area of concern for shipments by air involves the pressure build-up based on the use of unpressurized aircraft or unheated cargo holds on certain aircraft. When packaging is breeched, it is often associated with the ground handling and not directly related to the air portion of the move.

Emerging technologies that address the capability gap: When possible, pressure gauge and temperature range normalities may be transferred via IR and, in some cases, radio transmission during the loading and unloading ground operations. The possibility of in-flight communication with ground tracking is not deemed feasible currently.

Market adoptability rating: **6** (Medium adoptability = **Medium market adoptability need**)

Rationale for market adoptability rating: Due to the international regulations for shipments made by air, the operating conventions of International Air Transport Association (IATA)/ICAO will need to be canvassed to determine how enforcement and practical applications are covered.

Challenges/obstacles to market adoption: Airlines are currently not seeking additional capital outlay programs because of the market fluctuations regarding the availability of fuel. The likelihood of additional provisions for a limited business activity does not seem practical at this time.

B. Equipment Reliability—Vehicle and cargo equipment are structurally sound and properly maintained. Capability exists to sense/detect problems such as engine failure or loss of steering. Vehicle is able to protect its crew from serious injury under most accident circumstances.

Aircraft and cargo loading equipment are routinely inspected and, depending on the certificate of the airline, the timing and frequency of inspections may be routinely monitored. The Federal Aviation Administration (FAA) and the airline manufacturers have to commit to airworthiness directives as required by the supporting national agencies.

Technical capability rating: **8** (High capability = **Low technical capability need**)

Rationale for technical capability rating: Air crews are required to pre- and post-flight each aircraft prior to each activity for a flight period. In addition, this mode has licensed repair and maintenance personnel who must maintain licensed aircraft and power plant licenses to make certificated repair or adjustments to a certificated aircraft. There is no other transportation mode which requires such regimented service and maintenance programs. Air carriers must maintain complete maintenance programs to be allowed to operate aircraft for hire both domestically and in foreign commerce.

Emerging technologies that address the capabilities gap: The primary technology efforts involve the conservation of fuel and the more efficient use of resources for aircraft maintenance for aircraft and power plant. Human engineering will also be important as it relates to aircrew utilization and mandated rest periods. The cost of reducing air crews to no more than two uniformed personnel on the flight deck is the standard for most commercial activities based on aircraft tonnage; it is important to remember that single pilot operation is permitted on some smaller aircraft and in remote locations.

Market adoptability rating: **5** (Medium adoptability = **Medium market adoptability need**)

Rationale for market adoptability rating: The primary direction is the utilization of aircrews to reduce labor costs

Table D-12. Extracted screened technologies—marine mode.

Technology Need	Description	Potential Solution(s)
HIGH PRIORITY **Cargo content identification**	Sensors to analyze the composition of different types of Hazmat cargo/substances.	IR spectroscopy to analyze for potentially hazardous chemicals, with chemical signatures stored that can be rapidly matched; networked RFID tag on each package with interrogators on container ships (to read from deepest containers stacked on ships); load assignment/shipping paper transcription via memory stick on conveyance, wireless transmittal, and broadband user enrollment.
HIGH PRIORITY **Cargo condition sensors**	Sensors to detect diminished container integrity, loss of material, temperature, hatch open/close, penetration by other than door opening.	Pressure gauges and/or chemical detection sensors; fiber-optic sensors and photonic sensor integrated wireless systems; container vibration patterns gathered from wireless RF sensor tags.
Operator condition monitoring systems	Medical monitoring devices that can detect and report physical conditions (such as drowsiness, heart attack, diabetic emergencies) and operator behavior (lane drift).	Mini-cameras and IR lights mounted above the steering wheel to monitor driver's eye and eyelid movements; devices that record heart rate, blood pressure, respiration, and brain waves; the use of risk perception algorithms to determine whether the vessel is being operated safely.
HIGH PRIORITY **Overcoming GPS "dark territory"**	Certain technologies that allow use of GPS by assisting it with wireless cell site location in a "bad view" area where a GPS device may have difficulty providing location information.	Fusion of imaging and inertial sensors (including the use of LIDAR and Doppler) that result in GPS-level navigation precision; beacon-based navigation (including pseudolites); signals of opportunity (SoOP)
HIGH PRIORITY **Innovative sensor power for vehicles**	Battery recharging, flexible batteries that never need to be recharged, electronics that can power themselves.	Wireless electrical or motion-powered technology; plastic thin-film organic solar cells with flexible polymer batteries; nanogenerators harnessing power from movement of flexible wires; very fast storage for solar power or a flash charge for cell phones and laptops.
Vessel/cargo stability	Systems that can detect and/or help improve conditions of stability, draft, and trim of a ship or barge.	Improved lashing systems for maritime containers; automated stability systems for ships.
HIGH PRIORITY **Advanced cargo locks & seals**	Locks and seals that not only secure but also transmit cargo or trailer/container status to back office systems.	Improved positive locking mechanisms that can disarm and disable conveyance hatches and locks using low life cycle cost plastic fiber-optic seals with RF communications running on a single battery with 4 years of life to support continuous monitoring; the external seals would have entry and state-of-health alarms sent to a receiver talking to "the world," with all messages stored at a data collection point, and using a remotely monitored sealing array (RMSA) with cryptographically authenticated messages (much more resistant to defeat).
HIGH PRIORITY **Vessel security**	Improved detection of weapons, mines, and swimmers.	Underwater imaging technology to map hulls of ships.
Language translation	Linguistic tools to improve communication with foreign vessels operated by individuals who are not fluent in the English language.	None specified.
HIGH PRIORITY **Vessel tracking**	Real-time visual vessel tracking including vessel name, speed, course, etc.	Intelligent video surveillance system capable of tracking Hazmat vehicle through high-threat urban area in real time using handoff from camera to camera; networked RFID combined with GPS and cargo monitoring; the GT Freight Data Collector system, a GPS-based instrument; E-Transport River Information Services (RIS) vessel tracking and tracing telematics; satellite-based tracking out beyond 200 miles in conjunction with NAIS; Internet-delivered, remote asset telemetry Asset Management Platform using GSM communications; GSM-based GPS device with built-in RF receiver (for sensor reception), camera, and impact detector; and the use of geofencing.
HIGH PRIORITY **Alert/incident notification systems**	Systems capable of automatically detecting and transmitting anomalies or incidents involving the driver, vehicle, or cargo.	Event data received by sensor technology is compared with programmed values in data tables to identify matches indicating an actual/emerging problem. When such patterns are identified, alert messages are automatically sent via fax, email, pager, text message, and/or voice message. System also includes the ability to inventory vulnerable targets (e.g., critical infrastructure) and generate customized alerts to appropriate officials. Digital photograph (using an IR flash for conditions of darkness) can also be included in the report.

and the use of contract personnel in the area of maintenance and ground operations. Contractors do not have the associated labor costs of union members, and the ability to "bid or shop" fees seems to be limited to the actual license holder, not necessarily the actual individual providing the servicing capability.

Challenges/obstacles to market adoption: The rising cost of new aircraft and the corresponding expense of fuel have had their impact on all but a few flag carriers which have significant cost alignment programs based on the nationalized airline. The greater concern is the certificated airline of foreign registry that would operate in international commerce and may be transporting dangerous goods in aircraft less well-maintained.

C. Operator Performance—Operator is able to successfully maneuver vehicle under normal and off-normal conditions. Capability also exists to sense operator performance degradation due to fatigue, acute health problem, substance abuse, etc., and alert the operator and back office to this situation.

For licensed air crews, the role of the Airline Pilots Association (APA) and the International Airline Pilots Association (IAPA) in cooperation with ICAO is to closely monitor the standards for aircrews based on the training necessary, in-flight hours, re-certification and the use of monitored simulation, and accident fault tree assessment protocols. The required age restrictions of Class 1 medicals and the retirement decreed at 60 years of age for any U.S. licensed commercial pilot helps assure a flying population of highly qualified professionals. The license and medical certification requirements for commercial pilots are only exceeded by the military system (which supplies a majority of the pilots for the commercial airlines).

Technical Capability Rating: **8** (High capability = **Low technical capability need**)

Rationale for technical capability rating: Before a pilot is permitted to operate a certificated commercial aircraft he or she must possess an airman license, have received a minimum number of hours in the type and class of aircraft, and have been tested by the chief pilot or his designee for that specific airline. In addition, his or her physical condition must be documented within the limits of an FAA certified flight surgeon. Currently, aircrews must be tested and approved every 6 months for currency requirements.

Emerging technologies that address the capability gap: The greatest effort has been expended on the health and well being of the certificated airman which is understandable for many reasons, not the least of which is the high cost of maintaining current aircrews. As mentioned, many of the medical regimes have been tested and perfected in military applications and have then been modified or customized by the individual airlines.

Market adoptability rating: **7** (High adoptability = **Low market adoptability need**)

Rationale for market adoptability rating: Although many of the practices and procedures have evolved from military activities, when implemented in the commercial aviation arena cost, and the level of sophistication have slowed adoption directly.

Challenges/obstacles to market adoption: There is one stumbling block that hampers the widespread implementation of advancing medical and human performance management standards. The limitation is the high cost of demanding all aircraft crews to maintain level one certification; this is particularly true for non-U.S. crews that may operate for foreign flag carriers either on cargo-only aircraft or charter licensed airlines.

D. Hazmat Commodity Identification and Awareness—Ability to identify the cargo being shipped either in person or via remote access.

Technical capability rating: **9** (High capability = **Low technical capability need**)

Rationale for technical capability rating: Specifically for this mode there is a strong need to know the category of dangerous goods being offered or being transported. The primary description tool is the shippers' declaration of dangerous goods and the airway bill. Both of these documents must comply with the IATA/ICAO dangerous goods regulations. These regulations are then adopted and enforced by the legal entity of the individual member states with the ability of additional state requirements. Currently, the United States has the largest number of additional requirements beyond the IATA/ICAO requirements. The role of the air carrier must be described as well, in that some carriers either severely restrict the acceptance of dangerous goods either by class or use or, in some cases, there is a complete ban of any dangerous goods accepted for any transport by that airline.

Emerging technology that address capability gap: In order to economically compete and to provide for a more uniform system of classification, the majority of airlines will no longer accept classification documentation by any method other than electronic delivery. In some instances, the delivery of the documentation must be completed by a certain time before the scheduled departure of the aircraft to ensure complete identification and compatibility with other commodities whether dangerous goods or not. The ultimate acceptance criteria remain with the Pilot in Command. The Air Line Pilots Association, International (ALPA) S.T.O.P. Program permits that if there is any concern for any reason, the captain of the flight may reject any shipment, even if the product is accurately described and submitted for flight; the captain is in charge of the flight and its entire configuration.

Market adoptability rating: **6** (Medium adoptability = **Medium market adoptability need**)

Rationale for market adoptability rating: There is the need for Hazmat commodity identification information in the event of a Hazmat accident or unplanned release of product. The immediate adverse impact of a Hazmat release occurring during flight operations makes it crucial to have correct and immediate information on the Hazmat commodity. Because shippers make mandated surcharges on the shipment of dangerous goods, current economics have actually reduced the number of dangerous goods shipments to those that are time-critical for their recipients. One drawback is that some may be tempted not to declare dangerous goods contained in packages.

Challenges/obstacles to market adoption: When a shipper chooses to utilize air transport, there are several considerations for the selection of premium transportation. The assessment is primarily based on quantity limitations and time-sensitive delivery status. The use of limited quantity and small quantity exceptions may allow a shipper to continue to utilize air shipping protocols and still remain economically viable with other less expensive methods. Accurate quantity and proper descriptions are of utmost importance when considering potential incident scenarios.

E. Communication—The aircrew and ground operations are in constant radio and electronic communication. This would include both flight and ground operations.

Technical Capability Rating: **9** (High capability = **Low technical capability need**)

Rationale for technical capability rating: All air crews regardless of origin or type of aircraft are required to maintain access both vocally and electronically with air traffic controllers as well as with company flight directors (although there are communication "dead spots" within some air traffic control sectors). Commercial air operations are monitored fully and, in the era of post-9/11, involve some of the most stringently prescribed conditions for transport of dangerous goods.

Emerging capabilities that address capability gap: In consideration of full compliance, there are only the interruptions in commercial air traffic that may result during increased sun spot and solar flare activities.

Market adoptability rating: **9** (High adoptability = **Low market adoptability need**)

Rationale for market adoptability rating: Air carrier operations are required to be able to maintain active and real-time communications as a necessary part of business. Commercial dangerous goods air transport companies must comply with the requirements adopted by the domestic and international regulatory bodies.

Challenges/obstacles to market adoption: This business practice is mandated and therefore there are not any alternative business practices available.

F. Tracking—Location of in-flight aircraft and receiving ground vehicles (LTL) is known.

Technical capability rating: **9** (High capability = **Low technical capability need**)

Rationale for technical capability rating: All commercial aircraft are required to file a flight plan whether transporting dangerous goods or not. Aircraft are identified by aircraft tail sign and company call sign. In addition to these regular identification routines, aircraft are identified based on fixed or rotary wing, land or seaplane, and in certain irregular occurrences as lifeflight or air ambulance. This classification does not address military cargo; although in tracking activities, civil and military aircraft can use the same airway alignment system.

Emerging technologies that address capability gap: The technology that is advancing this type of air activity involves the use of combined civil and military routing and tracking overseas where the military operations area overlay the commercial routes. There still will be redundant systems when it comes to military transport in active combat arenas.

Market adoptability rating: **9** (High adoptability = **Low market adoptability need**)

Rationale for market adoptability rating: The mandated level of compliance by individual member states keeps concurrence levels high.

Challenges/obstacles to market adoption: Perhaps the only hindrances to full compliance are the use of uncertified carriers in either remote operations or operations outside the country of origin.

G. Security—Aircraft, cargo, and operator are resistant to theft, diversion, sabotage and other intentional acts.

Technical capability rating: **9** (High capability = **Low technical capability need**)

Rationale for technical capability rating: Aircraft, cargo operations, and support operations are mandated to be resistant to theft, diversion, sabotage, and other intentional acts. Current practices within the industry (post-9/11) require the identification of all persons who could come in contact with a commercial aircraft. In many cases, this secured activity is required by current FAA regulations for both ground and carrier activities. In addition, it is the responsibility of each municipal Airport Authority to employ (or contract for) uniformed personnel to verify the identification of those permitted to access an aircraft regardless of the aircraft's type (i.e., whether a passenger, cargo, or combination transport vehicle).

Protecting the vehicle, cargo, and operator from security-related risks requires technology solutions for each task. The area of greatest concern is the identification and background inquiries for the contractors used to load or offload aircraft at the ground locations. This may also include contractors involved with fueling aircraft.

Emerging technologies that address the capability gap: Contractors and their proper identification are subject to increasing use of authentication technologies such as biometrics and smart cards. The use of RFID has been adopted in limited locations for cargo. This is commonly a transfer point where cargo may be held for a few hours before continuing to its final destination. Security is higher when cargo is moving.

Market adoptability rating: **9** (High adoptability = **Low market adoptability need**)

Rationale for market adoptability rating: The initial and continuing costs of these systems have proven to be the primary deterrent to the complete adoption of these practices.

Challenges/obstacles to market adoption: There are limitations with some foreign states that permit undocumented vendor activities to apply to some flights into the United States. The use of vendors based principally on cost seems to be the potential weak link.

H. Emergency Response—Qualified emergency response is delivered to incident and accident sites in as timely a manner as necessary.

Technical capability rating: **8** (High capability = **Low technical capability need**)

Rationale for technical capability rating: It is critical that first responders are fully prepared for responding to incidents or accidents involving aircraft transporting dangerous goods. It is important to recognize that inherent to aircraft operations, there may be onsite and sometimes offsite locations where the ability to contain large amounts of highly volatile fuels is needed.

Emerging technologies that address the capability gap: There are systems in place at ground operation sites that can provide the aircraft load manifest and plan to first responders. These systems are relatively simple in practice but require other technologies such as multiple access band communication and GPS technologies.

Market adoptability rating: **6** (Medium adoptability = **Medium market adoptability need**)

Rationale for market adoptability rating: These systems must be used in conjunction with other technologies.

Challenges/obstacles to market adoption: Based on the origin of the transport, either in-flight or at an airport location, multiple agencies would need access to cargo information. Also, in view of the already high level of safety consciousness involving both employees and response crews, additional expenditures during challenging financial conditions is more difficult.

Technology Development Priority—Air Mode

Table D-13 is a recap of the functional requirement gap rating—air.

Table D-14 is a recap of the mode importance rating.

Based on Tables D-13 and D-14, Table D-15 provides the development priorities for the air mode functional requirements.

Extracted Screened Technologies—Air Mode

Table D-16 contains technologies the modal lead selected from the screened research list as being applicable for the air mode. No technologies are considered high priority development needs so none are in bold type.

Table D-13. Functional requirement gap rating—air.

Market Adoptability Need Rating	Technical Capability Need Rating: Low	Medium	High
High	**Medium**	**High**	**High**
Medium	**Low** A. Package Integrity B. Equipment Reliability D. HM Commodity ID H. Emergency Response	**Medium**	**High**
Low	**Low** C. Operator Performance E. Communication F. Tracking G. Security	**Low**	**Medium**

Table D-14. Mode importance rating.

Serious Consequence Potential (Volume Per Shipment)				
	High	**Medium** Air	**High** Rail Barge	**High**
	Medium	**Low**	**Medium**	**High** Truck Pipeline
	Low	**Low**	**Low**	**Medium**
		Low	Medium	High
		Modal Activity Level (Ton-Miles)		

1.5 Pipeline Mode

Functional Requirements—Pipeline Mode

NOTE: The pipeline mode has seven generic functional requirements. It does not have the "F. Tracking" functional requirement like all other modes.

A. **Package Integrity and Tracking**—Ensures that the material contents of the pipeline are not breached during normal and abnormal operations, and capability exists to detect pressure build-up and/or material release.

Technical capability rating: 7 (High capability = **Low technical capability need**)

Pipelines are an economical and reliable transportation mode for natural gas, oil, and refined products. Pipelines are typically made from high strength steel that has been engineered to provide good tolerance to natural and human events that could cause the product to escape. Most pipelines are buried with a protective coating used to minimize the growth of corrosion, along with cathodic protection methods to back up the coatings. Pipelines are actually quite robust and resilient. Their improvements offer materials issues and related opportunities to (1) minimize capital expenditures (CAPEX) and facilitate risk management and (2) minimize operating expenses (OPEX) and maximize the asset value over its life cycle.

For leak detection, pipeline operators typically use a combination of flow verification through an accounting method, aerial, or land surveillance to find dead vegetation or other indications of a leak, and/or Computational Pipeline Monitoring (CPM) systems to monitor for pipeline leaks. CPM is

Table D-15. Functional requirement technology development priority—air.

Mode Importance Rating				
	High	**Medium**	**High**	**High**
	Medium	**Low** A. Package Integrity B. Equipment Reliability C. Operator Performance D. HM Commodity ID E. Communication F. Tracking G. Security H. Emergency Response	**Medium**	**High**
	Low	**Low**	**Low**	**Medium**
		Low	Medium	High
		Functional Requirement Gap Rating		

Table D-16. Extracted screened technologies—air mode.

Technology Need	Description	Potential Solution(s)
Implementation of improved first responder chemical detection system technology with validated capabilities.	Improved chemical sensors.	Joint ventures with the Department of Homeland Security Service training mission in order to provide training to responders.
Decision support.	Decision support system.	Establish table topic exercises on decision matrixes and fault tree diagrams.
Equipment for mitigating biological agents.	Protective foam (starting to appear in marketplace).	Coordinate response with Health and/or Center for Disease Control. Determine locations that offer communicable disease ward training.
Shipping container cargo contents identification.	Not specified.	Consider color coding of private containers or requiring shippers to provide external identification regimes.
Emergency responders need access to contents of shipping papers electronically to determine commodity, have the ability to tie into the shipper's data, and tap into a database to get information on chemical properties of the commodity and response advice.	Electronic freight manifest.	Current applications exist in the form of bar code readers for information distribution, however the inputting of the information is not standardized.
Unique identifier on container.	Not specified.	Establish UN identification for commodity codes and require shipper to affix.
Master database of information on what is in a shipment.	Electronic freight manifest.	Access FAA 90 carrier file and automate for recurring shipment types and origin and destination routings.
Capability to get reliable information to emergency responders in remote areas.	Not specified.	Interlink with GPS monitors that permit satellite telephone downlink.
Security identification credential (for transportation, not emergency response) that is universally accepted.	Not specified.	Establish standards for either eye or ear recognition. Possible funding may be available in conjunction with Homeland Security or Department of Justice.
Need one universal identification card that is simple, interoperable, and is read by one standard reader. When a person leaves the system, where they had access is known so that it can be closed out.	Biometrics-based universal security credential.	Universal credentialing system that carriers can adopt and monitor based on TSA profiles.
Behavioral monitoring.	Risk perception algorithms to determine whether vehicle is being operated safely.	FAA human criteria studies would establish baseline criteria.
Advanced cargo seals.	Use of low life cycle cost plastic fiber-optic seals with RF communications running on a single battery with 4 years of life, under continuous monitoring. External seals would have entry and state-of-health alarms sent to a receiver talking to "the world," with all messages stored at a data collection point; Remotely monitored sealing array (RMSA) with cryptographically authenticated messages (much more resistant to defeat).	Once standards are in place in multi-modal applications just ensure air requirements of temperature and pressure for mishandling incidents.
Physical condition/drowsy driver monitoring.	Eye movement cameras, brain waves, movements.	Replicate findings on the highway mode.
Innovative security sensing transportation applications.	Fiber-optic sensors and photonic sensor integrated wireless systems.	Establish standards in ground operations.
Detecting hazardous and chemical materials.	IR spectroscopy to analyze for potentially hazardous chemicals, with 25,000 chemical signatures stored that can be matched in 20 seconds.	Implement standards from the National Fire Protection Association (NFPA) and OSHA.

a computer-based monitoring tool which allows the pipeline controller to respond to an anomaly that may indicate product release. Additionally, pipeline operators use preventative methods such as internal pipeline inspection, hydrotesting, direct assessment (an assessment methodology that may indicate active corrosion sites related to external corrosion, internal corrosion, and stress corrosion cracking [SCC]), and damage prevention programs to monitor for pipeline threats such as corrosion, SCC, and third party damage.

Rationale for technical capability rating: Modern pipeline steels have good toughness to resist catastrophic failure due to corrosion growth or excavation equipment striking the pipeline. Federal regulations require that pipeline in populated areas be thicker, further reducing the likelihood of release due to natural or human events. Valves to stop flow in the rare case of the release of product can be closed, often remotely from a central control room. While pipelines are not designed to withstand an intentional attack, many of the safeguards used to prevent or minimize the effect of a release are applicable.

Existing leak detection techniques have trouble reliably detecting small pipeline leaks, while preventative inspection and test programs do not reliably detect all pipeline threats (microbial induced corrosion, SCC, etc.). Offshore pipelines present many additional problems related to inspection and repair capabilities. Additionally, the emergence of products from alternative energy technologies (ethanol and carbon dioxide) will introduce new problems for pipeline systems. Ethanol contains components that cause cracking in steels, so pipelines often have to be protected from the product. The U.S. DOT PHMSA project "Understanding how Fuel Grade Ethanol and other ethanol-rich products might be transported via pipelines" is addressing this issue along with industry research by the Pipeline Research Council International (PRCI).

One of the leading causes of pipeline leaks is third party excavation in the pipeline right of way. One very visible example was a 1993 accident in which 330,000 gallons of diesel fuel leaked from a 36-inch pipeline and eventually into the Potomac River upstream of Washington, DC. The pipe was damaged during the installation of a parking lot over the pipeline. PHMSA has many projects in the area of detecting equipment in the right-of-way and precise location of underground piping systems. One large effort has been the development of an autonomous distributed sensor system that uses low frequency sound wave detection to detect and report excavation activity and its location as well as sense third party damage. These efforts can also be characterized as security issues if they are attempting to stop intentional damage, but accidental damage is far more prevalent.

Emerging technologies that address the capability gap: Higher strength steels have been developed to lower the cost of installation of new pipelines. The resistance to breach by excavation equipment has also improved. The concept of steel pipe with reinforcing fibers to limit the size of a breach is being investigated. Liquid line methods including mass balance and statistical methods and the application of Coriolis Effect mass flow meters can be used for leak detection. Verification of container integrity can be provided by airborne leak detection technologies, including the PHMSA project Airborne Natural Gas Emission LIDAR (ANGEL) technology for the detection of small hazardous liquid and refined product leaks. Unmanned Aerial Vehicles (UAVs) with low cost sensors can help ensure the integrity and security of the nation's pipelines.

Other technologies include airborne infra-red chemical sensors, mass balance leak detection, acoustic emission leak detection, fiber-optic sensing, pressure analysis leak detection, real-time pipeline monitoring, long-range guided wave technologies, mechanical damage fault tree analysis, Ground Penetrating Radar (GPR) system for pipe location, magnetic tracer for locating plastic pipe, and inspection technologies for unpiggable pipeline. (NOTE: "Pig" is an acronym for Pipeline Inspection Gauge which refers to the use of the gauge to get measurements or other information from within a pipeline while product is flowing.) Also helpful will be a GPS-based system that warns (1) inspectors of excavation activity that is occurring in an area without a valid One-Call ticket (i.e., a feature of pipeline operations responding to the requirement that an operator of a pipeline or utility respond within a set time to a request for marking the asset when excavation in an area is imminent) and (2) excavators and operators of the proximity of excavation equipment to underground facilities.

Market adoptability rating: **7** (High adoptability = **Low market adoptability need**)

Rationale for market adoptability rating: Current leading-edge technologies are being used in an increasing number of new pipeline construction projects. However, retrofitting pipelines with modern materials and equipment is not performed on a routine basis. Pipelines are engineered for decades of operation, so the adoption of new technology can happen quite slowly.

Challenges/obstacles to market adoption: Challenges to successful implementation of the emerging technologies include garnering industry interest in moving prototype systems into commercialization in view of their cost. The cost of energy products is typically at the forefront of public debate, and increasing the cost for improved safety and security will not be easily accepted. For example, implementing real-time monitoring on a 1,000 mile pipeline at a current cost of tens of thousands of dollars per mile is clearly quite expensive.

B. Equipment Reliability—Ensures that the pipeline equipment is structurally sound and properly maintained, and capability exists to detect problems.

Technical capability rating: **5** (Medium capability = **Medium technical capability need**)

Rationale for technical capability rating: Federal regulations for inspection and maintenance help ensure that the pipeline is structurally sound. "One-Call" and 811 systems have been adopted to help prevent accidental damage to pipelines. The pipeline right of way is checked on a periodic basis for signs of unauthorized excavation that may have caused damage. Above ground surveys check the cathodic protection and coating systems used to prevent the initiation and growth of corrosion anomalies. Inspection tools are run inside the pipeline to assess the pipe for corrosion, dents, and other anomalies that may grow to failure, allowing the product to escape. Materials are available to repair the pipeline without disrupting delivery.

Compressor and pump station reliability and availability are essential to overall pipeline delivery dependability, yet the pipeline infrastructure is aging with equipment operating well beyond its expected operating life. Old equipment can be problematic in finding parts for repairs (therefore reducing system reliability and redundancy) as well as complying with the requirements for reducing environmental emissions. If redundancy is not available, scheduled and unscheduled maintenance can lead to outages in supply. The U.S. DOT Office of Pipeline Safety (DOT OPS) requires the use of excess flow valves that stop the flow of product when the flow exceeds a specified amount. Automatic shut down valves can have reliability problems, resulting in operators manually overriding fault signals.

Starting turbines using natural gas results in significant volumes of gas vented to the atmosphere. The venting of gas represents considerable loss of revenue as well as the potential exposure to pending greenhouse gas (GHG) regulations. Alternative, cost effective, environmentally friendly, methods for starting gas turbines in pipeline compression service are needed.

Preventative inspection and test programs do not reliably detect all pipeline threats (microbial induced corrosion, SCC, etc.). Offshore pipelines present many additional problems related to inspection and repair capabilities. Additionally, the emergence of products from alternative energy technologies (ethanol and carbon dioxide) will introduce new problems for pipeline systems. The U.S. DOT PHMSA project "Understanding how Fuel Grade Ethanol and other ethanol-rich products might be transported via pipelines" is addressing this issue along with industry research by the Pipeline Research Council International (PRCI).

Emerging technologies that address the capability gap: Technologies include more reliable shut down valves and more efficient turbines; use of composite systems (not reinforced polymers but rather thinner steel used within a reinforcing scheme); and new or replacement materials other than steel.

Market adoptability rating: **3** (Low adoptability = **High market adoptability need**)

Rationale for market adoptability rating: While some newer designs of equipment are available, they have not been widely implemented because older equipment continues to be used.

Challenges/obstacles to market adoption: Emerging technologies can be implemented on new pipelines, but convincing pipeline owners to retrofit existing pipelines can be difficult.

C. Operator Performance—Operator is able to successfully conduct job function under normal and abnormal conditions. The capability exists to sense operator performance degradation.

Technical capability rating: **7** (High capability = **Low technical capability need**)

Section 12 of the "Pipeline Inspection, Protection, Enforcement, and Safety Act of 2006" (*54*) provides general guidance regarding regulations that will require operators to manage the human factors risks in their control room. A partial quotation from Section 12 is provided: § 60137. Pipeline control room management: "*(a) IN GENERAL.—Not later than June 1, 2008, the Secretary shall issue regulations requiring each operator of a gas or hazardous liquid pipeline to develop, implement, and submit*" **. . .** "*a human factors management plan designed to reduce risks associated with human factors, including fatigue, in each control center for the pipeline.*" Few pipeline incidents are typically attributed to human factors. The most frequently cited causes of oil pipeline incidents are third party damage, corrosion, and equipment-related failure (*55*). However, several recent investigations of severe pipeline incidents have determined that controllers did not correctly identify and respond to abnormal situations in an effective and timely manner; thereby contributing to the severity of the accident (*56*).

Rationale for technical capability rating: Federal regulations exist in 49 CFR 192 and 49 CFR 195 related to operator qualifications as well as drug and alcohol programs. Pipeline operators who perform covered tasks must be qualified. "Qualified" means that an individual has been evaluated and can (a) perform assigned covered tasks and (b) recognize and react to abnormal operating conditions. While relatively few technologies are in use to monitor operator performance, personnel are well-trained in the alerting response technologies, and there is not a large gap.

Emerging technologies that address the capability gap: Since pipeline operators do not operate vehicles in the delivery of the commodity, devices such as brain-wave monitors to ensure alertness are not as critical. One system that may have utility is video monitoring to detect adverse behavior patterns (for example in a control center) that may indicate drowsiness or a physical emergency.

Market adoptability rating: **3** (Low adoptability = **High market adoptability need**)

Rationale for market adoptability rating: Personnel monitoring systems exist but have not been implemented to any appreciable degree.

Challenges/obstacles to market adoption: Pipeline operations have less perceived need and are less inclined to invest in technologies that detect operator degradation.

D. Hazmat Commodity Identification and Awareness—Ability to identify the cargo being transported.

Technical capability rating: **7** (High capability = **Low technical capability need**)

Rationale for technical capability rating: Federal regulations exist in 49 CFR 192 and 49 CFR 195 that require pipelines to be marked to indicate danger, name of the commodity (gas or liquid), operator name, and telephone number. Markers often do not indicate the exact product being transported nor the operating pressures and temperatures. Although this minimizes security concerns, it can be problematic for emergency response efforts if this information is unknown or incomplete. The locations of all energy pipelines were required to be mapped and the data entered into a DOT database called the National Pipeline Mapping System (NPMS). This database became available in summer 2001 and was shut down just after 9/11 for security reasons. This database is needed for Hazmat awareness, since local authorities, first responders, and the public could use the database to identify the product in the pipeline.

Emerging technologies that address the capability gap: The NPMS now has a viewer by county, a compromise to address security concerns. The NPMS database is growing and includes natural gas transmission lines, hazardous liquid trunklines, and liquefied natural gas (LNG) plants. Information on other types of pipelines and facilities are included in the database, such as gathering and distribution lines. Additional facilities are being added on a voluntary basis.

Market adoptability rating: **5** (Medium adoptability = **Medium market adoptability need**)

Rationale for market adoptability rating: Technologies for providing commodity identification and awareness are becoming more widely used. Some gaps exist such as identifying hazardous products that are transported in batches.

Challenges/obstacles to market adoption: This is more of political issue than a technology issue. Many of the technologies that improve Hazmat commodity identification and awareness can negatively impact security (e.g., the belief that a placard on a railcar helps someone with malicious intent identify the most dangerous substance in the train).

E. Communication—Ensure two-way communication at all times between control stations and other critical infrastructure.

Technical capability rating: **6** (Medium capability = **Medium technical capability need**)

Most pipeline systems use a Supervisory Control and Data Acquisition (SCADA) system. SCADA systems are computer-based communication tools that monitor, process, transmit, and display pipeline data and provide an integrated summary of remote pipeline sensors and controls. Pipeline controllers engaged in SCADA operations monitor and control pipeline operations from a console in a pipeline control room, which is typically equipped with multiple SCADA consoles used to monitor and control separate sections of a larger pipeline system. SCADA systems may also be used directly for leak detection, can provide support for a leak detection system, or can be used independently of a leak detection system. Current technologies in use consist of a variety of radio, cellular, microwave, and satellite wireless technologies that are used for data transmission. Pipeline operators also utilize hand-held radios when out in the field.

Rationale for technical capability rating: Authentication of users and systems using old technology may lack up-to-date cyber-security protocols, while more reliance on Internet and commercial-off-the-shelf (COTS) software brings new vulnerabilities. The move from proprietary technologies to more standardized and open solutions together with the increased number of connections between SCADA systems and office networks and the Internet has made them more vulnerable to attacks. Consequently, the security of SCADA-based systems has come into question because they are increasingly seen because they are extremely vulnerable to cyber-terrorism attacks.

Emerging technologies that address the capability gap: Next generation protocols such as unified architecture take advantage of XML, web services, and other modern web technologies, making SCADA IT systems more easily supportable. Surety Enhancement for Wireless Automated Control Networks allows a secure automated control system that depends on a hybrid wired/wireless communication infrastructure and standards-based protocols. Cost-effective, high performance solutions are needed for critical infrastructure cyber security, including an energy management system (EMS)/SCADA and all related business functions.

Market adoptability rating: **8** (High adoptability = **Low market adoptability need**)

Rationale for market adoptability rating: These technologies are being successfully incorporated into pipeline information systems.

Challenges/obstacles to market adoption: The prevalence of cyber attacks means that systems must constantly be up to the task of defeating them.

F. Tracking—This functional requirement does not apply to the pipeline mode.

G. Security – Pipelines, equipment, cargo, and operators are resistant to theft, diversion, sabotage, and other intentional acts.

Technical capability rating: **3** (Low capability = **High technical capability need**)

Rationale for technical capability rating: The hundreds of thousands of miles of pipelines that crisscross the United States are monitored remotely and have a significant potential for undetected theft, sabotage, or other intentional acts. Theft is a problem in Mexico, South America, and Africa, but is rare in the United States. Diversion, while possible for other transportation methods, is less likely since an infrastructure would have to be established. Pipeline damage from excavation equipment is a constant consideration for pipeline operators. This is a similar threat to sabotage, just not intentional. Worldwide, attempts to breach pipelines have been made, but most are unsuccessful because pipeline materials are designed to resist damage. However, some attempts are successful in disrupting delivery of energy products for extended times. Also, if damage from an unsuccessful attempt goes undetected, it could eventually cause failure.

However, the consequence of sabotage can be great and this must be considered. Some pipelines are a single source of natural gas for a large population area, which can be problematic when the public relies on this for heat. If a natural gas pipeline is breached in a populated area, the results could be catastrophic if ignition occurs. If an oil or products line is breached near a waterway, the environmental impact can be substantial.

Pipeline operators typically use a combination of flow verification through an accounting method, aerial, or land surveillance to find dead vegetation or other indications of a leak, and/or CPM systems to monitor for pipeline leaks. CPM is a computer-based monitoring tool which allows the pipeline controller to respond to an anomaly that may indicate product release. Additionally, pipeline operators use preventative methods such as internal pipeline inspection, hydrotesting, direct assessment (an assessment methodology that may indicate active corrosion sites related to external corrosion, internal corrosion, and SCC), and damage prevention programs to monitor for pipeline threats such as corrosion, SCC, and third party damage.

Rationale for technical capability rating: Theft is typically performed in small quantities. Existing leak detection techniques have trouble reliably detecting small pipeline leaks. Inline inspection methods can detect taps on the pipeline that could indicate an attempt to steal the contents. Systems being developed to detect third party damage would typically be useful for detecting sabotage as well. One of the leading causes of pipeline leaks is third party excavation in the pipeline right of way. One of the most visible examples was a 1993 accident in which 330,000 gallons of diesel fuel leaked from a 36-inch pipeline into the Potomac River upstream of Washington, DC. The pipe was damaged during the installation of a parking lot over the pipeline. U.S. DOT PHMSA has many projects in the area of involving detecting equipment in the right-of-way and precise location of underground piping systems. One large effort has been development of an autonomous distributed sensor system that uses low frequency sound wave detection to detect and report excavation activity and its location as well as sense third party damage. These efforts can also be characterized as security issues if they are used to stop intentional damage, but accidental damage is far more prevalent.

Emerging technologies that address the capability gap: The same technologies that detect commodity release can help detect a security incident in which a pipeline is breached. Airborne leak detection technologies, including U.S. DOT PHMSA project's Airborne Natural Gas Emission LIDAR (ANGEL) technology to the detection of small hazardous liquid and refined product leaks. UAVs with low cost sensors to ensure the integrity and security of the nation's pipelines. Other technologies include Airborne LIDAR/infrared chemical sensors, mass balance leak detection, acoustic emission leak detection, fiber-optic sensing, pressure analysis leak detection, real-time pipeline monitoring, inspection technologies for unpiggable pipeline, long-range guided wave technologies, mechanical damage fault tree analysis, GPR system for pipe location, and magnetic tracer for locating plastic pipe.

Also, a GPS-based system that warns (1) inspectors of excavation activity that is occurring in an area without a valid One-Call ticket (i.e., a feature of pipeline operations responding to the requirement that an operator of a pipeline or utility respond within a set time to a request for marking the asset when excavation in an area is imminent) and (2) excavators and operators of the proximity of excavation equipment to underground facilities.

Market adoptability rating: **4** (Medium capability = **Medium market adoptability need**)

Rationale for market adoptability rating: Current leading-edge technologies are being used in an increasing number of locations.

Challenges/obstacles to market adoption: Challenges to successful implementation of the emerging technologies will be cost and garnering industry interest in moving prototype systems into commercialization. For example, implementing real-time monitoring on a 1,000 mile pipeline currently costs tens of thousands of dollars per mile.

H. Emergency Response—Qualified emergency response, including repair and remediation, is delivered to an incident site in a timely manner.

Technical capability rating: **8** (High capability = **Low technical capability need**)

Rationale for technical capability rating: Federal regulations exist for requiring the development of emergency response

Table D-17. Functional requirement gap rating—pipeline.

Market Adoptability Need Rating	Low	Medium	High
High	**Medium** C. Operator Performance	**High** B. Equipment Reliability	**High**
Medium	**Low** D. HM Commodity ID H. Emergency Response	**Medium**	**High** G. Security
Low	**Low** A. Package Integrity	**Low** E. Communication	**Medium**
	Technical Capability Need Rating		

plans. For natural gas pipelines, operators are required to have Emergency Plans (including training of personnel) under 192.615. For liquid pipelines, operators are required to have Emergency Plans under 195.403(e) and Emergency Response Training under 195.404. Both require operators to follow the guidance in *American Petroleum Institute Recommended Practice* (API RP) 1162, First Edition, December 2003. Technologies that alert operators to problems are in use.

Emerging technologies that address the capability gap: A number of repair methods are being developed. One is continuing development of composite wrap sleeves. New applications and different types of composites are being developed and they have also been used for other applications such as external sleeve crack arrestors on pipelines. After a relatively slow start and an extended industry/regulatory acceptance period, composite wraps are becoming more standard in the pipeline industry.

Market adoptability rating: **4** (Medium adoptability = **Medium market adoptability need**)

Rationale for market adoptability rating: Current systems provide emergency response capabilities for Hazmat leak detection and response. New remediation and repair technologies such as composite wraps are being embraced but not rapidly.

Challenges/obstacles to market adoption: The relative scarcity of major leaks of dangerous substances from pipelines is perhaps the biggest obstacle to this technology area.

Technology Development Priority—Pipeline Mode

Table D-17 is a recap of the functional requirement gap rating—pipeline.

Table D-18 is a recap of the mode importance rating.

Based on Tables D-17 and D-18, Table D-19 provides the development priorities for the pipeline mode functional requirements.

Extracted Screened Technologies—Pipeline Mode

Table D-20 contains technologies the modal lead selected from the screened research list as being applicable for the pipeline mode.

Table D-18. Mode importance rating.

Serious Consequence Potential (Volume Per Shipment)	Low	Medium	High
High	**Medium** Air	**High** Rail Barge	**High**
Medium	**Low**	**Medium**	**High** Truck Pipeline
Low	**Low**	**Low**	**Medium**
	Modal Activity Level (Ton-Miles)		

Table D-19. Functional requirement technology development priority—pipeline.

Mode Importance Rating	Functional Requirement Gap Rating: Low	Functional Requirement Gap Rating: Medium	Functional Requirement Gap Rating: High
High	**Medium** A. Package Integrity D. HM Commodity ID E. Communication H. Emergency Response	**High** C. Operator Performance	**High** B. Equipment Reliability G. Security
Medium	**Low**	**Medium**	**High**
Low	**Low**	**Low**	**Medium**

Table D-20. Extracted screened technologies—pipeline mode.

Technology Need	Description	Potential Solution(s)
Small volume leak detection.	Ability to pinpoint leaks.	Liquid line methods including mass balance and statistical methods and the application of Coriolis Effect mass flow meters.
Pipeline repair improvements.	Improved ability to repair damaged pipeline.	Composite patch materials.
Leak stoppage via a chemical reaction produced by the commodity itself.	The marriage of nanotechnology and microencapsulation to produce a leak control scheme inexpensive enough to include with the product (regardless of transport mode).	The commodity does not adversely react in end-use but activates when a leak exposes it to shear-stress flowing through a crack coupled with a trigger reaction driven by oxygen.
Airborne leak detection.	Unmanned Aerial Vehicle (UAV).	Light Detection and Ranging (LIDAR).
Materials for pipelines to compensate for the current lack of quantity and quality of steel.	New pipeline materials.	Composite materials, thinner steel used within a reinforcing scheme.
Improved simulator training.	Advanced simulators.	Simulator training applications are not limited to abnormal operating condition training. In many process control industries, the opportunity of presenting infrequent (or even never-before-encountered) conditions through simulation tend to result in a focus on abnormal operating condition training.
Provide a means of both facilitating and tracking communications between schedulers and controllers.	Computer-based communication tools.	Automated communications forms that require the entry of key delivery parameters (e.g., origin, destination, product volume, flow rate, scheduled start, scheduled stop, and operational considerations).
Computerized procedures or documented heuristics that aid users in decision-making.	Decision support tools.	If implemented and used appropriately, decision support tools can aid decision-making by walking users through the relevant set of decision questions and often pulling the relevant decision parameters directly from the SCADA system. Such aids may reduce decision-making time.
Reduce the number of manual calculations needed.	Systems to automate calculations required.	Manual calculations, manual record-keeping, or extensive data entry can be time consuming and error prone. This
Some workers experience fatigue for reasons not associated with the work environment.	Sleep disorder screening technologies.	A variety of technology approaches have been researched. Several U.S. transportation operators who have identified worker alertness as an operational risk have instituted confidential sleep disorder screening as part of their broader fatigue management programs.
Existing pipeline leak detection techniques have trouble reliably detecting small pipeline leaks.	Mass balance leak detection.	Commercial systems undergoing continuous improvement. Competition from competing technologies drives development.
Existing pipeline leak detection techniques have trouble reliably detecting small pipeline leaks.	Acoustic emission leak detection.	Some DOT sponsored work, but commercial systems available and being developed privately.
Existing pipeline leak detection techniques have trouble reliably detecting small pipeline leaks.	Fiber-optic sensing.	Fiber-optic/photonic or wireless sensors for fixed point monitoring of infrastructure health and environment problems. Some DOT sponsored work, but commercial systems available and being developed privately.

(continued on next page)

Table D-20. (Continued).

Technology Need	Description	Potential Solution(s)
Existing pipeline leak detection techniques have trouble reliably detecting small pipeline leaks.	Pressure analysis leak detection.	Commercial systems undergoing continuous improvement. Competition from competing technologies drives development.
Offshore pipelines presenting many additional problems related to inspection and repair capabilities.	Improved inspection pigs.	Some DOT-sponsored work, but commercial systems available and being developed privately.
Products from alternative energy technologies (ethanol and carbon dioxide) will introduce new problems for pipeline systems.	Development of new inhibitors.	Protect the pipeline.
Preventing third party excavation in the pipeline right-of-way.	Acoustic, fiber-optic, seismic, etc.	Implementing real-time monitoring on a 1,000 mile pipeline currently costs tens of thousands of dollars per mile.
Start-up inefficiencies.	More efficient turbines.	Starting turbines using natural gas results in significant volumes of gas vented to the atmosphere.
Pipeline Damage Prevention—Onshore.	DTRS56-02-T-0005, "Digital Mapping of Buried Pipelines with a Dual Array System."	There are many commercial methods to map underground utilities. None are perfect, so development continues. This is more a problem for distribution pipelines. Transportation pipelines are marked and are typically easier to find since they are steel.
Pipeline Damage Prevention—Onshore.	DTRS56-02-T-0006, "Pipeline Damage Prevention Through the Use of Locatable Magnetic Plastic Pipe and a Universal Locator"	There are many commercial methods to map underground utilities. Passive systems use magnetometers to detect the ferromagnetic steel, active systems impress an AC current on the pipe (conductivity needed); this gives a better estimate of depth. Plastic pipes are especially difficult since they are not conductive or ferromagnetic.
Pipeline Damage Prevention—Onshore.	DTRS56-04-T-0006, "Effectiveness of Prevention Methods for Excavation Damage."	Process development, not new technology.
Pipeline Damage Prevention—Onshore/Alaska.	DTRS56-04-T-0007, "Infrasonic Frequency Seismic Sensor System for Preventing Third Party Damage to Gas Pipelines."	PIGPEN low freq sound wave (infrasonic) detection to sense third party damage, DTRS56-04-T-00078, DTRS57-05-C-10110, DTPH56-08-T-000019 and DTRS57-04-C-10002.
Pipeline Damage Prevention—Onshore.	DTPH56-06-T-000005, "Differential Impedance Obstacle Detection Sensor (DIOD)—Phase 2."	Directional drilling equipment can bore directly into pipelines. The sensors developed on this project are intended to detect pipelines and guide equipment in alternate directions.
Pipeline Damage Prevention—Onshore/Alaska.	DTRS57-05-C-10110, "Infrasonic Frequency Seismic Sensor System for Pipeline Integrity Management."	PIGPEN low freq sound wave (infrasonic) detection to sense third party damage, DTRS56-04-T-00078, DTRS57-05-C-10110, DTPH56-08-T-000019 and DTRS57-04-C-10002.
Pipeline Damage Prevention—Onshore.	DTPH56-07-P-000046, "Determine the Requirements for Existing Pipeline, Tank and Terminal Systems to Transport Ethanol without Cracking."	Ethanol contains components that cause cracking in steel. Pipelines often have to be protected from the product. This project is developing guidelines for safe transportation of ethanol including use of coatings and inhibitors.
Pipeline Assessment and Leak Detection—Onshore/Offshore/Alaska.	DTRS56-04-T-0012, "Hazardous Liquids Airborne Lidar Observation Study (HALOS)."	DTRS56-04-T-0012, DTPH56-05-T-0004, and DTPH56-08-T-000019 are similar projects with similar objectives. The product (Hazmat Liquids, Natural Gas) and sensor type vary.
Pipeline Assessment and Leak Detection—Onshore/Alaska.	DTPH56-05-T-0004, "Use of Unmanned Air Vehicle (UAV) for Pipeline Surveillance to Improve Safety and Lower Cost."	DTRS56-04-T-0012, DTPH56-05-T-0004, and DTPH56-08-T-000019 are similar projects with similar objectives. The product (Hazmat Liquids, Natural Gas) and sensor type vary.
Pipeline Assessment and Leak Detection—Onshore.	DTPH56-08-T-000017, "GPS-Based Excavation Encroachment Notification."	Damage prevention by continuously monitoring the position of excavating equipment.
Pipeline Assessment and Leak Detection—Onshore.	DTPH56-08-T-000019, "Advanced Development of Proactive Infrasonic Gas Pipeline Evaluation Network."	PIGPEN low freq sound wave (infrasonic) detection to sense third party damage, DTRS56-04-T-00078, DTRS57-05-C-10110, DTPH56-08-T-000019 and DTRS57-04-C-10002.
Low cost monitoring of pipelines for third party intrusion, theft, and sabotage.	Similar technologies for detection of third party damage.	Implementing real-time monitoring on a 1,000 mile pipeline currently costs tens of thousands of dollars per mile.

APPENDIX E

Synopses of Peer Reviews

The purpose of the peer reviews was to get feedback from industry and government Subject Matter Experts on the research approach and findings. Seven peer reviewers were identified and agreed to participate on a voluntary basis. They were provided the following by e-mail:

- Summary guidance on the purpose of the review
- The link to the TRB project description of HMCRP Project 04 (http://144.171.11.40/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=2660)
- A 15-page "executive summary" version of the HMCRP Project 04 technology selection process and results including tables and figures, such as the overall step-wise process and a table with the most promising technology selections
- A table duplicating the preliminary most promising technology selections with amplifying information and a general characterization of the selections
- Mention of the common security credential, one of the original preliminary most promising technologies, a link to the TRB HMCRP Project 08 solicitation, and an explanation that the HMCRP Project 04 team recognizes the common security credential technology investigation will be addressed by HMCRP Project 08
- Two spreadsheets, each with four sheets, provided to give insight into how extensively the research was conducted but that did not require the reviewer to get into very detailed information

Four of the seven invitees responded. Table E-1 characterizes those four and is followed by their written responses, which are shown in bold type. After considering the reasoning in one of the responses, the team elevated technologies related to container integrity to most promising technology status. (Simultaneously and independent of peer review activity, another of the original most promising technology selections—fast power charge/storage—was considered to have already reached product status. So in effect, the one selection was substituted for the other.)

Peer Reviewer Responses

Reviewer: Official of Class I Railroad

1. Were the objectives and instructions provided to peer reviewers adequate?
   Yes
2. Was the project objective clearly explained?
   Yes
3. Was the characterization of the research approach easy to understand?
   Yes
4. Does the research approach appear comprehensive and fair?
   Yes. Well thought out in advance of the research.
5. Are the conclusions reached (i.e., the selection of the ten most promising technologies) properly supported?
   Yes
6. Is there one or more technology you would have expected to see in the most promising technology selections but did not? If so, what is the technology and its significance?

   Coverage exceeded expectations (and was actually quite informative already).
7. To what target audience(s) do you think these results will have great interest? Why?
   Technology holders/entrepreneurs—to an extent this project is highlighting potential markets for existing and adaptable products

   Industry—technology advances are a viable frontier for enhancements in safety and security, and with cost efficiencies
8. Other thoughts and observations on the process and results.
   Item 3 Assumptions, second bullet point, has the curious inclusion of "—including corrosives" that doesn't seem to

Table E-1. Peer review responders.

Organization	Number Responding
Class I Railroad	1
Marine Shipper	1
Chemical Manufacturer/Shipper	1
Regulatory Agency	1

have relevance by singling out this hazard class. As it doesn't add significance (at least to me), future inclusion of this cite should better explain the reasoning.

Development of Table 3 could use an expanded explanation. I didn't follow the analysis of communications and the rail mode (which seems to be a need area on Table 3, but a low priority on Table 1b). It may just be my feeble brain waves.

Overall, an excellent interim report and with an approach much different (and more appealing) than I'd expected.

Reviewer: Marine Shipper Official

1. Were the objectives and instructions provided to peer reviewers adequate?
   The objectives are clear and instructions adequate.
2. Was the project objective clearly explained?
   The project objective is clearly explained.
3. Was the characterization of the research approach easy to understand?
   Once I had time to focus on this, I could understand the research approach.
4. Does the research approach appear comprehensive and fair?
   At first, my thought was the approach was comprehensive and fair, but after reviewing the details of the interviewees, I have concerns that individual bias and unique experiences have given undue weight to unrepresentative needs.
5. Are the conclusions reached (i.e., the selection of the ten most promising technologies) properly supported?
   My response to question 4 notwithstanding, for the most part conclusions have proper support.
6. Is there one or more technology you would have expected to see in the most promising technology selections but did not? If so, what is the technology and its significance?
   Technology is not my general interest for study. I have nothing more or new to offer.
7. To what target audience(s) do you think these results will have great interest? Why?
   Government regulatory agencies and some product developers and vendors.
8. Other thoughts and observations on the process and results.
   First, let me state my experience and expertise comes from 36 years in the Inland Barge Transportation Industry. The observations and conclusions related to Marine seem more directed at "blue water" shipping than "brown water," where I'm from. I don't believe we have as many, and certainly not as significant, "requirement gaps" as shown in this study.

   My biggest concern about the project is that little, if any, energy went into addressing the third objective, "to identify potential impediments to . . . their development, deployment, and maintenance (e.g., technical, economic, legal, and institutional)." The functional requirements appear much as a wish list and development of technologies will tend to be driven by the perceived cost vs. benefit analysis. Quite frankly, some of them would not appear (to me) to make the grade, but that is off the top without proper analysis.

Chemical Manufacturer/Shipper Official

1. Were the objectives and instructions provided to peer reviewers adequate?
   Yes
2. Was the project objective clearly explained?
   Yes
3. Was the characterization of the research approach easy to understand?
   Yes
4. Does the research approach appear comprehensive and fair?
   NOT SURE. Quite honestly, I was surprised by the results in that "detection and response" related technologies seemed to be rated much higher in priority than technologies focused on "deterrence and prevention." Much of the collaborative work that industry and government are engaged on today in the rail transportation sector is focused on "prevention"—i.e., improving the integrity of the rail tank car against various safety and security threats. This work is being folded into the Advanced Tank Car Collaborative Research Program—which is likely to fund research in this area in the range of $15 million over the next 5 years. It is not clear how that can be reconciled with the conclusions in your report.

   Part of the issue may be that under your rating scheme, tank car survivability is rated fairly low because there is only one "high priority" check in the box. That fails to recognize that that one check represents the single greatest safety and security risk the chemical industry faces in the transportation sector—e.g., although the frequency of TIH incidents by rail is very low, the potential consequences could be extremely high. In that context, your ranking scheme may "undervalue" the need for additional research to address low probability/high consequence events.
5. Are the conclusions reached (i.e., the selection of the ten most promising technologies) properly supported?
   See response to question 4.

6. Is there one or more technology you would have expected to see in the most promising technology selections but did not? If so, what is the technology and its significance?
   See response to question 4.

   Specific technologies that are being evaluated to improve tank car survivability are listed in the supporting spreadsheet (lines 128-144). If those types of technologies were out-of-scope for the purpose of this study, I do not believe that was clearly stated in the project scope and objectives. By failing to include those technologies, or at least acknowledge that they were not included for a stated reason, I believe the report could be misleading (and ultimately criticized).
7. To what target audience(s) do you think these results will have great interest? Why?
   Government and private sector parties involved in Hazmat transportation and vendors of listed technology solutions.
8. Other thoughts and observations on the process and results.
   I was confused by tables 1a through 1e, because it appears the axes are labeled improperly. The tables show ratings going from "high" in the lower left corner to "low" at the top and right. I believe that is exactly the opposite of the way ratings are normally presented—and it appears to contradict the language in the boxes of those tables, which indicate that as you move up and to the right the ranking increases from "low" to "high"—not from "high" to "low."

   Thank you for the opportunity to review this draft report.

Regulatory Agency Representative

1. Were the objectives and instructions provided to peer reviewers adequate?
   The purpose of having the peer review was not clear. Before receiving this evaluation format I had no clear idea about what type of feedback would be valuable to the TRB. The instructions provided at the initial submission of the 15-page project summary and the accompanying spreadsheets were not adequate. Also, being a first-time TRB peer reviewer, I did not have an adequate introduction to the organization or the project.
2. Was the project objective clearly explained?
   The project objectives, as stated in Section 1 (titled Project Purpose), were clearly stated, but the other documentation was very difficult to comprehend.
3. Was the characterization of the research approach easy to understand?
   No. The method of application of each functional requirement was not explained and the tables directly following the functional requirement definitions were not explained and were confusing. For example, the "Package Integrity" requirement does not specify which type of packaging will be the comparison standard. For the Roadway transportation mode, does the package refer to tank trailers, drums, cylinders, etc.? It seems as if the research team was trying to capture all types of packaging, but no specifics were given.
4. Does the research approach appear comprehensive and fair?
   Without a better explanation of the project, I cannot make that determination at this time.
5. Are the conclusions reached (i.e., the selection of the ten most promising technologies) properly supported?
   I cannot make that determination at this time.
6. Is there one or more technology you would have expected to see in the most promising technology selections but did not? If so, what is the technology and its significance?
   No
7. To what target audience(s) do you think these results will have great interest? Why?
   These results would have greatest interest to those seeking to manufacture devices to satisfy these needs or for those who are in the process of writing research proposals. As a Hazmat employee who deals mostly with pressure vessels and other types of packaging, my knowledge of emerging technologies outside of this field is limited.
8. Other thoughts and observations on the process and results.
   Overall, the project summary was not written with the audience in mind. The project summary and its supporting documentation are quite voluminous, but at the same time, a great deal of basic information is missing. In my opinion, the peer reviewers likely have diverse backgrounds and experience, so to expect that they will all have an adequate understanding of all of the technology sectors and its implications on transportation is not realistic. Furthermore, my answers to the questions on this peer review document reflect the preparedness of this document for an unindoctrinated audience and its effectiveness in communicating what was done in this research. Though I am sure those who have been closest to this research and the preparation of the peer review documents have a thorough understanding of the research, its methodology and the conclusions, the job of bringing it out of the heavens for external consumption was not well executed.

APPENDIX F

Developer Interview Research Template

Interview Template for Contact with Developers of Most Promising Technology Selections

The Transportation Research Board (TRB) has awarded a series of projects under the Hazardous Materials Cooperative Research Program (HMCRP). Our project is HM-04: *Emerging Technologies Applicable to the Safe and Secure Transportation of Hazardous Materials.* Here is the Scope of Work: http://144.171.11.40/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=1606 on the TRB Website. The HM-04 research team, led by Battelle, is conducting this interview for this project. We have identified your organization as a developer of a promising emerging technology. We would like to get more information about your technology, its purpose, and your development process.

The objectives of HM-04 are to:

Develop a list of near-term (less than 5 years) and longer-term (5–10 years) technologies that are candidates for use in enhancing the safety and security of hazardous materials transportation, as applied by shippers, carriers, emergency responders, or government regulatory and enforcement agencies

Identify emerging technologies that hold the greatest promise of being introduced during these near- and longer-term spans

Identify potential impediments to and opportunities for their development, deployment, and maintenance (e.g., technical, economic, legal, and institutional)

The technologies being considered may be:

Evolutionary: Advances to existing products that will result in future improvements

Revolutionary: New technology concepts

Non-Typical Applications: Leading-edge technologies that are not being developed for Hazmat safety and security or even transportation per se

Your response to the interview will provide important insights and guidance to both industry and government. The interview data will be compiled and included in a public report that highlights emerging transportation technologies as well as opportunities and issues associated with product development, deployment and maintenance.

We commit to protect the confidentiality of your new technology by not revealing your name, your organization's name, or its location in our report or to any other party, unless you otherwise authorized that. We will characterize your organization generically, such as "a university engineering department" or a "mid-size automotive technology vendor." Likewise, we do not intend to use the product name (if any). We are more interested in its functionality.

The following questions are to help us better understand the emerging technology we have identified. We have sent it in advance of a scheduled phone interview, and you are encouraged to fill in the information to save time during the interview.

Information source (Battelle fills out how we found out about the technology)

___ Published literature
___ Patent search
___ Personal knowledge
___ Online Search

General Information

First, some general information about you and your company:

1. Contact information
   Company name: ______________________________
   Web site: ______________________________

Contact person: ______________________________
Title: ______________________________
Address: ______________________________
Phone: ______________________________
E-mail: ______________________________

2. What is the size of your organization?
   ___ Small (less than $10M annual revenue)
   ___ Medium ($10-$100M annual revenue)
   ___ Large (over $100M annual revenue)
3. What type of organization are you?
   ___ Privately held
   ___ Publicly traded
   ___ Non-profit research
   ___ Educational
4. What is the technology product you are developing?
   ____
   ____
5. Briefly describe what it does.
   ____
   ____
6. What recent information has been released regarding your technology (last six months)?
   ____
   ____
7. Who is your primary target market?
   ____
   ____
8. What benefit(s) could your technology provide in the area of hazardous materials transportation (check all that apply)?
   ___ Safety
   ___ Security
   ___ Efficiency
   ___ Productivity
   ___ Regulatory compliance
9. If the technology is expected to provide a safety or security benefit, in what phase(s) can it be helpful (check all that apply)?
   ___ Preparedness
   ___ Prevention
   ___ Mitigation
   ___ Response
10. Choose the major application area(s) that the technology will support and enter on the lines why your technology meets needs in that application area.

   Personnel______________________________
   ____
   Conveyance______________________________
   ____
   Cargo______________________________
   ____

   Back Office
   Tracking & Locating______________________________
   ____
   Security______________________________
   ____
   Logistics & Business Efficiency ______________________________
   ____
   Software Applications & Information Technology___
   ____

   Public Sector
   Emergency/Incident Response______________________________
   ____
   Regulatory Compliance______________________________
   ____

   Infrastructure
   Surface & Air modes______________________________
   ____
   Pipeline-specific______________________________
   ____

   Any other applications______________________________
   ____
11. For what transport mode(s) is the technology targeted (check all that apply)? Or if not targeted at a transport mode, to which mode might it be?
   ___ Truck
   ___ Rail
   ___ Marine
   ___ Air
   ___ Pipeline
   ___ Intermodal transfer
12. For what user(s) is the technology targeted or could be targeted (check all that apply)?
   ___ Shipper
   ___ Carrier
   ___ Emergency responder
   ___ Government official
   ___ Other______________________________
13. Is this a new technology or a next-generation of an existing technology?
   ___ New
   ___ Next Generation
14. Listed in the bulleted section below are characteristics that define readiness on a 1 to 5 scale. What technology readiness level on this scale best describes your technology?
   ___ Level 1 – basic technology principles have been observed
   - Fundamental scientific principles and assumptions used in new technology are defined
   - Basic characterization data exists

   ___ Level 2 – equipment and process concept formulated
   - System conceptual design, functional requirements and components identified

- Individual parts of the technology work
- Availability of output devices are known
- System performance metrics established
- Risk areas and mitigation strategies identified
- Manufacturing capability known
- Performance predictions made for each component
- Experimental design formulated

___ Level 3 – prototype demonstrated in laboratory environment

- Relationships between system and components are understood at engineering scale
- Operating environment for final system known
- Collection of maintainability, reliability and supportability data
- Verification of component compatibility
- Performance baseline (including cost, schedule and scope) established
- Operating limits and off-normal operating responses for components determined
- Scaling issues that remain are identified and understood
- Interface control process established
- Pre-production hardware available to support system fabrication
- Engineering feasibility fully demonstrated

___ Level 4 – technology product operational in limited real-world environment

- Discrete components of the product successfully tested under controlled "real-world" conditions to ensure optimal function
- Product successfully demonstrated within the "system" it is designed to operate (i.e., test with other technologies that the product is anticipated to interact with) under controlled "real-world" conditions
- Receive feedback regarding recommended changes from beta users
- Make product changes based on test results and user feedback

___ Level 5 – technology product fully operational in real-world environment

- Product successfully used by customers under a wide range of environmental conditions, thereby ensuring proper robustness and functionality
- Training and supportability plans implemented
- Active mechanism in place to make product improvements in response to customer suggestions

15. What is the anticipated time for your technology to reach Level 5?

___ Within a year
___ 2-5 years
___ 6-9 years
___ 10-15 years

16. Please share any details you can on the timeline involved in the technology development.

____
____

17. What special efforts (if any) are needed to bring the technology to Level 5?

____
____

18. Are you aware of likely or potential interactions between your technology and other technologies? If so, would it be positive or negative interaction?

____
____

19. Are you aware of any impediments to developing, deploying, and/or maintaining your technology?

____
____

20. Can you share (or estimate) your total costs to bring your technology into the market? What have you invested so far and how much more do you need?

____
____

21. Roughly how much (as a range or estimate) will it cost the user to acquire and operate your product when it reaches the market?

____
____

22. Based on your estimate, what is the average payback time to the customer in years?

____
____

23. Did you follow any technology development best practices? If so, what were they?

____
____
____
____

24. Is there any other information you want to share?

____
____
____
____

If you have any questions about this survey, please call:

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APPENDIX G

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Abbreviations and acronyms used without definitions in TRB publications:

AAAE	American Association of Airport Executives
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI–NA	Airports Council International–North America
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	Air Transport Association
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
HMCRP	Hazardous Materials Cooperative Research Program
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
PHMSA	Pipeline and Hazardous Materials Safety Administration
RITA	Research and Innovative Technology Administration
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S.DOT	United States Department of Transportation