Alternative Technologies to Railroad Tank Car Placarding
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EXECUTIVE SUMMARY

Subsequent to the events of September 11, 2001 Congress passed the Aviation and Transportation Security Act (ATSA), Public Law 107-71, 115 Statute 597 on November 19,2001. Currently, Transportation Security Administration (TSA) has broad responsibility and authority for "security in all modes of transportation . . . ." TSA and the Information Analysis and Infrastructure Protection Directorate (IAIP) of DHS are considering measures to enhance the security of rail shipments of toxic inhalation hazard (TIH) materials (*1*).

As part of TSA's work to develop and establish policy regarding rail shipments of TIH materials, TSA initiated this research to evaluate the potential for alternative technologies applicable to replace the current hazardous material placard system. The research was focused on evaluating known technologies rather than attempting to invent a new technology to meet the purposes of replacing the current placard system.

To ensure that the research results meet the intended purpose of replacing the placard system the stakeholders who rely on the placard to provide information for their safety were surveyed. The stakeholders for this research are the first responders, the railroad industry, the chemical industry, the emergency management community and public officials. The survey, in the form of stakeholder meetings, provided this research with what information the stakeholders rely on the placard to provide and what the current placard system information limitations are with respect to individual stakeholder communities needs.

The results of this research can be summarized as follows:

- **Information obtained from the placard is essential.** In an incident involving a railroad tank car, first responders use the placard to make a quick initial assessment and evaluation of the hazard and pass on correct information regarding material involved in an incident.
- **Each stakeholder community has alternate primary uses for the placard.** The first responder primarily uses the placard during the initial stages of assessment during an incident. The railroad industry is required to ensure that the placard is properly placed on required tank cars and that the placard is correct for the declared product in the tank car. The chemical industry is required to provide the placard on the tank car for use by other stakeholders. The emergency manager community and public officials use the placard to develop emergency response plans for commodities passing through their sphere of responsibility.
- **International border crossings of tank cars.** International border crossings of placarded tank cars are estimated at approximately 16,000 car crossings. Border crossing delay of nearly one calendar-year is estimated to be required if the current placarding system is substantially altered without foreign concurrence.
- **Alternative technology to replace current placard system.** The current placard system was evaluated and its functional requirements assessed to establish a basis for alternative technologies to be evaluated against. Nine alternatives were developed in three categories.

- **Cloaking devices –** Individual systems incorporated on the tank car that provide equivalent placard information when queried or when triggered by an incident.
- **Decentralized systems –** Component systems that rely on a distributed database to supply information on tank car contents through some means or method of communication other than the tank car.
- **Centralized systems –** Systems that use a centralized database to maintain all tank car information for authorized user access.

- **Ranking of technology compliance with the current placard system –** An analysis was carried out to rank the technologies against the base case of the current placard system. Subsequently, a sensitivity analysis was performed to ensure no significant error falsely eliminated a placard equivalent system.

Limitations of Current Study

One of the critical factors in conducting this research has been the establishment of the functional requirements. There are a number of ways that a study such as this one could have been conducted to achieve this critical point of departure. This current study sought to establish functional requirements by holding focus groups with interested stakeholders. Two alternative approaches to this critical juncture are worthy of discussion. First, a survey of stakeholders that would be representative of all stakeholder groups would provide greater insight into the criticality of each functional requirement. This could still be done to fine-tune the functional requirements for an alternative to the hazardous materials placard system currently in use. Second, both the focus groups employed herein and the surveys suggested above rely on stakeholders to represent the nature of the functional requirements. The research team is convinced that the focus group participants have done that to the best of their ability. However, the participants are human, and as such they are reporting their beliefs and attitudes about the functional requirements. A thorough study of behavior in actual incidents, to represent the kinds of events that have occurred in the past five to ten years, would represent behaviors of actual use of placards in real incidents. Such a study would be far stronger to base functional requirements on than the current focus group approach. Such a study could provide considerable validation of the functional requirements developed herein. A study to further validate the functional requirements is strongly recommended.

The consideration of alternatives to replace the current hazardous materials placard system centers on the balance between potential increases in security provided by the alternative and the potential losses in safety of first responders, emergency personnel, and the public. This issue was raised in every stakeholder meeting in a variety of forms. In brief, the consensus position seems to be that modest gains in security do not warrant the loss of considerable safety. Hence, alternative systems need to be able to fully meet the functional requirements of the existing system, and should probably exceed in some areas to warrant the cost (financial, human, and risk) associated with making the change.

The current study has not considered car markings, or other factors that may make identification of hazardous materials in tank cars not only possible but probable. Hence, before any transition to an alternative system can be considered, no matter how good the alternative may be, the system must be considered in the context of these other considerations.

CHAPTER 1:
INTRODUCTION

On a daily basis, approximately 800,000 shipments of hazardous materials travel through the U.S. (*2*). During the 1997 Commodity Flow Survey, it was found that over 1.56 billion tons of hazardous materials traveled by all modes in the U.S. Of that, 869.7 million tons were moved by truck, representing 56 percent, and 96.6 million tons were moved by rail, representing 6 percent of the total (*3*). The remaining quantities were moved via water vessels, air, and pipeline. However, in terms of ton-miles, the railroads moved similar levels of hazardous materials as trucks with rail moving 71.7 billion ton-miles (27 percent) and trucks moving 74.9 billion ton-miles (28 percent) (*3*). The exposure to hazardous material by communities in the U.S. is extensive with highways and rail lines virtually through every community. Even small towns with gas stations receive hazardous materials shipments.

Utilizing recently released data from the Bureau of Transportation Statistics and analyzing community proximity to rail lines, it was estimated that 18,800 of the total 34,600 places within the continental U.S. reside near rail lines (*4*). The population for the 12,000 places with population values totaled almost 150 million persons. In an additional analysis it was found that 444 out of the 448 continental U.S. urbanized areas with populations greater than 50,000 intersected rail lines (*5*). All but two of the state capitals in the continental U.S. have rail lines operating in their boundaries. The 554 freight railroads in the U.S. operate almost 142,000 miles of track (*6*).

The number of incidents involving hazardous material in 2003 was 15,200. Highway transport accounted for almost 90 percent (13,650 incidents), while rail accounted for slightly more than 5 percent (809 incidents). Of these rail incidents, 14 resulted in fatalities. The focus of this project is limited to railroad tank cars, which is a small fraction of these accidents.

Since the attacks of September 11, 2001, great efforts have been undertaken to increase security of the nation's transportation system. Transportation of hazardous materials is of particular concern because of the potential impact created by an incident. This is easily seen with the numbers above showing the quantities of hazardous materials transported and the population exposed to that transport. Specific concerns exist as to the potential information provided to terrorists by the current placard system, especially those located on rail tank cars. There are an estimated 245,000 rail tank cars utilized by the rail industry to transport tank car compatible commodities in the U.S. (*7*).

This project considers alternative technologies potentially capable of replacing the existing placard system on rail tank cars, thus increasing security against terrorist attacks and also maintaining equal or greater safety levels for first responders and the emergency response community.

PLACARDS AND EMERGENCY RESPONSE

The hazardous material placard system is a low-cost system that provides information to shippers, railroads, and emergency responders. The hazardous materials placard is used by railroad yardmen to identify and position tank cars in trains to comply with safety regulations. Train crewmen (engineers, conductors, and brakemen/switchmen) use the placard to identify hazardous material tank cars, ensuring their placement is consistent with regulations designed to protect the crew's safety in the event of a mishap or derailment. Emergency response personnel utilize the placards for primary notification of what material is involved and what actions should be used or avoided to safely handle the hazardous materials involved in the event of train derailments or other emergency incidents involving hazardous materials in trains.

Hazardous material incidents are primarily handled by local fire departments. Fire departments in the U.S. are vastly volunteer in nature, with 93 percent of the 26,354 total fire departments represented by volunteer firefighters. This includes 19,224 that are completely volunteer, 3,845 that are mostly volunteer, and 1,407 that are mostly career (*8*). These 26,354 departments are made up of over one million active firefighters, of which 75 percent are volunteers (822,850) (*9*). Training and equipping these departments and over one million firefighters for hazardous material incidents is a considerable task. The difference in capabilities will greatly vary between a major urban professional department and a rural, volunteer department. Currently, all departments focus on the placard as the primary source of information. To aid first responders when they arrive on the scene of a potential hazardous material incident, the U.S. Department of Transportation (USDOT) recently announced that over 1.73 million copies of the *Emergency Response Guidebook 2004* are to be distributed to police, fire, and other emergency response entities (*10*). This guidebook is the key reference for all emergency responders in case of hazardous material incidents.

Previous Efforts

Finding the balance between security and safety is a particularly difficult endeavor. The major question is how much is security going to increase by altering the current placard system compared to the impact of safety to both the general public and the first response community during a hazardous materials incident? As previously indicated, the placard system is a long-standing, embedded system that is widely understood and utilized. A system-wide alteration to that system could potentially require extensive training and implementation costs. However, with the increased security concerns and advancements in technology, multiple efforts have been undertaken over the past decade to examine the placard issue.

A recent study completed by the Research and Special Programs Administration (RSPA), titled *The Role of Hazardous Material Placards in Transportation Safety and Security*, extensively examined the use of placards and investigated alternative technologies and security techniques. The report did not focus strictly on rail tank cars but on all transportation of hazardous materials. In terms of removing placards, the report concludes that "removing placards would not significantly improve security because there are many useful alternative sources of information that terrorists could use to identify hazmat shipments for theft or destruction, especially as part of a planned terrorist attack" (*2*). It did, however, conclude that for a limited selection of extremely high-risk materials drastic actions, such as removing placards, may be necessary.

The RSPA report identifies several additional efforts including a discussion of a congressional mandate in 1990 calling for the investigation of incorporating a centralized reporting system that would provide real-time hazardous material movements by all modes for use by first responders. In the 1993 document by the Transportation Research Board (TRB) titled *Hazardous Materials Shipment Information for Emergency Response*, the committee concluded the critical information required at the scene of an incident was provided by the current placard system, but that a central reporting system could enhance the existing information (*2*).

Additionally, the report identifies a USDOT position paper titled *Transportation Security and Placarded Hazardous Materials Shipments*, which made several conclusions related to placards and security. These include "removing placards would have minimal effect on the overall security of hazardous materials in transportation" and "would have detrimental effects on first responders, transport workers, and international transportation of hazardous materials (*2*)."

A Hazardous Materials Roundtable by the International Association of Fire Chiefs (IAFC) clearly identifies the emergency response stance that "no changes to the placards should be made until a better method is created, implemented, and proven successful" (*11*). The Roundtable was also concerned that any new system must be available to the first responder but "cannot depend on any significant level of technology" (*11*).

Report Organization

This research examines technological approaches available to replace the placard system for railroad tank cars. This report describes the research effort to undertake this directive. It is organized by first describing the history and background associated with the current placard system, including legal establishment (c.f., Chapter 2). The remainder of the report catalogs the methods utilized for this project to receive stakeholder input and to identify and analyze alternative technologies (c.f., Chapter 3); discusses the alternative technologies selected for analyses (c.f., Chapter 4); presents the assessment of the alternatives (c.f., Chapter 5); and details conclusions and recommendations from the project (c.f., Chapter 6).

CHAPTER 2:
HISTORY AND BACKGROUND

In order to fully understand the placards' role in hazardous materials transport and emergency operations, it is important to understand the history of placarding and the role of the placard in all aspects of hazardous materials transport as well as emergency operations. Simply put, a placard is an identification system. Identification systems for hazardous materials were put in place in order to inform personnel working in the area of the material how to react in case of an emergency. The placard, as we know it today, evolved from a series of legislative actions.

In 1966 the Department of Transportation Act was the first attempt to consolidate the Federal regulatory responsibility for transportation of hazardous materials. Prior to that time each agency was responsible for regulating hazardous materials being transported by their particular mode (*12, 13*).

The current system is the result of the implementation of the Hazardous Materials Transportation Act (HMTA) of 1975. This act imposed the Federal requirements for labeling and identification of hazardous materials during transport. HMTA was refined and reauthorized by the Hazardous Materials Transportation Uniform Safety Act of 1990 (HMTUSA). The above regulations define hazardous materials that present a danger during shipment (*12, 13*).

The USDOT adopted and enforces a United Nations standard for placards and labels for hazmat transportation. This identification system is mandated and required per 49 Code of Federal Regulations (CFR) 172. RSPA is currently the responsible agency for hazardous materials rules (*12, 13, 14*).

49 CFR 100-199 requires shippers and carriers to communicate the hazards of their shipments. The regulation requires that once it has been determined the materials shipped are hazardous, per 49 CFR 172.101, a label or placard must be affixed to the shipment. The standard placard is a 10 ¾″ square that is affixed to four sides of the shipping container (front, rear, and both sides). The view of the placard must not be obstructed in any way. It should be placed right side up and be contrasting to the background color of the container. The placard utilizes color, the hazard class symbols, the United Nations/North American (UN/NA) code to identify the hazard (number found at the bottom of the placard), and a hazardous class designation or a four-digit identifier code (number found at the center of the placard). Figure 1 represents an example of the placard. Further requirements state that the identification must be in English and on durable material (*12, 14*).

Figure 1. Example of Placard.

USDOT placarding requirements are based on the United Nations Model Regulation on the Transport of Dangerous Goods. This regulation provides the basis for transportation of hazardous materials worldwide and its provisions are widely adopted in both national and international regulations. The regulation is also the basis for the International Marine Dangerous Goods (IMDG) Code, which is the international code for transporting dangerous goods by sea. The IMDG specifies how hazardous materials shipments for sea transport should be marked, labeled and placarded. In practice, this means that from the legal point of view, the whole of the IMDG Code is mandatory and USDOT placarding satisfies those requirements (*14*).

In addition to the above regulations addressing the labeling and identification of hazardous materials during shipment, Congress passed regulations establishing the Emergency Planning and Community Right-to-Know Act (EPCRA) in 1986. Passed as a Title III of the Superfund Amendments and Reauthorization Act (SARA) of 1986, the purpose of EPCRA is to encourage and support emergency planning efforts at both State and local levels, as well as provide the public and local governments with information concerning potential chemical hazards in their communities. Triggered by the 1984 disaster in Bhopal, India, where an accidental release of methyl isocyanate killed 3,800 people, 40 people experienced permanent total disability, and 2,680 people experienced permanent partial disability, the Community Right-to-Know provisions of EPCRA are intended to increase the public's knowledge and access to information on chemicals at individual facilities, their uses, and releases into the environment. Placards also fulfill the requirement in both SARA as well as the Hazardous Waste Operations and Emergency Response (HAZWOPER) regulations regarding provision of information regarding hazardous materials to workers (*13, 14, 16*).

Although not perfect, the USDOT placard system is a simple and functional tool that can be utilized by both shippers and emergency responders. The USDOT placard system also allows transporters to meet the requirements outlined in EPCRA regarding the Community Right-to-Know regarding chemicals being shipped through their communities. Most importantly, the placard allows first responders the ability to make a quick initial assessment and evaluation of the hazard and pass on correct information regarding material involved in an incident (*13*).

The first use of a placard during the incident is by the first responder as a means of identifying that the incident may involve hazardous materials. In actuality there are two levels of first responder, the awareness level responder and the operational level responder. An awareness level for first responders is defined as an individual who is "likely to witness or discover a hazardous substance and who has been trained to initiate the emergency response sequence by notifying the authorities of the release" (*13*). These responders include any worker who works near hazardous materials. Persons trained for the first responder awareness level learn to recognize placards as an indicator of the presence of hazardous materials. The operational level first responder is a worker who actually responds to an incident from outside of the actual spill or incident area. These personnel are expected to initiate an action in response to the incident that will minimize the hazards produced by the spill. This initial response may include protection of persons, property, or the environment. These responders provide the initial defensive action and use distance as a primary protection from the hazard. The operational level first responder also provides additional input regarding the type of hazard posed. These responders also use placards extensively to assess the hazard, and they are trained in the use of the *Emergency Response Guidebook* (*17*).

Responders use the *Emergency Response Guidebook* for the initial response phase of an incident involving hazardous materials. Placards and the information provided by the placard, particularly the UN/NA code and the hazardous class designation or a four-digit identifier code, can be utilized in conjunction with the *Emergency Response Guidebook* to provide the responder with valuable information. The information includes but is not limited to potential hazards regarding fire, explosions, and health; public safety including initial evacuation distances; the need for protective clothing, special first aid procedures, and supplemental information. The guidebook also provides information on inhalation hazards, chemicals that may be water reactive, and shelter in place actions that may be taken by groups unable to evacuate.

Once an incident is past the initial response stages, placards still provide a valuable source of information by providing information on containers, vehicles, cars, and etc. that may be located on the periphery of an incident, as well as sight location of cars on consists or shipping papers. This process of locating documented material and rendering it safe may continue throughout the containment phase of the operation (*13*).

Placards are only one means of identifying a material as hazardous. Shipping documents or papers contain the specific information regarding the contents of the shipment. These documents, however, are either in the cab of the vehicle or in possession of the train crewmember and may not be readily available to emergency responders. This is especially true for the first responders at the scene. In summary, the placards are often the most visible means and sometimes the only means of initially determining whether a material is present and the type of danger the material presents.

BORDER TRAFFIC IMPLICATIONS

Cross Border Hazardous Material Tank Car Traffic Analysis

The implication of removing the current hazardous material placard from hazmat tank cars destined for movement across international borders is presented below.

Based on the latest data available (1997) from the USDOT, Bureau of Transportation Statistics (BTS) there were 13,152,000 tons of hazardous materials shipped to Canada and 6,053,000 tons (by inference) to Mexico, by all modes from U.S. origination points. The hazardous materials moved by all trucks in the U.S. is 56 percent while rail handles 6 percent of the traffic. Assuming that the same distribution of traffic is indicative of cross border movement, then 789,120 tons of hazardous material can be expected to move by rail into Canada and 363,180 tons into Mexico for the 1997 period. The Association of American Railroads (AAR) Waybill Sample provides information on the number of hazardous material car loads originating in the U.S. Based on the waybill sample supplied by the railroads, the estimated number of car loads (Factored Car Loads) is calculated to be 3,231,538 for 2001. Using the distribution of the

Factored Car Loads and the estimated tons per car for each standard transportation classification code (STCC) the average U.S. origin hazardous material tank car load was estimated to be 71.3 tons.

Using the estimated 1997 cross border data of 789,120 tons of hazardous materials moved by rail into Canada, and the average car load at 71.3 tons in 2001, the best estimate available for tank cars crossing the border into Canada is 11,068 cars. Using the same approach for exports to Mexico, there were 6,053,000 total tons exported. At 6 percent of total exports being carried out by rail, then 363,180 tons were moved by tank car or 5,093 tank cars of hazardous material were exported to Mexico.

No equivalent data source could be found to support an analysis of imports of hazardous materials in railroad tank cars from Canada or Mexico. Data exists regarding import valuation for each three digit standard international trade classification (SITC) code group. However, to obtain a useful data set for hazardous material movement by tank car, an extensive effort beyond the scope of this report is required.

The delay associated with reconfiguring placards on imported hazardous material tank cars is expected to be approximately equivalent to the delay associated with export tank car reconfiguration. Additionally, tank car hazardous material imports are expected to only amount to a fraction of exports.

A likely scenario for configuring a tank car to comply with international treaty obligations by adding hazardous material placards at international borders was developed. When a train reaches the international border it will need to comply with international treaty requirements to clear the receiving country's Port of Entry. As the train approaches the border crossing rail yard, the supervisor of train inspecting forces would examine the train orders to determine if there are hazardous material tank cars in the Consist. When hazardous material tank cars are included in the train, the supervisor would determine the appropriate placards needed for each tank car and assemble them in the proper order for application to each car. Not all trains crossing international borders will contain hazardous material tank cars, so time will be spent examining train orders where no other effort is needed by the supervisor. It was estimated that this activity will require an average of 10 person-minutes per tank car by the supervisor. The supervisor will notify the proper labor forces that a train requiring placarding is approaching the yard and placards are available for pick up to be applied to the train.

The likely scenario might continue with an inspecting laborer having to go to the proper place and pick up the placards to be applied to the arriving train. After the train arrives, the laborer will proceed to carry out the normal international crossing car inspection. However, as the inspection proceeds down the train length, the inspector will have to pay special attention to each tank car to note the car number and verify that it is or is not a hazardous material tank car in compliance with the train make up. As each hazardous material tank car is located, the inspector will add the applicable placards as provided by the supervisor to that car. The laborer will have to apply a placard to the holder on one side of the car, then climb up the end-step and move along the end walkway to apply a placard to the end placard holder. The laborer will then climb down the other car side end-step to the ground and walk the length of the car to apply a placard in the holder. The inspector will then climb the opposite end-step to the end walkway and apply the last placard to the holder and proceed to climb down the end-step to the ground on the side of the car originally on. Lastly, the inspector will return to the point where the first placard was applied. This portion of the process is estimated to require approximately 20 person-minutes per hazardous material tank car.

Hence, a total time requirement of 30 person-minutes is estimated to be required to apply placards to hazardous material tank cars for either export or import. In the case of the shutter technology (masking/covering the placard), no extra time is expected to be required. All other technologies are estimated to require placarding to comply with international treaty obligations.

The estimated export volume of hazardous material tank cars is 11,068 to Canada and 5,093 to Mexico, for a total of 16,161 tank cars requiring 30 person-minutes of time per car for a total additional delay of trains at international borders of 8,080 hours, nearly a calendar year or approximately four man-years (one man-year, 2080 work hours) of train delay.

The Transport Canada representative at the Washington, D.C., stakeholder meeting stated, "The Canadian First Responders, told him to make the point that, if the hazardous material placard is removed from railroad tank cars carrying hazmat, firefighters and hazmat responders will not respond to train accidents."

CHAPTER 3:
THE FUNCTIONAL REQUIREMENTS

METHODS

This chapter presents the approach used to develop the functional requirements for the placard system from the stakeholders' point of view. Functional requirements are not synonymous with the legal requirements. Since the current regulatory structure requires placards, it is presumed that any alternative that did not require placards would have to be implemented with a change in statute to reflect the new system. Therefore, the functional requirements rather than legal requirements provide a more realistic standard for a study of alternatives. The placard system is herein considered to be comprised of the hazardous material placard itself, the United Nation's identification number, and the Emergency Response Guide used to interpret the placard information and guide initial responses in incidents, emergencies and potential emergencies. Five classes of stakeholders were incorporated into this study:

- first responders,
- railroad industry personnel
- chemical industry personnel,
- emergency managers, and
- public officials.

The development of the functional requirements was approached in a four step process: (1) identification of stakeholders, (2) focus groups with stakeholders, (3) summary of functional requirements under normal operations, in transition, and during emergency operations for each stakeholder group, and (4) accumulation across stakeholder groups. *Normal operations* are distinguished by the routine activities of all stakeholders. Under normal operations trains are guided by the standard operational procedures of the day-to-day routine. When an incident occurs, the first 15 to 30 minutes are designated as a *transition period*. This period is characterized by activities that cannot be guided by the standard operating procedures of day-to-day activities, and yet they also are not guided by an incident command structure, as it often does not exist in this initial period of the emergency. The *emergency operations* period is characterized as the remaining duration of the emergency after the incident command structure arrives on the scene.

Identification of Stakeholders

Two primary focus group meetings were held as part of this research. The first meeting was held in conjunction with the National Fire Protection Association (NFPA) Technical Committee for Standards 471, 472, and 473 on August 27, 2004. The NFPA represents over 75,000 individuals from around the world. Established in 1896, its mission is to "reduce the worldwide burden of fire and other hazards on the quality of life by providing and advocating scientifically-based consensus codes and standards, research, training, and education" (*18*). The Technical Committee for Standards 471, 472, and 473 writes standards for hazardous material emergency response on railroads. The focus group produced a clear consensus of what characteristics of the hazardous material placard the first responder and emergency operations user relies on.

The second focus group, held October 8, 2004, consisted of railroad, chemical industry, government, emergency managers and first responder representatives that had previously participated in a conference conducted and facilitated by TSA on July 25, 2003. TSA representatives felt strongly that this group needed to be reassembled to participate in this study because of the commitments made by TSA to involve these representatives in future aspects of this overall effort. TSA personnel participated in this focus group to provide continuity and leadership, and assure participants of their ongoing support for the effort. A complete list of focus group participants for both groups is presented in Appendix A.

Focus Groups with Stakeholders

The focus groups were well aware that hazardous materials placards are required under the Hazardous Material Safety Act of 1975 (c.f., 49 CFR 172.500). The legal requirements include: placards must 1) be visible from a distance, 2) depict graphic hazard symbol, 3) provide hazard class, and 4) be placed on all four sides of car. The stakeholders understood that these primary functions would be used as system requirements from a functional point of view.

In discussing the extent to which hazardous materials satisfy the safety function intended stakeholder observations were noted to assure functional requirements are understood in the context of the existing placard system. First responders made it clear that more information rather than less is essential in conducting their initial assessment of an incident. In addition, it was clear that more timely information is preferable to information that comes too late to contribute to decision-making. These general discussions were used to set the tone for an open, frank, and candid examination of what placards are really used for in railroad tank car emergencies.

While placards are required under current laws, the stakeholder groups were asked to focus on the primary functions of the placards in an incident during normal operations, in transition, and during emergency operations. By discussing the use of placards in each phase (i.e., normal operations, in transition, and emergency operations) a detailed ongoing discussion of placard use in each time period resulted. These detailed comments were sometimes repetitive, often abstract, occasionally illustrated with concrete examples, but indicative of the actual use of placards in the field.

The focus groups were asked to consider three types of alternative systems: centralized systems, decentralized systems, and cloaking. Centralized systems are systems that are driven by a connection to a centralized database of hazardous materials. Examples include CHEMTREC, barcodes, unique serial numbers, and using a global positioning system (GPS) to track train or car location. What each of these has in common is a link to a centralized database to attain detailed information about car content. Decentralized systems are systems that are driven by data contained on the train or car in question. Examples include RFI tags, train tags, radio telemetry, and MEMS technology. Each of these has in common the encoding of information associated with a car on or near that car. Cloaking devices are systems deployed on each placard (or car) that essentially makes the information unavailable except under incident conditions or perhaps only to people with specialized equipment. Examples include drop-off covers, breakaway doors, or light systems that are activated only when needed. Each of these systems has in common the fact that information is made available only when needed by authorized personnel.

At the close of the focus group, critical functions in each period were summarized and presented to each group. The groups were asked to consider each function individually, and the list as a whole. When necessary, additional items were added to the critical functions list, and others were deleted. In the end the focus groups agreed to the consensus list of critical functions of placards in each period.

Functional Requirements Matrix

In all stakeholder meetings, discussions often turned to scenarios where placards are of little or no functional value. For example, it was mentioned multiple times that in some cases the placards are destroyed due to fire or the spill itself, or viewing was obscured due to darkness, smoke, position of car (on its side or in an entanglement) or nearby structures (c.f., Figure 2). Functional requirements were collected by phase of incident, and noted by reference to each stakeholder group. These emergency phases are described below and the functional requirements are summarized in Table 1 by phase of incident or emergency.

Figure 2. Train Derailment.

Normal Operations—Normal operations comprise most of the total operations time and reflect the normal day-to-day activities of rail operations. A consensus among stakeholders indicates that placard functions in normal operations are of secondary importance. During normal operations first responders do not use the placards, except in their roles as emergency managers, emergency planners, and public officials. Conversely, emergency managers and public officials use placards to initiate emergency planning. As such they use placards to monitor commodity flows through their jurisdictions. These commodity flows allow emergency planners to understand for which types of hazardous materials they need to prepare as they train emergency personnel on the use of placards at the same time. The placard supplies the class, division, and United Nations number of the hazardous material, which can be used for planning and training first responders and emergency managers in the community to provide better emergency preparedness should it become needed. Public officials use the placards as a screen or trigger for enforcement issues. The chemical industry primarily uses the placards to assure compliance and as backup information should electronic records on shipments become temporarily lost or unable to be retrieved. In addition, the chemical industry uses the placards in a secondary manner to spot hazardous materials cars in loading/offloading areas of the plant. Like the chemical industry, the railroads use placards to assure compliance and as backup when needed, but they also use the placards to verify car placement in the train and affirm other sources of information about train/car content. In addition, the railroads use placards as a secondary source of information to assure safety measures in handling, switching, and holding cars in rail yards.

In Transition—The transition period is marked by rapid collection of relevant data about what has happened, and what the initial actions should be to protect both the public and emergency personnel. This period comprises the first 15 minutes after an incident and can extend to as much as 30 minutes. A consensus among stakeholders indicates that the placards are most critical in this period. The first responders use the placard to scan the incident from a distance, usually at least 300 feet. They also use the placard to locate hazardous materials both in those cars entangled in the incident itself (e.g., in a derailment) and cars not in immediate danger due to their location in the train. The placard comprises the first source of information that establishes initial actions, including the setting of initial perimeter parameters. The placard supplies the class, division, and United Nations number of the hazardous material in the placarded container. Emergency managers and incident commanders primarily use the placard information as a redundant source of information to crosscheck other sources of information required in the ordering of public emergency warnings and protective actions. The chemical industry uses placards as a secondary source of information to reference car content if responsible employees are not available. The railroad does not use placards in the transition period.

Emergency Operations—The emergency operations period begins with the arrival of the incident command team and continues throughout the remainder of the emergency, which is usually signaled by an all clear. A consensus among stakeholders shows the placard of least importance in this period because actions in this period require more detailed information than that available in the placard system. First responders use the placards in a secondary function during the emergency operations period to continuously assess the accident/incident site. Emergency managers and railroad personnel use placards for scene management during the emergency. Together they identify peripheral hazardous materials cars and locate hazardous materials in the incident site. The chemical industry does not use placards during emergency operations. This may be the result of the fact that chemical industry personnel have direct access to the content of the tank car, and industry personnel's role during emergency operations occurs when the chemical content is known and hence the placards are of limited value.

Table 1. Functional Requirements by Stakeholder Group and Phase of Incident.

	First Responders Requirements	**Uses by Emergency Managers and *Public Officials***	**Chemical Industry Users Requirements**	**Railroad Transportation User Requirements**
Condition	Placard/ERG tied as System	Placard Element of Regulatory Code		
Normal Operations	**Not Used**	**Primary:** • Initiates the Emergency Plan • Monitor commodity flow • Placard supplies - Class, Division & UN # • *Enforcement*	**Primary:** • Compliance • Backup **Secondary:** • Spotting cars at loading stations	**Primary:** • Compliance • Verification • Backup **Secondary:** • Safety measures
In Transition (first 15-30 minutes)	**Primary:** • Scan of incident from distance • Locate Hazmat in incident • First source of information • Establish initial actions • Placard supplies - Class, Division & UN #	**Primary:** • Redundancy • Public Hazard Warning	**Secondary:** • Reference car content when responsible employees not available	**Not Used**
Emergency Operations	**Secondary:** • Continuing assessment of the accident /incident site	**Primary:** • Scene management • Identify peripheral Hazmat cars • Locate Hazmat in incident	**Not Used**	**Primary:** • Scene management • Identify peripheral Hazmat cars • Locate Hazmat in incident

SUMMARY OF FUNCTIONAL REQUIREMENTS

This section summarizes functional requirements by phase of incident or emergency.

Normal Operations—During normal operations there are two primary and seven secondary functional requirements. The primary functional requirements are compliance and backup. Compliance involves the meeting of regulatory requirements for the shipment of hazardous materials, and the compliance with company or union safety guidelines for safe operations. Backup involves the use of placard information as the best available information, when other information (e.g., shipping papers, consists, etc) are not available. Beyond supplying the class division and United Nations number of the hazardous material contents, the placards are also used as a triggering device or screen for regulatory enforcement, verification of shipping papers, spotting cars at various locations (e.g., plant, rail yards). More importantly they are used to initiate emergency planning, monitoring of commodity flows to enhance emergency planning, and generally trigger safety measures when handling cars with placards.

In Transition—During the first 15 to 30 minutes of an incident there are eight primary functions and one secondary function. Most important among these is the initial scan of the incident from a distance to determine the extent of hazardous materials involvement. In this sense it gives, especially first responders, a first source of information to locate hazardous materials in the incident and establish initial parameters for action. Of course the placard supplies the class, division, and United Nations number of the hazardous material involved and thereby provides a redundant source of information needed to initiate public hazard warning. In addition, the placard is used as a secondary source of information to reference car content when responsible employees are not available.

Emergency Operations—During emergency operations placards have three primary uses and a secondary function. Scene management relies on placards to identify rail cars that are not immediately involved, but contain hazardous materials. Such cars can be removed from the immediate danger zone, or even removed from the area entirely to assure their continued safety. They can also be used to locate hazardous materials that are reported in the shipping papers but not yet found in the incident, and conversely identify peripheral hazardous materials cars. Finally placards are used in a secondary manner to continue the assessment of the accident (or incident) site.

These critical functions establish the essential functions any alternative system must meet. As such they are examined in conjunction with each alternative system in Chapter 5.

CHAPTER 4: ALTERNATIVE TECHNOLOGIES

The technology discussions in this chapter are based on review of technology descriptions from sources in published reports; anecdotal discussions with railroad, chemical industry, and first responders; and assessments by the research team. The technologies reviewed are categorized into three groups: radio frequency based, central database, or decentralized database. Each technology was evaluated according to the operating mode and determined to be either active or passive. *Active mode technologies provide information about some characteristic of the hazardous material tank car while the passive mode requires user action to obtain data.* Each technology was evaluated regarding how stable the technologies main characteristic is and assigned a 5, 10, or 20 year life. For example, if the technology is currently a mature technology that is widely used and has not changed significantly in the past ten years, it was assigned a 20 year life. However, if a technology is based on rapidly changing products to operate, e.g., computer chips, it was assigned a five year life. The life span of all the remote reader technologies was assigned a life of only five years because of the rapidly changing field of handheld computer devices.

The availability of the technologies was evaluated regarding current availability in a readily usable form or if the technology required modification or if it is a developing technology and not currently available in any usable form. Significant characteristics of the technologies availability are listed.

Each technology was evaluated to determine what other items not specific to the technology are required to support it for application as an alternative to the current placard. Examples of support elements are an intermediary to extract data from a database and relay it to a first responder, a new radio to communicate with a database to update the database with current information, power source, etc.

The cost of implementing the technology is estimated by evaluating the cost of the tank car components needed, the installation of the components, and the maintenance of the components. The cost of materials and maintenance needed at the shippers' and receivers' facilities is estimated. The railroad material needed to support each technology is estimated, including the maintenance.

The number of additional employees for either the railroad or industry is estimated at an annual cost of $100,000 per person. The average salary of railroad personnel is $84,881, according to the AAR and average salaries for chemical industry personnel are $82,000 reported by Bureau of Labor Statistics. Wages and benefits do not comprise the entire cost of maintaining employees. There is an overhead cost for employees often overlooked when estimating costs. A reasonable estimate of overhead costs to support and care for employees is 17 percent. By adding 17 percent to the total compensation for each of the above results in a railroad employee average cost of $99,310 and a chemical industry employee cost of $95,940 (*20*).

The number of named towns having their geographic center within 2 miles of any rail line is 18,804 (*4*). Database information does not provide the individual number of fire houses. In order to recognize there are more fire houses than there are towns it was decided to increase the number of towns by approximately 1,100 (~ 6 percent) for a total of 19,900 towns. The number of each support element in the estimate for each town is, three of each item needed allocated for the fire department, two of each item needed allocated to the emergency medical service (EMS), two of each item needed for the police department, and one of each item needed for the emergency managers or planners (EM), for a total of eight of each item needed to support the technology for each named town. The maintenance of the support items is estimated using the same basis as the maintenance estimate for the other users, i.e., the material cost divided by the life of the material.

Other elements required to support a technology are estimated individually when they are included. Some items that will require a one time cost to implement a technology have not been included in the estimate because they are items that will be replaced, removed, or eliminated by the new technology. If the item is to be eliminated, such as the placard holder, the cost of removal is not included because the savings of the discontinuance of the placard is considered to be an off-setting savings.

Training for first responders to correctly use the alternative technology is estimated by using the current training cost of the hazardous material familiarization level training course, 8 hours training, $215, at Texas A&M University System, Texas Engineering Experiment Station, Fire Fighting School (*18*). The number of first responders to be trained is estimated to be the number of professional and volunteer firefighters and an equal number of local, county, and state police officers. There are 1,088,950 (rounded up to 1,100,000) active firefighters in the U.S. (*9*). While there are 26,354 fire departments, only an estimated 19,900 of them are on a rail line. Rather than include an estimate and evaluation for how many emergency managers or emergency medical service personnel should be trained in the new hazmat response method, it was determined to use the full number of U.S. firefighters as the number to train. The EM and EMS personnel requiring training in new technology equipment for hazardous materials in railroad tank cars can be reasonably expected to be included in the estimated training.

COST OF IMPLEMENTATION

Cost of Implementation (CoI) includes estimated equipment cost, installation cost, annual maintenance cost, and the additional training cost.

EC = The individual tank car equipment technology cost
UR = The number of units required on the tank car
IC = The cost of installing equipment on the car
RE = The reader equipment cost
SC = The system equipment cost
CT = The individual firefighter/emergency responder/police training cost; fixed cost $215 ea. person

The CoI is based on the following criteria for each technology:

- TC = # of tank cars -- 245,000
- NT = # of named towns -- 19,900 places within 2.0 miles of railroad
- FD = # of support units for each fire department -- 3
- SU = # of support units for each named town, excluding FD -- 5
    - Emergency Medical Services -- 2
    - Police Department -- 2
    - Emergency Manager -- 1
- RRT = # of railroad terminal facilities where trains may be made -- 2,157
- CLpt = # of chemical origin/destination -- Assuming there will be at least one loading/unloading facility for every named town -- 19,900
- M = Maintenance is the one year bundled cost of maintaining the tank car equipment, the readers, and the systems. This is assumed to be five year replacement of the tank car and reader equipment, and ten year replacement of the system equipment. The calculation is expressed as (Material -- Equipment cost/Life). M_{TC} = Maintenance of tank car and M_{SC} = Maintenance of system equipment
- FF = # of fire fighters and emergency responders to be trained -- 1,100,000.
- PP = Police personnel to be trained are estimated to be equal to firefighters and emergency responders because all state police are required to be trained -- 1,100,000.

Cost of the tank car technology is estimated or quoted. Installation costs will double the material cost unless otherwise noted.

Reader cost is an estimate or quote as noted. All mobile reader technologies are expected to have a short life expectancy equal to five years due to changing technology and expected rough field treatment.

System cost is comprised of the equipment cost estimate of the system plus the installation cost of the system, which is estimated to effectively double the equipment cost for the installed system at each facility. Unless otherwise noted, system life expectancy is estimated to be ten years. This equipment is generally more robust and in a protected environment of a building or office.

A detailed example is presented in Appendix C.

TECHNOLOGY DISCUSSION

Cloaking

The first category of technology discussions is the concept of cloaking the hazardous material tank car. This may be done in several ways, but to carryout this concept successfully, all tank cars must be equipped with the cloaking technology. If only hazardous material capable tank cars are equipped with the cloaking equipment the terrorist will still be able to selectively target the hazardous material tank car fleet. The result of an attack on the fleet becomes the statistical value of the randomness of the loaded tank car out of the total hazardous fleet operating at the moment of attack. The following technologies are reviewed and an estimate for the cost of implementing the technology is provided.

Shutters

Operating Mode: Active, *Inherently Safe* (Inherently safe design is defined as equipment arranged in an "inherently fail safe" manner. A typical approach arranges system components so that any failure will cause the mechanism to shut down in a safe way).

System Life: 10 years

Availability: Minor development of fixture and mechanical actuator

Support Elements: Special fixture for placard holder, non-invasive mechanical sensor on brake air pipe, air charging system at tank car loading racks, additional car maintenance.

Description: A cover shield over the current placard using the frame or fixture for the placard as the support base for shutters. An independent air system extending to each placard holder and the tank car brake pipe, made up of ¼ inch iron pipe is mounted to the tank car incorporating a simple accumulator with a volumetric capacity of approximately one U.S. gallon. At each placard holder, a low cost miniature air cylinder with a built-in spring return is to be mounted. A lever mechanism arrangement that opens and closes doors or shutters is attached to the piston rod of the cylinder. A mechanical pressure sensor with an integral vent valve connected to the independent air system is to be affixed to the tank car brake pipe.

During tank car loading, the loading facility would carry out all the normal procedures currently used to load the tank car with one additional requirement. After loading and verifying everything was correct and safe, the loader would charge the independent air system. When the air system is charged with the proper pressure the miniature air cylinders will close the doors or shutters over the placard. One additional inspection of the car to ensure all the shutters are closed and the placards are covered clears the tank car for release to be picked up by the railroad.

In the event of a train derailment or other serious incident, the train's braking system will go into the emergency brake application mode. When the train brake emergency mode is initiated, the brake pipe air is released to atmosphere. This condition results in a rapid reduction of air pressure in the brake pipe, which initiates the mechanical sensor attached to the tank car brake pipe to open the integral vent valve. The air in the independent air system is then released, allowing the spring in each miniature cylinder to open the placard shutters or doors.

This system returns an equipped tank car involved in a train incident to the same condition the first responder finds it in without the shutter mechanism.

Cost of Implementation: The cost of material, installation on each tank car, support facilities at each loading station, and periodic maintenance and repair will be required to implement this system. Some additional training will be required to prepare first responders to deal with non-accident incidents involving potential or actual releases of hazardous materials. This technology is expected to have a ten year operating life.

Materials: Piping = \$30; Pressure sensor = \$100 – one per car; Shutter mechanism = \$40, four per car; Cylinders = \$15, four per car; Installation = Material cost; TOTAL = (\$350 + \$350) × 245,000 tank cars = \$171,500,000

Maintenance = \$171,500,000 / 10 year = \$17,150,000

Additional equipment necessary at each loading facility is estimated to not exceed \$20,000,000 to equip the entire tank car loading and unloading industry. It is expected that no more than an industrial grade low volume and pressure (100 psig) air compressor and 100 feet of 3/8 inch air hose is required.

Industry Maintenance = \$20,000,000 / 10 years = \$2,000,000

Training is estimated to require approximately 4 hours, as it is essentially the same system in use, but training will be needed to familiarize first responders with the necessity of accuracy in recording car information. Training cost is estimated to be \$107.50 per person versus \$215 quoted for a full day of training. Training is expected to be provided to first responders, emergency responders, and police at a cost of \$236,500,000.

CoI = \$210,650,000 + \$236,500,000 **= \$447,150,000**

Shutter Negatives:	**Shutter Benefits:**
If the brake pipe leaks down, the system will not deploy (open shutters) unless the air pipe is recharged. The system does not deploy except under emergency brake application. The system requires the independent air system to be recharged to reset the shutters if falsely actuated. Requires train yard operating procedure modifications to protect shutter system from deploying when train is disconnected from locomotives: generally the train line air is released, much as in an emergency brake application and the shutters would open.	Uses existing hazmat placard in-place system. Prevents unauthorized use of placard.

LED Light Placard

Operating Mode: Active

System Life: 10 years

Availability: Requires development, technology off-the-shelf – encapsulated light emitting diode (LED) arrangement.

Support Elements: Onboard power storage, built-in security authorization

Description: This technology is very similar to the shutter technology with the exception that the LED light placard is visible at night and in other low visibility conditions. The system does not require the independent air system, but the additional requirement of electrical power onboard the tank car removes the system from the *Inherently Safe* product. The LED light placard device by itself can be totally encapsulated to make it inherently safe. However, the power source and an external activation mechanism using on-board wiring is not believed to be able to be made so that there is no risk of electrical arcing in the event of a severe accident.

Cost of Implementation: The elimination of the current placard holder is not considered in the estimate of CoI. The battery (power source) is self contained with a solar panel recharging system in each LED light placard unit.

Materials: Lighted Placard is estimated to cost $300 - four per car; wiring - $200 per car; Automatic and Manual activation components - $200; Installation = Material; TOTAL = ($1,600 + $1,600) x 245,000 = $784,000,000

Maintenance = $784,000,000 / 10 years = $78,400,000

Rail yard facilities: Mobile readers = $400; TOTAL = (($400 × (2,157) + (($400 × (2,157) × 1/5)) = $1,035,360

Named towns equipment: Mobile reader and maintenance = $400 per reader; TOTAL = ((($400 × (19,900) + ($400 × (19,900 × 1/5)) × 8) = $76,416,000

Training is estimated to require a half of one day training for the use and maintenance of the LED light placard remote because it is essentially the same system in use with some enhanced features. Training cost is estimated to be $107.50 per person versus $215 quoted for a full day of training. Training is expected to be provided to first responders, emergency responders, and police at a cost of $236,500,000.

CoI = $784,000,000 + $78,400,000 + $1,035,360 + $76,416,000 + $236,500,000 = **$1,176,351,360**

LED light placard Negatives:	LED light placard Benefits:
Potential arcing source from power and wiring external to the encapsulated placard.	Activation at will by authorized users. No intermediary required. No external communication link required for first responders. Complies with current placard system with only minor exceptions. Improved visibility.

Dangerous Placard

Operating Mode: Passive

System Life: 20 years

Availability: Current

Support Elements: Central database, railroad tank car intermediary required, method to authenticate first responders

Description: The dangerous placard is a technology disclosure that is described as presented by the railroad sponsor during meeting discussions. The dangerous placard is a generic notification that is to be applied to all hazardous material loaded tank cars replacing the current USDOT placard.

In the event of an incident, the first responder will establish that a tank car is involved and that a dangerous placard is present. The first responder is required to establish secure authorized communication with a representative of the operating railroad or a national database representative. Once contact with the intermediary is established, the First Responder will relay the tank car number data to the intermediary. The intermediary would perform a database query and report the car condition, content, any material safety data sheet (MSDS) data information, and time of loading, etc.

Once the first responder has a list of the content of all dangerous placarded tank cars involved in the incident, scene assessment can continue on a normal basis.

Cost of Implementation: This technology requires no new or additional equipment for the first responder. The first responder must learn new hazardous material tank car evaluation procedures to safely deal with an incident. New placards would replace existing placards but should not introduce incremental costs for placards. The central database support will be an incremental cost addition for this technology approach.

Central database modification is estimated to cost 20 percent of a new central database. TOTAL = $4,682,500

Training, like the LED light placard is estimated to require a half of one day because it is essentially the same system in use, but training will be needed to familiarize first responders with the necessity of accuracy in recording car information. Training cost is estimated to be $109 per person versus $218 quoted for a full day of training. Training is expected to be provided to first responders, emergency responders, and police at a cost of $236,500,000.

CoI = $4,682,500 + $236,500,000 **= $241,182,500**

Dangerous Placard Negatives:	**Dangerous Placard Benefits:**
Not accessible to all interested parties.	Not usable by unauthorized users.
Requires large support system.	Could hold large amount of information.
All tank cars to be equipped.	Coded information always in agreement with shipping papers.
All tank car shippers and receivers require access to secure database system.	
All first responders require access to secure equipment.	
Every tank car in train must be identified and content confirmed prior to taking action during transition.	

Decentralized Database

Decentralized database technologies use an element on-board the tank car for use by the tank car loading and off-loading facility to record or update the tank car information. Such information may be limited or highly informative. Like the cloaking technology approach, all tank cars must be equipped with this technology to make the application of the technology successful. A background discussion is provided for the decentralized database in the following first discussion.

Decentralized Database

Operating Mode: Active

System Life: 20 years

Availability: Currently in use, modifications required

Support Elements: Multiple large computer systems required, multiple communications access points necessary, all tank car origin/destination points must be equipped (shipping paper methodology), railroad tank car intermediary required, means to authenticate first responders

Description: Decentralized databases for railroad tank cars currently exist. For example, each railroad Train Order (train make-up) is part of the Train Dispatcher's control system. The database necessary for containing, updating, and disseminating tank car lading and other potentially necessary information for first responders in an incident could be accessed through the operating railroad's database. Further, the operating railroad could develop a separate but parallel database that all tank cars accepted by their railroad are entered into for data duplication and ready access in the event of an incident or other authorized inquiry.

In the event of an incident the first responder would identify that a tank car is involved and then communicate with the designated railroad tank car intermediary to obtain information. The first responder, using a railroad specific authentication protocol would conduct an authorized communication with a representative of the operating railroad. Once contact with the intermediary is established, the first responder could then relay tank car number data to the intermediary. The intermediary would perform a database query and report the car condition, content, any MSDS data information, and time of loading, etc.

This system is required to be incorporated as a support element for the technologies evaluated in this category. These database systems could be made available to other public officials and users for commodity flow purposes and developing emergency preparedness plans, etc.

Cost of Implementation:

Car materials and maintenance: TOTAL = 0

Industry stations including maintenance: TOTAL = 0

Railroad facilities including maintenance (five year life on communication lines):

Dedicated communication lines = $200; 10 required each Class I railroad and 6 each regional railroad; Dedicated personnel to support the system = $100,000, 2 each railroad, 10 railroads; TOTAL = ($200 × ((10 × 6) + (6 × 4))) + (($200 × ((10 × 6) + (6 × 4))) × 1/5)) = $20,160

Personnel requirements: TOTAL = (($100,000 x 2) x 10) = $2,000,000

Named towns equipment: TOTAL = 0

Training for the serial number, like the dangerous placard is estimated to require a half of one day. Serial numbers provide a visual warning, but training will be needed to familiarize first responders with the necessity of accuracy in recording car lading information. Training cost is estimated to be $107.50 per person versus $215 quoted for a full day of training. Training is expected to be provided to first responders, emergency responders, and police at a cost of $236,500,000.

CoI = $20,160 + $2,000,000 + $236,500,000 = **$238,520,160**

Bar Codes

Operating Mode: Passive, *Inherently safe technology*

System Life: 5 years

Availability: Mature technology requiring only configuration and implementation

Support Elements: All tank car loaders and railroad transporters require full access to the database, bar coding equipment required at loading facilities and rail yards, mobile readers (Laser), secure first responder computer (reader terminal)

Description: The bar code system was tried in the past by railroads to identify and track equipment, much as the current automated equipment identification (AEI) tag system is used today. The bar code system as matured today may meet the operating criteria of the railroad environment regarding readability and reliability, but distance limitations of approximately 50 feet remain a problem. Further, the vibration of the moving car and bar code plate is no longer an issue for the laser system.

As applied to the tank car to replace the current placard, the bar code would be placed one on each side of the car, as the placard is used. However, the bar code would not be repetitive or identifiable by color, number of bars, etc. The tank car loader would provide all the data for the shipping papers as currently carried out. A bar coding and printer system would be required at the loading site to provide the bar code element. The loading facility would automatically print the bar codes for application to the tank car. Each rail yard facility would also require a bar coding and printing system to replace any obviously missing or damaged bar codes.

During an incident, the first responder would use a laser connected to a dedicated bar code reader system to scan the bar codes on the tank cars. The system would use a reader to decode the bar code. The first responder would not have to have any personal communication with the database because security could easily be built into the local reader, i.e., authorized password protection techniques, thumbprint, iris scan, etc.

Access to bar code reader systems could be extended to other public officials and authorized users in order to obtain information for emergency management and planning purposes. The ability to obtain tank car information would allow commodity flow studies to continue.

Cost of Implementation:

Tank car materials and maintenance: Bar Code mounting board \$20, 4 per car; Installation = Materials; TOTAL = ((\$40 × 4) + ((\$40 × 4) × 1/5) × 245,000) = \$47,040,000

Industry remote readers (5 year life) and program stations including maintenance (10 year life) = \$8,000; 19,900 required; TOTAL = ((\$800 × (19,900) + ((\$800 × (19,900) × 1/5)) + ((\$8,000 × 19,900) + (\$8,000 × 19,900) × 1/10)) = \$194,224,000

Rail yard facilities: Mobile readers = $800; Program stations = $8,000; TOTAL = (($800 × (2,157) + (($800 × (2,157) × 1/5)) + (($8,000 × 2,157) + ($8,000 × 2,157) × 1/10)) = $21,052,320

Named towns equipment: Mobile reader and maintenance = $800 per reader; TOTAL = ((($800 × (19,900) + ($800 × (19,900 × 1/5)) × 8) = $152,832,000

Training is estimated to be similar to other training efforts for first responders, emergency responders, and police training at a cost of $473,000,000.

CoI = $47,040,000 + $194,224,000 + $21,052,320 + $152,832,000 + $473,000,000 = **$888,148,320**

Bar Code Negatives:	**Bar Code Benefits:**
Not accessible to all interested parties.	Not usable by unauthorized users.
All tank cars to be equipped.	Increase in information available to authorized users.
All tank car shippers and receivers require access to secure database system.	Could hold large amount of information.
All first responders require access to secure equipment.	Coded information always in agreement with shipping papers.
Every tank car in train must be identified and content confirmed prior to taking action during transition.	

Radio Communication Equipment (AEI Tag)

Operating Mode: *Inherently Safe*, Active with internal battery terminal and protected input lead access

System Life: 5 years

Availability: Currently in use but requires modification to increase radio frequency (RF) range.

Support Elements: Decentralized database, encrypted, communication link, high output RF transmitter, selective receiver

Description: The AEI tag is widely used in the transportation industry to identify equipment. The majority of the tags are passive in nature. That is, they are programmed one time with information. The information is essentially attached to the equipment and whenever the equipment passes a fixed reader, the reader provides the AEI tag data to the user's tracking system. The tracking system updates itself by incorporating the latest available reader data.

The AEI tag technology is expandable by incorporating additional data into the onboard chip. In the case of the active tag, the tank car loader could readily load all the pertinent data regarding the lading onto the active tag.

In the case of an incident, first responders would determine if there were tank cars involved. If tank cars were involved, the first responder would use a mobile reader to communicate through a radio link to the data on the tag. The data recorded on the tag at the loading facility would be immediately available to the first responder at the incident site.

Extension to poll the tag could be extended to other authorized users, i.e., emergency managers or planners, police departments, etc.

Cost of Implementation: Science Applications International Corporation (SAIC) discussed the potential for developing an active tag of the type envisioned for this application with the researchers. After discussing the potential number of units required, SAIC suggested that a cost estimate for individual modified RF active tags of $300 each may be feasible. The $300 estimate used in this analysis is based on a feasibility discussion and it is not an offering by SAIC for an active tag.

Car materials and maintenance: Active RF tag = $300, two per car; Installation = ½ Materials; TOTAL = ((($300 × 2) + $300) + ((($300 × 2) + $300) × 1/5) × 245,000) = $264,600,000

Industry remote readers (5 year life) and program stations including maintenance (10 year life) = $8,000, 19,900 required; TOTAL = (($800 × (19,900) + (($800 × (19,900) × 1/5)) + (($8,000 × 19,900) + ($8,000 × 19,900) × 1/10)) = $194,224,000

Rail yard facilities: Mobile readers = $800; Program stations = $8,000; TOTAL = (($800 × (2,157) + (($800 × (2,157) × 1/5)) + (($8,000 × 2,157) + ($8,000 × 2,157) × 1/10)) = $21,052,320

Named towns equipment: Mobile reader and maintenance = $800 per reader; TOTAL = ((($800 × (19,900) + ($800 × (19,900 × 1/5)) × 8) = $152,832,000

Training is estimated to be similar to other training efforts for first responders, Emergency Responders and police at a cost of $473,000,000.

CoI = $264,600,000 + $194,224,000 + $21,052,320 + $152,832,000 + $473,000,000 **= $1,105,708,320**

AEI Tag Negatives:	AEI Tag Benefits:
Not accessible to all interested parties.	Not visible to unauthorized users.
Requires large support network.	Could hold large amount of information.
Not readily replaceable subsequent to identified failure.	Permanently fixed to car.
Failure of active tag.	Electronic record of car data may reduce error during stressful operations.
The technology is easily defeated.	Readable at night and other adverse weather conditions.
All first responders require access to secure equipment.	Tag information always in agreement with shipping papers.
Every tank car in train must be identified and content confirmed prior to taking action during transition.	

Micro Electro Mechanical Systems (MEMS)

Operating Mode: *Inherently safe when fully encapsulated***,** self contained, auto communication with other compliant units, RF based communication,

System Life: 5 years

Support Elements: Decentralized database, computer system for program input, battery power, remote reader (100 meters, 300 meters if super RF)

Availability: Technology not available, under development

Application Description: The MEMS technology can supply full detail of the tank car content. Multiple MEMS units can be used on each tank car to add additional functionality. Host MEMS units can be included that appear to be capable of communicating with either the locomotive or the end of train device to provide a separate on-site source of train MEMS information.

In the event of an incident the first responder would note the presence of a tank car involvement. The MEMS portable reader would be activated and the information retrieval process initiated. Once the information retrieval process was completed (up to one minute) the first responder would have access to a complete set of information for all hazardous material from tank cars in the train.

The information format could be memory loaded for scrolling review on a handheld or vehicle mounted monitor, a printed format, or other combination required by the responder.

One possibility of the MEMS technology appears to support the ability to locate the placement of the equipped tank cars after an incident. This ability would be advantageous in the event of a serious incident in which cars submarine each other and become reordered. MEMS encapsulated RF would rebroadcast their information through other units and reestablish the order they encountered their communications sequence.

First responder transition process would be affected only by the delay to activate the MEMS remote reader.

Cost of Implementation: Refer to EXAMPLE on page 18 for a complete analysis.

$$CoI = [((EC \times UR) + IC) + (((EC \times UR) + IC) \times 1/Life) \times TC] + [(RE \times (NT) + ((RE \times (NT) \times 1/Life)) + (SC \times NT) + (SC \times NT) \times 1/Life)] + [(RE \times (RRT) + ((RE \times (RRT) \times 1/Life) + (SC \times RRT) + (SC \times RRT) \times 1/Life)] + [((RE \times NT) + (RE \times NT) \times 1/Life)) \times (FD + SU)] + [CT \times (FF + PP)]$$

CoI = \$17,640,000 + \$189,448,000 + \$20,534,640 + \$114,624,000 + \$473,000,000
= **\$815,246,640**

MEMS Negatives:	**MEMS Benefits:**
Not accessible to all interested parties.	Not usable by unauthorized users.
Requires large support system.	Could hold large amount of information.
All railroads, tank car commodity shippers, and receivers require a complete reader/programming system.	Coded information always in agreement with shipping papers.
All first responders require readers.	May be designed to provide tank car data to front or rear of train for on-site redundancy and data protection.

GPS Train Tag

Operating Mode: Active

System Life: 20 years

Availability: Requires new configuration of current technologies and systems.

Support Elements: Additions to current database or new database, additional dedicated railroad radio bandwidth Federal Communications Commission (FCC) authorization, new radio system (automatic pulse broadcast), railroad tank car intermediary between first responder and tank car and means to authenticate first responders, OR secure access to dedicated railroad radio bandwidth and computer to read train tag database

Description: GPS can be incorporated to provide a continuous train location database. The GPS train tag system requires additional dedicated railroad radio bandwidth (DRB) because of large increases of data communication the railroad industry has incorporated in its operations. The DRB would communicate train location on a short time schedule basis.

In the event of an incident, the first responders would use their communication link to the new intermediary or the secure access radio to query the railroad database to identify the train by its current location. The database would contain all the train information as normally maintained by the railroad regarding car location in the train and car lading.

Access to the automatic pulse broadcast radio could be extended to other public officials and authorized users in order to identify the train and obtain information for emergency management and planning purposes. Access to the radio information would imply the ability to contact the database manager to obtain information about hazardous material shipments in the train.

Cost of Implementation:

A Chemical Industry company reports $2,000 per unit cost per car for equipment, installation is extra, but believed to be less than the material cost; $100 per month per unit monitoring.

AAR Statistics: 38,370,000 car loads originated – 2003
20,774 Locomotives – 2003

Assumptions: 30 percent of cars loaded require movement as empties.
Average train is 100 cars.
20,000 Locomotives require GPS tag system installation

Trains per day (T/D) = (38,370,000 x 1.30) / (100 x 365) = 1,366 T/D
Locomotives = 20,000 x $2,000 = $40,000,000
Maintenance = ($40,000,000 x 1/5) = $8,000,000
Capital Cost = ($40,000,000 + $4,918,000 + $8,000,000) = $52,918,000
Monitoring = (T/D x 3 days / train) x (12 mo / yr x $100 /mo) ~ $4,918,000 / yr

Modified Central Database cost = $4,682,500 is used for estimating the Monitoring Function in the analysis since it is an estimate used elsewhere and is very close to the third party monitoring estimate.

Training is estimated to be similar to other training efforts for First Responders, Emergency Responders and police at a cost of $473,000,000.

CoI = $40,000,000 + $8,000,000 + $4,682,500 + $473,000,000 = **$525,682,000**

GPS Train Tag Negatives:	**GPS Train Tag Benefits:**
Not accessible to all interested parties. Requires large support network. All first responders require access to secure equipment. In event of serious accident cars may not be in order with tag car location, causing misidentification of car and lading unless additional measures or procedures are enforced. Every tank car in train must be identified and content confirmed prior to taking action during transition. AAR standards require modification to accommodate this technique.	Not visible to unauthorized users. Could hold large amount of information. Permanently part of infrastructure. Electronic record of car location in train may reduce error during stressful operations. Accessible at night and other adverse weather conditions.

Central Database

The central database technology uses the tank car identification to access data regarding the tank car's current lading. There is no information available on the tank car that provides the first responder with timely information. All central database technologies require some means of communicating between the database and the first responder. The central database technologies can not effectively incorporate an electronic component to identify the tank car. Therefore, there is no means to establish a secure communication link for the first responder to access the database. Without the capability to directly communicate with the database, an intermediary must be introduced to make the system work.

Like the cloaking and decentralized database approaches, the central database approach must be applied to the entire tank car fleet to effect a substantial reduction in risk of a terrorist successfully attacking a loaded hazardous material tank car.

Central database construction, operation, and maintenance cost is estimated as follows. Construction = \$6,000,000; Operation = 20 people @ \$100,000/year = \$2,000,000; Maintenance includes a new facility and database maintenance = (\$15,000,000) + ((\$15,000,000 / 20) × 0.15 utilities, facilities maintenance, etc.) + (\$6,000,000 / 20)) = \$15,412,500

CoI = \$6,000,000 + \$2,000,000 + \$15,412,500 = **\$23,412,500**

Train Orders

Operating Mode: Passive

System Life: 20 years

Availability: Currently in use, modifications required

Support Elements: Centralized database, railroad tank car intermediary required, communications link, means to authenticate first responders

Description: The train order concept removes the hazardous material placard from the tank car and identifies the hazardous material loaded tank car by referencing the shipping papers provided to the railroad by the shipper. Train orders provide all the information provided by placards; they identify the tank cars with hazardous material lading, they provide all the pertinent information regarding the commodity or a reference source to obtain the information, the location of the hazardous material tank car in the train, where and when the tank car was loaded, when the railroad picked the tank car up, when it was put in the current train and how long the train was in operation prior to the incident. The current railroad operating system incorporates the train order and is expected to be able to handle the volume of additional traffic associated with a move to the train order concept.

In the event of an incident, the first responder would establish that a tank car was present. After establishing a tank car was present the first responder would initiate communication with a prearranged railroad tank car intermediary. The intermediary would establish the first responder's authenticity and then provide assistance. The first responder would provide the tank identification information, e.g., the serial number, to the intermediary. The intermediary would access the railroad database and establish the tank car's content, etc. The intermediary would also establish if any other tank cars were in the train consist and provide all pertinent information to the first responder.

This process may provide as timely and accurate information regarding the content of tank cars involved in a train incident as the current process used with hazardous material placards and follow-up verification processes.

Cost of Implementation: New training of the entire responder community.
CoI = $473,000,000

Train Orders Negatives:	**Train Orders Benefits:**
Not accessible to all interested parties. Requires a railroad tank car intermediary to access information. All tank cars treated equally hazardous. All First Responders require specialized means for identification. Every tank car in train must be identified and content confirmed prior to taking action during transition. No redundancy for First Responder.	Not usable by unauthorized users. Potential to increase information available to authorized users. Since all tank cars are unmarked the likelihood of a successful random targeting by terrorist is reduced.

Specialized Tank Car Serial Numbers

Operating Mode: Passive

System Life: 20 years

Availability: Currently in use, requires modification to meet specialty requirements

Support Elements: Centralized database, communications link, railroad tank car intermediary required, means to authenticate first responders

Description: The specialized tank car serial number is a reversion technology approach, i.e., an old concept with a new twist. The technology success relies on incorporation of an abundance of other technologies to support it. The system would develop a specialized but individual code for every tank car. The code would have no bearing on the tank car commodity, for example an inhalation hazard tank car may have a code of BBXAH and a molasses car may have the code BBXAG. Using only alpha characters for the codes, five characters provides capacity for over ten million cars. Certain character groups spelling common words that describe hazardous materials would need to be excluded, such as, ACIDS, BOMBS, etc. The characters could be painted 5 feet high on the sides of the cars and 2 feet high on each end.

In an incident, the first responder would be able to read the tank car number from a substantial distance with the naked eye and from a very long distance using binoculars. Using the communications link and a security identifier, the first responder would contact the intermediary to obtain the database information on the car.

Access to the database could be extended to other public officials and authorized users in order to identify tank car lading to use in commodity flows, information for emergency management, and planning purposes.

Cost of Implementation:

Materials: Paint characters four places per car cost = $300; TOTAL = $1,200 × 245,000 = $294,000,000

Maintenance = $294,000,000 / 20 years = $14,700,000

Central database construction, operation, and maintenance. See page 34 for detail of implementation costs for a new central database system to support the specialized serial number concept. $23,412,500

Training is estimated to be similar to other training efforts for first responders, emergency responders, and police at a cost of $473,000,000.

CoI = $294,000,000 + $14,700,000 + $23,412,500 + $473,000,000 = **$805,112,500**

Serial Number Negatives:	**Serial Number Benefits:**
Requires an intermediary to provide data in an incident. All first responders require individual security verification. Not accessible to all interested parties. Requires large database network. Every tank car in train must be identified and content confirmed prior to taking action during transition.	Not usable by unauthorized users. Permanently fixed to car. Five character identifier reduces potential for error in communicating car number to verify car lading.

The training estimated in this analysis is based on the minimum hazardous material training course provided in the training program for fire fighter training at Texas A&M University System, Texas Engineering Extension Service (TEEX). The training is a one day course providing familiarization with hazmat recognition. The various systems and procedures the first responder will become familiar with for protection in case of an incident are part of this minimum training course. The estimate includes 1,100,000 firefighters to be trained and an equal number of public and emergency medical service personnel. Evaluation of the training requirements needed for support of each alternative technology is based on two aspects, the inclusion of a remote activator and communication with an intermediary. If a remote activator and communication with an intermediary (or computer) are necessary to support the technology, a full day of training is expected to be needed. If the technology only requires one of the aspects and is supported with a visual placard on the tank car, then only a half day of training is expected to be needed. In the case of the shutter technology, the system is essentially the current placarding system when the first responder encounters an incident and training will be carried out via a familiarization bulletin considered to be part of the existing safety infrastructure. Table 2 provides a cost comparison of each of the alternative technologies previously discussed.

Table 2. Cost of Technology Implementation (Millions).

	Cost without Training	Training Cost	Total Cost
Cloaking			
Existing Placards	$-0-	$-0-	**$-0-**
Shutters	$210.65	$236.50	**$447.15**
LED Light Placard	$939.85	$236.50	**$1,176.35**
Danger	$4.68	$236.50	**$241.18**
Decentralized			
Bar Code	$415.15	$473.00	**$888.15**
AEI Tag	$632.71	$473.00	**$1,105.71**
MEMS	$342.25	$473.00	**$815.25**
Centralized			
GPS	$52.68	$473.00	**$525.68**
Train Orders	$ -0-	$473.00	**$473.00**
Serial Numbers	$332.11	$473.00	**$805.11**

CHAPTER 5: ASSESSMENT OF ALTERNATIVES

FINDINGS

This chapter compares the existing hazardous materials placards with nine alternative technologies (c.f., Chapter 4) in terms of the functional requirements (c.f., Chapter 3). The functional requirements are categorized as normal operations, in transition, and emergency operations. There are ten functional requirements identified in the normal operations period, eight in the transition period, and four in the emergency operations period. There are three categories of alternative technologies: cloaking, decentralized, and centralized. Three alternative technologies involve cloaking or hiding the information provided by placards, three involve decentralized data about hazardous materials shipments, and three involve centralized data sources about hazardous materials shipments. The existing placard system is found to meet all 22 functional requirements. Table 3 presents a summary of each alternative technology by functional requirement.

Cloaking Technologies

Cloaking technologies are considered the most straightforward and simple approaches to the problem as they leave most of the current system in place. Cloaking devices simply keep the information hidden from view until it is needed. Three kinds of cloaking technologies were considered: shutters, lights, and dangerous placards. The basic principle of shutters and lights is that they display the information only when needed. While shutters do this by covering the placard and the cover is removed at the time of the incident/accident, lights achieve this by becoming illuminated only when needed. Dangerous placards are a completely different principle, namely placard all hazardous materials the same with a simple dangerous placard. This vagueness enhances security through a “needle-in-the-haystack” principle. All hazardous materials would essentially become equally dangerous.

Shutters would provide all the information the current placard system provides without modification to the current system. Shutters satisfy the functional requirements completely in transition to and during emergency operation, because they are essentially the placards but covered during normal operations. The central problem for mechanical placard covers is arming them so that they will open when and only when needed. Current technology only allows them to be armed for opening at appropriate times, however it does not allow them to be opened and re-armed during normal operations. Hence they provide limited placard information during normal operations. They meet functional requirements in only three areas under normal operations: (1) they are identifiable in loading operations; (2) they can be opened for backup if other systems are not available; and (3) they are available at plant sites so they could be used for spotting hazardous materials cars.

Table 3. Technology Assessment.

	Existing Placards	Shutters	Clocking LED Lights	Danger	Bar Code	Decentralize AEI Tag	MEMS	GPS	Centralized Train Orders	Serial Number
Normal Operations										
Identifiable	X	X	X	@	X	X	X	O	O	@
Backup	X	X	X	@	X	X	X	O	O	@
Class Div UN #	X	O	@	O	XX	XX	XX	XX	XX	XX
Enforcement	X	O	@	@	X	X	X	O	O	@
Car Spotting	X	X	X	O	X	X	X	O	O	O
Compliance	X	O	O	O	X	X	X	O	O	O
Verification	X	O	O	O	X	X	X	O	O	O
Safety Measures	X	O	X	O	X	X	X	O	O	O
Initiates EM Plan	X	O	X	O	X	X	X	X	X	X
Commodity Flow	X	O	@	O	XX	XX	XX	XX	XX	XX
In Transition (first 15-30 min)										
Scan from Distance	X	X	XX	X	X	O	X	X	X	XX
Locate Haz Mat	X	X	XX	X	X	O	X	@	@	X
First Source	X	X	XX	X	X	O	X	@	@	X
Establish Action	X	X	X	O	O	@	X	@	@	@
Class Div UN #	X	X	X	O	XX	XX	XX	XX	XX	XX
Redundancy	X	X	X	X	O	O	O	O	O	O
Public Warning	X	X	X	X	O	O	O	O	O	@
Car Content	X	X	X	O	XX	XX	XX	XX	XX	XX
Emergency Operations										
Scene Management	X	X	X	O	X	X	X	X	X	@
Identify Peripheral Haz Mat	X	X	X	X	X	X	X	X	X	X
Locat Haz Mat	X	X	X	X	X	X	X	X	X	X
Continuing Assessment	X	X	X	0	O	O	O	O	O	@
X = meets standards										
@ = meets standards with exceptions										
O = examined but does not meet standards										
XX = exceeds standards										

LED lights also provide all the information the current placard system provides without modification to the current system. LEDs satisfy the functional requirements completely in transition to and during emergency operation, because they are essentially the placards but activated only when needed. They have some advantages over the current placards because when they are illuminated they would be more visible (a) at night, (b) under poor visibility conditions, and (c) from a distance. Under normal operations lights work slightly better than shutters because they are more easily turned off and on for inspection. They meet five functional requirements under normal operations. Like shutters they are (1) identifiable, (2) provide backup, and (3) can be used for car spotting, and in addition they can be used (4) to provide information for safety measures, and (5) to initiate emergency response planning. LED lights also meet with exception three additional functional requirements. When activated they provide the class, division, and United Nations number of the hazardous material; they provide information to initiate enforcement; and they provide information about commodity flows. These items are only met with exception, because only first responders and emergency personnel are envisioned as having the equipment to activate the lights.

Dangerous placards provide limited information in transition to and during emergency operations, because the information they provide is vague. They do not provide class, division and United Nation's number, or information about car content and are not sufficient to determine appropriate initial actions during the transition period. They are also too vague to meet the needs of scene managers during the emergency. Meanwhile, during normal operations the very vagueness that allows them to provide additional security means that it fails to meet standards on seven of ten functional requirements. Dangerous placards meet with exception just three requirements during normal operations because they are identifiable, provide minimal backup, and could trigger enforcement, but here again the limited nature of the information provided fails to fully meet these functional requirements.

Decentralized Systems

Decentralized systems represent adaptations of existing technologies for decentralized data management. Decentralized systems store the information associated with the hazardous material content of a car in a manner that makes it available only to authorized personnel with specialized equipment. Three kinds of decentralized systems were considered: bar codes, AEI tags, and Micro Electro Mechanical Systems (MEMS) technology. These systems work on the principle that the car content can be stored in a form that can be retrieved when needed. Bar codes are completely passive technologies that are inherently safe. AEI tags can be either passive or active and are inherently safe in their passive mode. MEMS technology is active and is inherently safe when encapsulated.

Bar codes provide complete information under normal operations. In fact, they could provide an enhancement with respect to the class, division, and United Nations number by providing complete detail of car content. Moreover, with authorized personnel conducting commodity flow studies, using the bar code information would provide this detailed information to emergency planners to develop, train, and exercise specific emergency response plans for car content. In the transition to emergency operations this additional information provides enhancement to existing placards by providing full car content. The critical drawback for these systems in transition to emergency operations is their limited ability to be scanned from a distance. Because bar codes are as identifiable as dangerous placards this visibility is central to their ability to meet functional requirements involving locating hazardous material, providing a first source of information, and redundancy. The required specialized equipment eliminates their ability to provide public warning in this period. During emergency operations bar codes meet three of four functional requirements because most of what placards are used for in this period is on the peripheral areas of the emergency scene where the distance issue is resolved; however, continuing assessment is not met as bar codes are not visually available with readily apparent content displayed.

AEI tags provide complete information under normal operations. Like bar codes, AEI tags provide enhanced information with respect to class, division, United Nations numbers, and commodity flows by providing actual car content to authorized personnel. In the transition period this complete information provides enhancement to placards with respect to the functional requirements of class, division, and United Nations number, and car content. Moreover because they can be active, and thereby available from a greater distance than bar codes, AEI tags meet with exception the established initial actions functional requirement. Finally, AEI tags meet the functional requirements during emergency operations in the same manner as bar codes. Unlike bar codes, they are not visually available with readily apparent content displayed.

MEMS technology provides complete information under normal operations, and like bar codes and AEI tags, MEMS provides enhanced information regarding class, division, and United Nations number as well as for commodity flows. This enhanced information is also available in the transition period, which provides car content to first responders. The most important differences between MEMS technology and AEI tags are in the transition period. Specifically because of the RF based communications (or super RF communications) MEMS technology enables the scan from a distance function, and makes location of hazardous material possible, as well as providing a first source of information that enables first responders to make decisions about initial actions. MEMS technology, like other alternatives in this category, meet most functional requirements under emergency operations because placards are not used in the immediate hazard zone. But also like other technologies in the category, MEMS is not visually apparent, so continuing assessment is not met.

Alternatives in this category are not visually available with readily apparent content displayed, which is why all technologies in this category (i.e., bar codes, AEI tags, and MEMS) provide improved security over placards.

Centralized Systems

Centralized systems represent adaptations of existing technologies for centralized data management. Centralized systems store the data associated with the hazardous material content of a car in a central location. These data would be accessible to authorized personnel through secure protocol to assure security. Three kinds of centralized systems were considered: geo-positioning systems (GPS), train orders or shipping papers, and unique serial numbers. Centralized systems work on the principle that the car content can be stored, updated, and kept current in a central location and retrieved when needed. In this sense they are all dependent on the reliability of the central database, and the access and security of that data in a timely manner when they are needed. GPS essentially keep track of each car in the system so that if an incident occurred the location of the incident would be used to match to the location of cars containing hazardous materials in that location. In a similar fashion train orders could be used to track cars within a train as a train moves though the system. Unique serial numbers would essentially be queried against a centralized database containing the content of each hazardous material tank car in transit.

While GPS and train orders are two separate technologies and were evaluated in terms of the functional requirements as two separate alternatives, they share the strengths and weaknesses associated with centralized data, and as such their performance on the functional requirements is the same. GPS and train orders meet or exceed three functional requirements under normal operations; they meet the requirement to initiate emergency planning and they exceed the requirements to provide class, division, and United Nations number, and conduct commodity flows. The former because they provide more detailed information on car content when activated, and the latter under the assumption that emergency personnel would be allowed access for emergency planning purposes. In transition to emergency operations both GPS and train orders meet the need to scan from a distance and exceed standards with respect to providing more information than class, division, and United Nations number because they would provide detailed car content. They meet with exception the functional requirement for locating hazardous materials in an accident, providing a first source of information, and thereby establishing appropriate initial actions in the transition period. Both GPS and train orders meet most of the functional requirements during emergency operations, but fail to provide for continuing assessment because they are not visually accessible.

While unique serial numbers share the strengths and weakness of the centralized data with GPS and train orders, because of the visual nature of the serial numbers they overcome a number of the associated limitations. Like GPS and train orders they provide complete car content so they exceed standards on class, division, and United Nations number, and commodity flows under both normal operations and in transition to emergency operations. In fact because of the visual nature of the unique serial numbers they provide enhanced ability to scan from a distance. Unique serial numbers also meet functional requirements for initiating emergency planning and can be scanned from a distance like GPS and train orders. In addition, unique serial numbers meet the functional requirement to locate hazardous materials in an incident and provide the first source of information on hazardous materials. In addition, unique serial numbers also meet with exception the functional requirement to establish initial actions, and provide public warning in the transition period. During emergency operations, serial numbers meet functional requirements to manage peripheral hazardous material and locate hazardous material, but meet with exception the requirements for scene management and continued assessment because of the vague nature of the visual information.

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

This chapter compares each system to the other alternatives in terms of their performance on the functional requirements. Table 4 presents the relative ranking of each system in terms of all the functional requirements in each phase. Alternatives are ranked from those that meet the functional requirements best on the left to those that perform most poorly on the right. This ranking is based on the principle that functional requirements in the transition period are the most critical; this ranking arbitrarily assigns requirements in this period 50 points. The second most important period is the normal operations period, and it is arbitrarily assigned 30 points. Because during the emergency operations period the use of the placards is secondary, functional requirements in this period are assigned the remaining 20 points. While the ranking of functional requirements by phase is arbitrary, the relative ranking of alternatives remains stable even if the in transition phase is given up to 70 points, or as few as 40 points. Even under equal weighting only the relative ranking of bar codes changes as it surpasses shutters. Moreover under all weighting scenarios examined, the top-five alternatives remained stable.

Meeting functional requirements at the same level as existing placards is weighted as 1.0; in this manner it is the same as placards in terms of this functional requirement. Meeting functional requirements with exceptions is arbitrarily assigned 0.5, while exceeding functional requirements is assigned 1.1. Failing entirely is assigned zero. Hence, meeting neither hurts nor helps an alternative's case, while partially meeting the functional requirement hurts the case more than exceeding the functional requirements helps. Failing on a functional requirement, of course, hurts its case the most. To examine the sensitivity of ranking to the arbitrarily assigned parameters, the meet with exception and exceeds parameters were varied while observing the impact on ranking. The meet with exception parameter could be as high as .8 or as low as .3 before any reordering of alternatives is observed. Meanwhile, the exceeds functional requirements parameter could be as high as 1.5 or as low as 1.0 without reordering the ranking of alternatives. These tests support the robustness of the results in terms of relative ranking of alternatives.

Table 4. Technology Assessment Rank Order.

	Placards	LED Lights	MEMS	Shutters	Bar Code	Serial Number	AEI Tag	GPS	Train Orders	Danger
Normal Operations	**30.0**	**19.5**	**30.6**	**9.0**	**30.6**	**14.1**	**30.6**	**9.6**	**9.6**	**4.5**
Identifiable	1	1	1	1	1	0.5	1	0	0	0.5
Backup	1	1	1	1	1	0.5	1	0	0	0.5
Class Div UN #	1	0.5	1.1	0	1.1	1.1	1.1	1.1	1.1	0
Enforcement	1	0.5	1	0	1	0.5	1	0	0	0.5
Car Spotting	1	1	1	1	1	0	1	0	0	0
Compliance	1	0	1	0	1	0	1	0	0	0
Verification	1	0	1	0	1	0	1	0	0	0
Safety Measures	1	1	1	0	1	0	1	0	0	0
Initiates EM Plan	1	1	1	0	1	1	1	1	1	0
Commodity Flow	1	0.5	1.1	0	1.1	1.1	1.1	1.1	1.1	0
In Transition (first 15-30 min)	**50.0**	**51.9**	**38.8**	**50.0**	**32.5**	**39.4**	**16.9**	**29.4**	**29.4**	**31.3**
Scan from Distance	1	1.1	1	1	1	1.1	0	1	1	1
Locate Haz Mat	1	1.1	1	1	1	1	0	0.5	0.5	1
First Source	1	1.1	1	1	1	1	0	0.5	0.5	1
Establish Action	1	1	1	1	0	0.5	0.5	0.5	0.5	0
Class Div UN #	1	1	1.1	1	1.1	1.1	1.1	1.1	1.1	0
Redundancy	1	1	0	1	0	0	0	0	0	1
Public Warning	1	1	0	1	0	0.5	0	0	0	1
Car Content	1	1	1.1	1	1.1	1.1	1.1	1.1	1.1	0
Emergency Operations	**20.0**	**20.0**	**15.0**	**20.0**	**15.0**	**15.0**	**15.0**	**15.0**	**15.0**	**10.0**
Scene Management	1	1	1	1	1	0.5	1	1	1	0
Identify Peripheral Haz Mat	1	1	1	1	1	1	1	1	1	1
Locat Haz Mat	1	1	1	1	1	1	1	1	1	1
Continuing Assessment	1	1	0	1	0	0.5	0	0	0	0
Total Assessment	**100.0**	**91.4**	**84.4**	**79.0**	**78.1**	**68.5**	**62.5**	**54.0**	**54.0**	**45.8**

1.0 = X = meets standards
0.5 = @ = meets standards with exceptions
0.0 = O = examined but does not meet standards
1.1 = XX = exceeds standards

SHADED ALTERNATIVES NOT RECOMMENDED FOR FURTHER STUDY.

Combined Systems

Potential combinations of alternatives were examined in terms of their ability to meet the functional requirements. It was determined that combining systems coming from the same approach is of limited value. For example, combining LED light and covers not only does not enhance the performance, but actually the shutters detract from the ability of LED lights during normal operations. Hence, combinations of alternatives considered only alternatives from different approaches. The performance of a combined alternative is presumed to be the best performance of the two alternatives being combined. Combinations where one alternative's functions are believed to defeat the performance of the other's superior performance were not considered. Hence, combined performance on each functional requirement is the maximum rating of either alternative to be combined on that function. Table 5 presents those combinations that provide enhanced performance. Enhanced performance is defined as increasing the number of functional requirements met or exceeded. Four combination systems improve their overall assessment scores by 7.4 to 20.7 percent over the best of the two alternatives being combined; and three out of four of the combined systems represent improvements over the existing placard system in terms of functional requirements that exceed current capabilities.

The combination of LED lights with MEMS technology takes advantage of the improvements offered by MEMS with respect to giving complete car contents and commodity flows during normal operations and in transition to emergency operations. Meanwhile the combination also takes advantage of the enhanced visibility of LED lights in the transition to and during emergency operations.

The combination of shutters and MEMS technology provides the improvements offered by MEMS with respect to giving complete car contents and commodity flows during normal operations and in transition to emergency operations. Meanwhile the combination also takes advantage of the visibility of the now open shutters in the transition to and during emergency operations. The improvements associated with this combination are not as numerous as those associated with the LED lights and MEMS combination, as the visibility reverts to the existing placards rather than the improved/enhanced visibility offered by LED lights.

The combination of unique serial numbers and LED lights takes advantage of the visibility of the LED Lights in all phases and the complete car contents provided by the centralized data base associated with unique serial numbers. In terms of functional requirements, unique serial numbers with LED lights is essentially equivalent to LED lights with MEMS. One potential advantage of unique serial numbers with MEMS technology is that its performance is based in both high technology and relatively robust minimal technological solutions. Unfortunately, this is also the combinations greatest weakness. If MEMS fails, the performance of serial numbers alone is not acceptable. With respect to the LED lights with MEMS combination, however, if either fails the remaining alternative alone provides greater protection in all phases under consideration than serial numbers.

Table 5. Combined System Alternatives that Improve Performance*.

	LED Lights MEMS	Shutters MEMS	Ser Num LED Lights	Ser Num MEMS
Normal Operations	**30.6**	**30.6**	**30.6**	**30.6**
Identifiable	1	1	1	1
Backup	1	1	1	1
Class Div UN #	1.1	1.1	1.1	1.1
Enforcement	1	1	1	1
Car Spotting	1	1	1	1
Compliance	1	1	1	1
Verification	1	1	1	1
Safety Measures	1	1	1	1
Initiates EM Plan	1	1	1	1
Commodity Flow	1.1	1.1	1.1	1.1
In Transition (first 15-30 min)	**53.1**	**51.3**	**53.1**	**42.5**
Scan from Distance	1.1	1	1.1	1.1
Locate Haz Mat	1.1	1	1.1	1
First Source	1.1	1	1.1	1
Establish Action	1	1	1	1
Class Div UN #	1.1	1.1	1.1	1.1
Redundancy	1	1	1	0
Public Warning	1	1	1	0.5
Car Content	1.1	1.1	1.1	1.1
Emergency Operations	**20.0**	**20.0**	**20.0**	**17.5**
Scene Management	1	1	1	1
Identify Peripheral Haz Mat	1	1	1	1
Locat Haz Mat	1	1	1	1
Continuing Assessment	1	1	1	0.5
Total Assessment	**103.7**	**101.9**	**103.7**	**90.6**
% improvement*	13.5%	20.7%	13.5%	7.4%
1.0	= X = meets standards			
0.5	= @ = meets standards with exceptions			
0.0	= O = examined but does not meet standards			
1.1	= XX = exceeds standards			
* improvement is defined in terms of the best of the two alternatives being combined.				
SHADED ALTERNATIVES NOT RECOMMENDED FOR FURTHER STUDY.				

Only alternative technologies that improve safety and reduce security risks are recommended for further consideration. This means only the combinations in Table 4 with a total assessment above 100 (the total assessment of existing placards) are recommended for further study. The combinations of LED lights and MEMS technology, the combination of serial numbers and LED lights, and the combination of shutters and MEMS technology meet this criterion and are hereby recommended for further study.

This evaluation indicates only one alternative is considered to be implementable with relatively little training. The placard shutter system allows training to be carried out as a bulletin notification.

The estimated train delay at U.S. international borders for export movements is estimated to be nearly one man-year of train delay. If action is taken to unilaterally remove placards from hazardous material tank cars entering Canada, Canadian first responders can be expected to carry out strong political protests.

Limitations of Current Study

One of the critical factors in conducting this research has been the establishment of the functional requirements. There are a number of ways that a study such as this one could have been conducted to achieve this critical point of departure. This current study sought to establish functional requirements by holding focus groups with interested stakeholders. Two alternative approaches to this critical juncture are worthy of discussion. First, a survey of stakeholders that would be representative of all stakeholder groups would provide greater insight into the criticality of each functional requirement. This could still be done to fine-tune the functional requirements for an alternative to the hazardous materials placard system currently in use. Second, both the focus groups employed herein and the surveys suggested above rely on stakeholders to represent the nature of the functional requirements. The research team is convinced that the focus group participants have done that to the best of their ability. However, the participants are human, and as such they are reporting their beliefs and attitudes about the functional requirements. A thorough study of behavior in actual incidents, to represent the kinds of events that have occurred in the past five to ten years, would represent behaviors of actual use of placards in real incidents. Such a study would be far stronger to base functional requirements on than the current focus group approach. Such a study could provide considerable validation of the functional requirements developed herein. A study to further validate the functional requirements is strongly recommended.

The consideration of alternatives to replace the current hazardous materials placard system centers on the balance between potential increases in security provided by the alternative and the potential losses in safety of first responders, emergency personnel, and the public. This issue was raised in every stakeholder meeting in a variety of forms. In brief, the consensus position seems to be that modest gains in security do not warrant the loss of considerable safety. Hence, alternative systems need to be able to fully meet the functional requirements of the existing system, and should probably exceed in some areas to warrant the cost (financial, human, and risk) associated with making the change.

The current study has not considered car markings, or other factors that may make identification of hazardous materials in tank cars not only possible but probable. Hence, before any transition to an alternative system can be considered, no matter how good the alternative may be, the system must be considered in the context of these other considerations.

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APPENDIX A – STAKEHOLDER MEETING ATTENDEES

ATTENDEE LIST
National Fire Protection Association Technical Committee Meeting
Braintree, MA
August 27, 2004

John Eversole – International Association of Fire Chiefs
Dave Trebisacci – NFPA
Manny Elrich – Chemtrec
Dieter Heinz – Heinz Training & Consulting, Inc.
Glen Rudner – Virginia Department of Emergency Management
Bud Berry – Risk Control Management
Jo McMullen – Akron General Medical Center
Gene Carlson – VFIS (a division of Glatfelter Insurance Group)
Don
Danny Simpson – TTCI
Paul Spurlin – Wayne Township Fire Department
Sandra Holka – Dow Corning
Paul Errico – Paul L. Errico Associates, Inc.
Richard Emery – Richard Emery & Associates, Inc.
Les Olson – TTI
David Bierling – TTI
George Rogers – TAMU

ATTENDEE LIST
TSA Placard Meeting
Washington, DC
October 8, 2004

Randy Speight – Chemtrec
Frank Nobles – DuPont
Robert Fronczak – AAR
John Lambert – USDOT/RSPA/Office of Homeland Safety
Frits Wybenca – USDOT/RSPA/Hazmat Safety
Bill Schoonover – USDOT/FRA/Office of Safety
Daniel Collins – Operation Respond
Alan Caldwell – National Association of Fire Chiefs
Paul Williams – Norfolk Southern
Fred Caudill – Norfolk Southern
Bob Goldhammer – International Association of Emergency Managers
John Read – Transport Canada
Mark Stehly – BNSF

APPENDIX B – ALTERNATIVE PLACARD COSTS

Cost estimates for Alternative Technologies

Alternaitve		Shutters	LED Lights	Danger	Bar Codes	AEI Tags	MEMS	GPS	Train Orders	Serial Number
Cost of Implementation	CoI	**$447,150,000**	**$1,176,351,360**	**$241,182,500**	**$888,148,320**	**$1,105,708,320**	**$815,246,640**	**$525,682,500**	**$473,000,000**	**$805,112,500**
Material Cost										
Tank Cars	MCTC	$188,650,000	$862,400,000	$0	$47,040,000	$264,600,000	$17,640,000	$48,000,000	$0	$308,700,000
Rail Facilities	MCRF	$0	$1,035,360	$0	$21,052,320	$21,052,320	$20,534,640	$0	$0	$0
Chemical Facilitites	MCCF	$22,000,000	$0	$0	$194,224,000	$194,224,000	$189,448,000	$0	$0	$0
Towns	MCT	$0	$76,416,000	$0	$152,832,000	$152,832,000	$114,624,000	$0	$0	$0
Central Data Base		$0	$0	$4,682,500	$0	$0	$0	$4,682,500	$0	$23,412,500
Training Costs	TC	$236,500,000	$236,500,000	$236,500,000	$473,000,000	$473,000,000	$473,000,000	$473,000,000	$473,000,000	$473,000,000
Unit Costs										
Unit Cost	EC	$87.50	$400	$0	$20	$300	$30	$2,000	$0	$300
Units/Car	UR	4	4	0	4	2	1	1		4
Instalations/Car	IC	$350	$1,600	$0	$80	$300	$30	$1,000	$0	$1,200
Reader Equipment	RE	$0	$400	$0	$800	$800	$600		$0	$0
Prog Station	PS	$0	$0	$0	$8,000	$8,000	$8,000	$0	$0	$0
System Cost	SC	$0	$0	**$0**	$800	$800	$600		**$0**	**$0**
Training Cost	CT	$108	$108	$108	$215	$215	$215	$215	$215	$215
Equipment Life Expectancy	Life	10	10	20	5	5	5	5	**20**	20
Mobile Reader Life	MRL	0	5	0	5	5	5			
Program Life	L	10	5	20	10	10	10	20	**20**	20
Number of Units										
Tank Cars	TC	245,000	245,000	245,000	245,000	245,000	245,000	245,000	245,000	245,000
Fleet Locomotives	FL							20,000		
Towns	NT	19,900	19,900	19,900	19,900	19,900	19,900	19,900	19,900	19,900
Fire Departments	FD	3	3	3	3	3	3	3	3	3
Other Support Units	SU	5	5	5	5	5	5	5	5	5
Terminals	RRT	2,157	2,157	2,157	2,157	2,157	2,157	2,157	2,157	2,157
Chemical Loading Facilities	CLpt	19,900	19,900	19,900	19,900	19,900	19,900	19,900	19,900	19,900
Fire Fighters	FF	1,100,000	1,100,000	1,100,000	1,100,000	1,100,000	1,100,000	1,100,000	1,100,000	1,100,000
Police Personnel	PP	1,100,000	1,100,000	1,100,000	1,100,000	1,100,000	1,100,000	1,100,000	1,100,000	1,100,000
	CoI p 19	$262,225,000	$417,783,200	$236,500,000	$625,656,560	$707,976,560	$591,902,420	$521,000,000	$473,000,000	$561,200,000
MCTC	(((EC*UR)+IC)+((EC*UR)+IC)/Life)*TC			*EXCEPT for GPS & Serial Numbers*						
MCRF	((RE*RRT)+(RE*RRT)/Life or MRL)+((PS*RRT)+(PS*RRT)/L or MRL)					*EXCEPT for LED Lights*				
MCCF	((SC*NT)+(SC*NT)/Life)+((PS*NT)+(PS*NT)/L)									
MCT	((RE*NT)+(RE*NT/Life))*(FD+SU)			*EXCEPT for LED Lights*						
TC	CT*(FF+PP)									
CoI	MCTC+MCRF+MCCF+MCT+TC									

APPENDIX C – DETAILED EXAMPLE OF ALTERNATIVE TECHNOLOGY IMPLEMENTATION COSTS

A detailed example of a Cost of Implementation (CoI) includes estimated equipment cost, installation cost, annual maintenance cost, and the training cost for the firefighters to recognize the new system and operate the required equipment to obtain the information available under the new system.

EC = The individual tank car equipment technology cost
UR = The number of units required on the tank car
IC = The cost of installing equipment on the car
RE = The reader equipment cost
SC = The system equipment cost
CT = The individual firefighter/emergency responder/police training cost; fixed cost $215 ea. person

The CoI is based on the following criteria for each technology:

- TC = # of tank cars -- 245,000
- NT = # of named towns -- 19,900 places within 2.0 miles of railroad
- FD = # of support units for each fire department -- 3
- SU = # of support units for each named town, excluding FD -- 5
    - Emergency Medical Services -- 2
    - Police Department -- 2
    - Emergency Manager -- 1
- RRT = # of railroad terminal facilities where trains may be made -- 2,157
- CLpt = # of chemical origin/destination -- Assuming there will be at least one loading/unloading facility for every named town -- 19,900
- M = Maintenance is the one year bundled cost of maintaining the tank car equipment, the readers, and the systems. This is assumed to be five year replacement of the tank car and reader equipment, and ten year replacement of the system equipment. The calculation is expressed as (Material -- Equipment cost/Life). M_{TC} = Maintenance of tank car and M_{SC} = Maintenance of system equipment
- FF = # of fire fighters and emergency responders to be trained -- 1,100,000.
- PP = Police personnel to be trained are estimated to be equal to firefighters and emergency responders because all state police are required to be trained -- 1,100,000.

Cost of the tank car technology is estimated or quoted. Installation costs will double the material cost unless otherwise noted.

Reader cost is an estimate or quote as noted. All mobile reader technologies are expected to have a short life expectancy equal to five years due to changing technology and expected rough field treatment.

System cost is comprised of the equipment cost estimate of the system plus the installation cost of the system, which is estimated to effectively double the equipment cost for the installed system at each facility. Unless otherwise noted, system life expectancy is estimated to be ten years. This equipment is generally more robust and in a protected environment of a building or office.

Example: $60 = MEMS equipment cost $30 each unit, plus installation.
$600 = MEMS reader (hardened industrial computer, secure comm. link)
$8,000 = MEMS system comprised of a programming and reader system with a software link to import and export shipping paper data with other pertinent chemical data for system. Installation cost anticipated to be minimal with this new technology.

Car materials and maintenance: MEMS = $30 - per unit, one unit required per car; Installation = Materials - $30; TOTAL = ((($30 × 1) + $30) + ((($30 × 1) + $30) × 1/5) × 245,000) = $17,640,000

Industry remote readers (5 year life) and program stations including maintenance (10 year life) = $600; 19,900 required; TOTAL = (($600 × (19,900) + (($600 × (19,900) × 1/5)) + (($8,000 × 19,900) + ($8,000 × 19,900) × 1/10)) = $189,448,000

Rail yard facilities: Mobile readers = $600; Program stations = $8,000; TOTAL = (($600 × (2,157) + (($600 × (2,157) × 1/5)) + (($8,000 × 2,157) + ($8,000 × 2,157) × 1/10)) = $20,534,640

Named towns equipment: Mobile reader and maintenance = $600; TOTAL = ((($600 × (19,900) + ($600 × (19,900 × 1/5)) × 8) = $14,328,000

Training is estimated to be similar to other training efforts for first responders, emergency responders, and police; TOTAL = ($215 × (1,100,000 + 1,100,000)) = $473,000,000.

CoI = [((EC × UR) + IC) + (((EC × UR) + IC) × 1/Life) × TC] + [(RE × (NT) + ((RE × (NT) × 1/Life)) + (SC × NT) + (SC × NT) × 1/Life)] + [(RE × (RRT) + ((RE × (RRT) × 1/Life) + (SC × RRT) + (SC × RRT) × 1/Life)] + [((RE × NT) + (RE × NT) × 1/Life)) × (FD + SU)] + [CT × (FF + PP)]

CoI = [((($30 × 1) + $30) + ((($30 × 1) + $30) × 1/5) × 245,000] + [($600 × 19,900) + (($600 × 19,900) × 1/5)) + (($8,000 × 19,900) + ($8,000 × 19,900) × 1/10))] + [(($600 × 2,157) + (($600 × 2,157) × 1/5)) + (($8,000 × 2,157) + ($8,000 × 2,157) × 1/10))] + [($600 × 19,900) + ((($600 × 19,900) × 1/5) × 8] + [$215 × (1,100,000 + 1,100,000)]

CoI = $17,640,000 + $189,448,000 + $20,534,640 + $114,624,000 + $473,000,000
= $815,246,640