Feasibility Study for Highway Hazardous Materials Bulk Package Accident Performance Data Collection

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HAZARDOUS MATERIALS COOPERATIVE RESEARCH PROGRAM

HMCRP REPORT 10

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HAZARDOUS MATERIALS COOPERATIVE RESEARCH PROGRAM

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

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

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

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The members of the technical panel selected to monitor this project and to review this report were chosen for their special competencies and with regard for appropriate balance. The report was reviewed by the technical panel and accepted for publication according to procedures established and overseen by the Transportation Research Board and approved by the Governing Board of the National Research Council.

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FOREWORD

By William C. Rogers
Staff Officer
Transportation Research Board

HMCRP Report 10: Feasibility Study for Highway Hazardous Materials Bulk Package Accident Performance Data Collection offers methodologies for collecting and analyzing performance data for U.S. DOT-specified hazardous materials bulk packages (i.e., portable tanks and cargo tank motor vehicles), identifies and evaluates institutional barriers to data collection, and makes suggestions for overcoming these barriers. The report offers a methodical approach for developing and implementing a reporting database system to collect information about damage to U.S. DOT-specified hazardous materials bulk packages involved in accidents, regardless of whether the damage resulted in a leak of contents, as well as the characteristics of the accidents. If implemented, the system would provide a comprehensive source of information to help the industry assess potential improvements in package design and allow decisionmakers to develop conditional probabilities of release and amounts of release in transport accidents by road.

Bulk packages are a common method of transporting hazardous materials. The ability to predict the performance of these packages in a transportation accident is critical in the evaluation of risks. Accurate data on the impact of various design specifications on package performance in accidents are essential for safety, robust risk analysis, and better packaging selection decisions by carriers, shippers, and regulators. A long-standing, private-sector initiative managed by the Railway Supply Institute (RSI) and the Association of American Railroads (AAR), the RSI-AAR Railroad Tank Car Safety Research and Test Project, has collected and analyzed damage reports on tank cars involved in railroad accidents, whether or not the damage resulted in a leak of contents. The resulting data have been used to develop conditional release probabilities and amounts released for tank cars having different design specifications and features. Such specifications and features include overall release probabilities as well as probabilities by the location of the leak (i.e., shell, head, top or bottom fittings, or multiple locations). No such data exist for cargo tank motor vehicles or portable tanks; therefore, risk estimates for these types of packages are based on loose estimates and anecdotes rather than quantitative data.

Under HMCRP Project 07, Engineering Systems, Inc., with the University of Illinois, was asked to (1) review package performance studies and analyses of U.S. DOT-specified hazardous materials bulk packages whether hauling hazardous or non-hazardous materials; (2) discuss the implications of different definitions for data collection, including the effects of various accident severity thresholds; (3) investigate existing data collection strategies; (4) interview package manufacturers, carriers, and shippers to determine how they have incorporated accident performance into their designs and specifications; (5) interview regulatory and enforcement agencies, as well as other potential users of the data, to understand their needs and uses of such data; (6) describe what data need to be collected, develop a data collection approach, and pilot test the approach; and (7) identify institutional barriers (e.g., legal, cost, privacy, and regulatory) and possible solutions. The final result is a report that offers methodologies for collecting and analyzing performance data for U.S. DOT-specified hazardous materials bulk packages, identifies and evaluates the institutional barriers to data collection, and makes suggestions for overcoming these barriers.

Appendices to *HMCRP Report 10* containing supplemental materials are provided on *CRP-CD-128*, which is provided with the report.

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

SUMMARY

Feasibility Study for Highway Hazardous Materials Bulk Package Accident Performance Data Collection

Bulk packages are a common means of transporting hazardous materials. Accurately estimating the safety performance of these packages in an accident is critical in the evaluation of transportation risks. Such an assessment requires reliable data on accidents, design characteristics of bulk packages, and failure of a package or its components. Accurate data would help carriers, shippers, and regulators make better decisions about package selection and design and would help guide overall risk analysis related to transportation of hazardous materials. HMCRP Project 07 was developed to address this research need. The objectives of HMCRP Project 07 were the following:

- Review data currently being collected about accidents involving U.S. DOT-specified hazardous material bulk packages (i.e., portable tanks, cargo tank motor vehicles).
- Determine what data are needed to develop a satisfactory bulk package accident performance database.
- Develop methodologies for collection and analysis of accident performance data.
- Identify and evaluate institutional barriers to development of such a database and make recommendations for overcoming them.

Information Needed to Assess Bulk Package Accident Performance

Information about accident performance and the conditional probability of release of hazardous materials when a bulk package is involved was identified by reviewing cargo tank classifications and specifications, industry practices, existing data collection methodologies, risk analysis strategies, container performance studies, and cargo tank accident investigations. In addition, potential database users were asked to identify components and information that should be collected.

The information was ranked by importance in predicting bulk package accident performance. The HMCRP Project 07 panel then specified a level of detail for a pilot study of a data collection program. The resulting data fields are categorized as follows:

- **Bulk Package Design Information.** This information enables prediction of how well a bulk package will withstand damage, includes design information from bulk package specification plates, and indicates whether the bulk package was jacketed.
- **Basic Commodity Information.** This information enables a risk-based decision-making approach to determine whether additional damage-protection measures are appropriate for a particular commodity; it includes commodity identification information typically found on shipping papers, and information on the packaged amount by compartment.

- **Bulk Container Damage Information.** This information describes the severity of the accident and enables identification of components or locations that are prone to damage and/or release of hazardous materials; bulk container damage information also can be used as a proxy for impact energy and forces involved in the accident. This information includes identification of damaged components; damage location, type, and size; indication of whether the damage sustained by the component resulted in a release; and, if applicable, the amount released and breach size.
- **Basic Accident Information.** This information accounts for variability in predicting the conditional probability of release and amount released from impact forces in different kinds of accidents and includes identification of a rollover and/or collision with other motor vehicles, the speeds of the vehicles involved, and identification of the physical object(s) that damaged the bulk package.

Data Collection Methodologies

Two options for recording cargo tank performance in accidents were considered: either modifying or emulating existing databases and data collection processes. To increase the quality of reported data and the ease of reporting, technical implementation and security methods were explored in further detail.

The following databases were considered for modification or emulation:

- FMCSA's Motor Carrier Management Information System (MCMIS) Crash File.
- PHMSA's Hazardous Materials Incident Reporting System (HMIRS).
- NHTSA's Trucks Involved in Fatal Accidents (TIFA).
- NHTSA's National Automotive Sampling System (NASS) General Estimates System (GES).
- Railway Supply Institute (RSI)-Association of American Railroads (AAR) Tank Car Accident Database (TCAD).

The programs were examined and the following dichotomies were identified:

- Participation in the data collection program could be either voluntary or mandatory.
- The program could be sponsored by either a consortium of industry organizations or by a government organization.
- The database could either be a standalone new data collection program or an extension of an existing one.

These options were presented in a survey of stakeholders. Although opinions were fairly evenly split regarding mandatory or voluntary participation, respondents were in favor of an industry-sponsored extension of an existing program. PHMSA's HMIRS was determined to be the most appropriate existing program because it collects approximately 70% of the desired information. HMIRS could be extended by modifying the existing Form DOT F 5800.1 to collect additional data or by importing the necessary information from Form DOT F 5800.1 and requesting additional information separately.

The following four options were considered for further analysis:

- A program of improved compliance with the existing Form DOT F 5800.1 modified to collect information about component performance, with mandatory participation.
- A government-sponsored extension of Form DOT F 5800.1 that collects all information required to evaluate component performance, with mandatory participation.

- An industry-sponsored extension of Form DOT F 5800.1 that collects all information required to evaluate component performance, with voluntary participation.
- A government-sponsored new database (independent of Form DOT F 5800.1) that collects all information required to evaluate component performance, with mandatory participation.

From these four options, the project panel recommended that the research team investigate the feasibility of implementing a government-sponsored extension of Form DOT F 5800.1, with mandatory participation. Accordingly, a pilot study was undertaken to explore collection of accident damage data. Results of the pilot study were used to evaluate the expected quality of data, identify improvements to the data collection system, demonstrate the types of analyses that the database would facilitate, and estimate how long it would take to collect incident data sufficient to support reasonable statistical analyses.

To facilitate data collection for the pilot study, an online tool was developed. To reduce errors and reporting time and to improve data quality, questions were dynamically adjusted based on logic and previous responses—for example, certain questions were displayed only if a response was logically expected. Drop-down menus, check-off boxes, and radio buttons provided consistency and uniformity in responses, and text-based response options were provided only when necessary. In addition, logical quality checks upon report submission helped ensure that responses were realistic and congruent. (These quality checks must be conducted whether or not responses are adjusted dynamically.)

Industry participants were solicited to provide bulk package performance data for the pilot study. Despite extensive efforts to involve the industry, the participation level was unsatisfactory. Therefore, data from NTSB accident reports, PHMSA HMIRS reports, FMCSA MCMIS reports, and news articles were used to populate the pilot database. Through this process, several improvements to the data collection tool were made, including improving the logic for presenting possible responses and increasing the robustness of the system so that it could handle unexpected actions (such as a respondent using the browser's refresh button).

In any broader implementation, data integrity measures will help ensure that collected information is valid. Accordingly, three levels of access are recommended: administrator, reporter, and public. Administrator access allows database owners to grant access to other users, create backups of the datasets, implement data quality checks, correct errors, track the number of views the dataset generates, and link to datasets generated by other organizations. Reporter access is granted to individuals or companies that are required to submit a report. The rights granted under reporter access must be sophisticated enough to allow the reporting individuals or companies to view and update their reports at a later date. Public access, granted by sharing either raw or processed data, requires careful consideration because it could influence the success of the program.

Data Analysis

Analytical statistical models for estimating bulk package performance were explored by first examining how these models relate to the risk of transporting hazardous materials. Once metrics of interest had been determined, data analysis methods were examined. The methods chosen emulated others that analyze similar data collected as part of the RSI-AAR TCAD. Because of anticipated variability in conditional probabilities of release, separate regression equations can be developed for each component-accident scenario pair using the methodologies presented in this report.

Although the pilot study did not have sample sizes sufficient to evaluate performance based on bulk package design, the information offered a preliminary understanding of component performance by location on the tank, under various accident scenarios. For example, a single incident could damage components in different areas of a tank; therefore, a component in one location might be less likely than one located in another area of the tank to result in a release of hazardous materials. Preliminary analysis of pilot study data showed that damage is most likely to occur to the top front passenger-side tank shell and to the piping and/or undercarriage below the tank. In general, damage to the top front passenger-side results from rollover accidents, while damage to the piping and/or undercarriage below the tank results from accidents involving other vehicles. Crushing damage to the tank shell, including dents, is the most prevalent type of damage; however, it is the least likely to result in a release of hazardous materials. More information is necessary, however, to determine the type of damage that will most likely result in a release. Pilot test data also showed that larger releases occur in accidents that involve crossing the median or centerline, running off the road, overturning, and catching fire, and that the greatest number of releases occurred when the bulk package struck both the roadway and the adjacent ground.

Finally, the time required to collect incident data sufficient to support reasonable statistical analyses was determined. Based on data from PHMSA HMIRS reports, FMCSA MCMIS reports, and news articles over a 7-month period, it was determined that approximately 132 accidents can be expected per month, with about 34 resulting in release of hazardous materials. Based on this expected accident rate, the minimum sample size to acquire statistically significant results was estimated using pilot study data.

Because pilot study data were insufficient to estimate variances for all types of bulk packages, sample size estimates were generated only for records corresponding to hazardous materials transported in MC 306 or DOT 406 containers. The analysis indicated that there are three tiers of variables.

Tier I variables, requiring sample sizes of less than 800 accident records, consist of the following:

- Design variables, including total capacity of the bulk package and head or shell thickness.
- The component that was damaged.
- Damage locations of the front head above the centerline and the passenger-side bottom middle.
- Damage type, including crushing, bending, and gouging or cutting.
- Whether the units separated in the crash (if the tractor-trailer was also towing a pup trailer).
- Accident characteristics, including whether a personal vehicle or heavy vehicle was involved, whether the bulk package crossed the centerline or median, ran off the road, rolled over, or struck the ground or a concrete barrier.
- Speeds of the vehicle(s) involved in the accident.

Between 858 and 1,286 accident records are required for the Tier II variables:

- Packaged amount.
- Damage locations of the driver-side bottom front and top rear and passenger-side top middle.
- Whether the bulk package struck the roadway.

Variables requiring sample sizes above 5,000 are classified as Tier III:

- Bulk package design pressure.
- Burst or ruptured damage.

- Damage locations of the rear head below the centerline; the bottom middle, top middle, and/or top front driver-side; and/or the bottom front, top front, and top rear passenger-side.
- Whether the bulk package struck the guardrail.

Compared to the rate of data acquisition for the corresponding variables and assuming an accident-reporting rate of 20%, these minimum sample sizes indicate that meaningful statistical analyses of Tier I variables can start within 2 years of program implementation. By the fourth year of data collection, the significance of Tier II variables could be tested. The research team assumes that other types of bulk packages will require similar sample sizes, and that they can be expected to take longer to acquire in proportion to their usage rates.

Institutional Barriers

Several industry concerns and institutional barriers must be addressed in order to have a successful data collection program. These barriers were identified through stakeholder surveys and discussion with industry representatives and are classified into three categories: implementation, participation, and information gathering.

Barriers associated with implementation include regulatory hurdles and cost. A reasonable basis for evaluating the costs, risks, and benefits of the proposed database can be extrapolated from the RSI-AAR TCAD. Rail industry associations that sponsor that database report savings of at least 11 times the cost of the implementation, bringing positive returns on investment in terms of improved safety and business operations. The credibility of the TCAD program has grown such that the rail industry is consistently successful in providing fact-based responses to regulatory proposals. Thus, institutional barriers can be diminished by developing the reporting form in cooperation with carriers already committed to risk-based approaches to safety.

Industry associations and member companies are reluctant to participate in a package damage database for a number of reasons, including the belief that accident data would be inappropriately used against a carrier in legal proceedings. Three options to address that concern are proposed:

- Implementation of a no-fault provision.
- Adoption of processes for storing and sharing data that prevent disclosure of trade or security-sensitive data (includes strict authorization procedures for access to database information).
- Adoption of a program that stores anonymous accident data separately from carrier/reporter information but requires carriers to provide proof of reporting during compliance checks.

An additional disincentive to participation is lack of compensation for time spent filling out a report. Therefore, the burden of reporting must be placed on the company rather than the person in possession of the hazardous material at the time of the accident. An alternative is to provide a monetary incentive for accident reporting.

Another concern is that the data would be used by shippers as a reason to select other modes of transportation and/or other types of bulk packages. To overcome these and other participation barriers, enforcement could be increased and/or safety ratings could be linked to accident-reporting performance.

Information-gathering challenges include the inability to access the accident scene to collect information because of safety concerns and the desire to clear the roadway as quickly as possible. To assist with data collection, crash-clearing procedures could be modified to include taking photos before removing the bulk package. In addition, if damage information must initially be estimated due to a lack of access to equipment following the accident, carriers should be allowed, and even encouraged, to revise that information when they are able to access the accident scene.

Conclusion

This project offers a methodical approach to developing and implementing a database system to collect information about damage to U.S. DOT–specified hazardous material bulk packages involved in accidents, regardless of whether the damage resulted in a leak of contents, as well as the characteristics of an accident.

Institutional barriers to data collection were identified, and strategies for overcoming those obstacles were proposed. A successful data collection system requires cooperation from multiple stakeholders in the industry. If implemented, the system could provide a comprehensive source of information to help the industry to proactively assess potential improvements in package design. The system would also inform and improve package design and policy decisions by providing quantitative data on safety and risks.

SECTION 1

Introduction

Hazardous materials are used as commodity chemicals in numerous manufacturing applications, specialty chemicals for pharmaceutical production and water purification, and in myriad other applications such as powering motor vehicles, heating homes and businesses, and cooking. Hazardous materials are transported from points of production to points of consumption via all modes, including pipelines, railways, waterways, and even, in small amounts, via airways. Nonetheless, no mode handles more hazardous materials shipments in the United States than trucks traveling on roads and highways. Not only do trucks transport more hazardous material shipments than any other mode, the highway system has a greater percentage of its network in close proximity to people than any other mode. This exposure includes drivers and passengers in other vehicles sharing roadways, pedestrians walking adjacent to roads, and individuals in homes and businesses located along the roadside. In the event of an incident involving a motor vehicle carrying hazardous materials, there is a substantial likelihood that people, the environment, and property will be impacted if there is a release.

In recognition of the potential hazard, U.S. DOT has developed extensive regulations governing the safe transport of these materials. Among these regulations are detailed specifications for the type and design of bulk packages used to transport hazardous materials. These specifications apply to a range of different portable tanks, cargo tank trailers, and cargo tank motor vehicles. Tank specifications and designs are intended to be commensurate with the hazards posed by the various products transported, with more damage-resistant designs required for more hazardous products. These regulations and specifications result in a generally safe record of highway transport. Nevertheless, when accidents occur, questions may arise regarding the adequacy of the current safety designs or regarding how designs can be improved. Furthermore, private and public sector organizations may be interested in the risk associated with highway shipment of hazardous materials so that they can improve their risk analysis and management efforts including hazardous materials routing decisions, choice of package design, or general understanding of the risk associated with various business activities.

Package design elements have a substantial effect on the probability and quantity of release if a vehicle transporting hazardous materials is involved in an accident. This is implicit in the regulatory differences in package specifications required for different types of hazardous materials. Yet, in spite of the need to understand the relationship between a hazardous materials bulk package's safety design features and its performance in accidents, quantitative understanding of these relationships is surprisingly poor. This is mainly due to insufficient reliable data on the number of hazardous materials bulk packages involved in accidents, the design specifications of the packages involved in these accidents, the nature and severity of the damages the packages incurred, and the frequency and severity of releases. Although a variety of highway safety and accident data are collected by private companies, various government agencies, and other organizations, these data do not provide a satisfactory basis for the type of analysis described above. The overarching goal of this study was to address these data gaps by determining the type of data needed, investigating the type of data already being recorded, and identifying any new data and data collection systems that would be required to satisfactorily address the problem.

Specifically, this study presents an approach to the development and implementation of an accident-reporting database system to collect information on the nature and extent of damage to U.S. DOT-specified hazardous materials bulk packages damaged in accidents as well as the characteristics of the accidents. The objectives of this study were to (1) determine what data are needed to develop a satisfactory database, (2) develop methodologies for systematic collection of the necessary performance data, (3) identify methodologies to analyze cargo tank performance using these data, and (4) identify and evaluate the institutional barriers to development of such a database and approaches to overcoming them.

SECTION 2

Information Needed to Assess Bulk Package Accident Performance

The first objective of this study, a review of the nature and quality of the data currently being collected, was achieved through a literature review, a review of relevant definitions used in analyzing bulk package accident performance, an investigation of existing data collection strategies, and an extensive interview process.

The literature review focuses on studies and reports in the following categories:

- **Cargo tank and portable tank classification and specifications.** The packages for which accident data will be collected are identified, and design attributes are noted, such as minimum head and shell thicknesses and type and location of valves and manholes.
- **Cargo tank motor vehicle industry practices.** Besides container design specifications, industry practices may influence the performance of cargo tanks in an accident scenario. Factors affecting the service life of a cargo tank that were identified in Bowman et al. (2009) are summarized.
- **Container performance studies.** Past studies were reviewed to determine how existing crash data have been used. For highway cargo tanks, a number of analyses have been performed to evaluate the performance of front heads as well as container performance in rollover scenarios. Key factors required to perform similar statistical analyses of container performance are identified.
- **Cargo tank accident investigations.** Accident investigations were reviewed to identify key factors for inclusion in a database enabling statistical analyses of container performance.

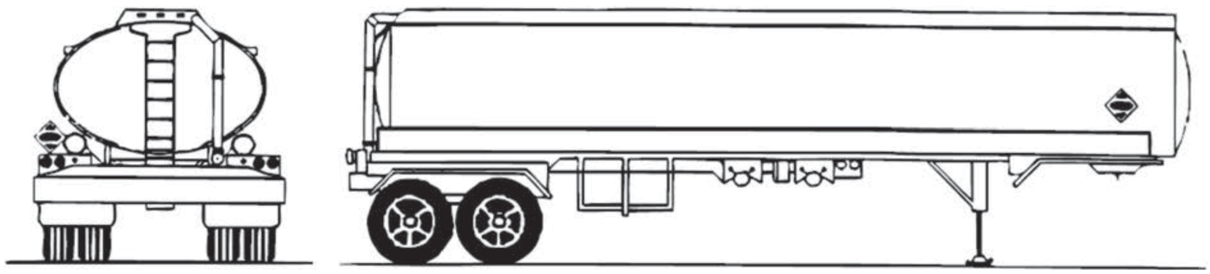
Data collected by existing programs were reviewed for applicability in evaluating cargo tank and portable tank performance in accidents. These existing programs include PHMSA's Hazardous Materials Incident Reporting System (HMIRS), the FMCSA's Motor Carrier Management Information System (MCMIS), the University of Michigan Transportation Research Institute (UMTRI)'s Trucks Involved in Fatal Accidents (TIFA), and NHTSA's National Automotive Sampling System (NASS) General Estimates System (GES). Additionally, the Railway Supply Institute (RSI)—Association of American Railroads (AAR) Tank Car Accident Database (TCAD) is an existing data collection process used for a comparable purpose in railroad bulk liquid transport.

Finally, an extensive interview process was undertaken. Several companies from each stakeholder group were visited and interviewed to determine the information currently recorded regarding bulk package design and/or accident damage. Through these stakeholder interviews, it was ascertained that, due to the large differences in bulk package use and accident performance associated with different specification containers, a process to engage a larger number of stakeholders was required. Therefore, a set of stakeholder online surveys were developed and distributed, where possible, through their respective industry associations. The purpose of the surveys was to gain insight on what information different stakeholders believe would be most useful in an accident damage database. Additionally, the survey was intended to provide information on what constraints might exist among stakeholders as well as various preferences they might have regarding the database. Questions were tailored to each survey group to collect information most appropriate to their interests and expertise.

Survey responses were used in conjunction with interviews, literature reviews, and existing database reviews, to identify and rank the most important types of data to be collected. These include bulk package design characteristics, the nature of the damage they experience, the circumstances of accidents involving hazardous materials packages, whether or not there was a release of product, and, if so, the quantity and other details about the release.

Literature Review

As part of a review to identify and evaluate the quality of bulk package performance data currently being collected, extensive searches for relevant literature were conducted.



Source: U.S. Department of Transportation et al. 2012

Figure 1. MC 306/DOT 406 non-pressure liquid tank.

The review focused on studies and reports in the following categories:

- Bulk package classification and specifications.
- Cargo tank motor vehicle assembly and repair.
- Container performance studies.
- Cargo tank accident investigations.

Bulk Package Classification and Specifications

One of the primary purposes of this study was to outline a database containing information about damage to highway bulk packages. An understanding of various cargo tank motor vehicles and intermodal containers currently in use was obtained through the following sources:

- **49 Code of Federal Regulations (CFR) Section 178—Specifications for Packagings.** This source provides the minimum design requirements for the lading retention system of certified cargo and portable tanks including authorized materials, minimum thicknesses, structural integrity requirements, and accident damage protection requirements.
- **Guidelines for Chemical Transportation Risk Analysis, Appendix A: Standard Container Illustrations and Specifications** (CCPS 1995). This source provides an overview of current motor carrier series cargo tanks including the types of materials typically carried in the tank, a description of the tank, and design features of the tank.
- **State of Ohio Hazmat and Weapon of Mass Destruction (WMD) Awareness for the First Responder: Instructor Guide Unit Three—The Ability to Recognize and Identify Hazardous Materials** (Ohio Hazmat/Decon Technical Advisory Committee 2009). This is a series of PowerPoint slides for first responder hazardous material training that provides detailed descriptions of cargo tank motor vehicles and intermodal tanks.

The following sections describe the packages for which accident data will be collected. Design attributes, such as minimum head and shell thicknesses and type and location of valves and the manhole, are noted because the proposed database is anticipated to allow analyses of the performance of these features.

MC 306/DOT 406—Atmospheric Pressure Cargo Tank

With a maximum allowable working pressure between 2.65 psig and 4 psig (49 CFR 178.346), MC 306/DOT 406 cargo tanks typically transport between 2,000 and 9,500 gallons of flammable and combustible liquids or poisonous materials (CCPS 1995). Figure 1 illustrates an MC 306/DOT 406 cargo tank.

MC 306/DOT 406 cargo tanks typically have a single shell oval cross-section and are equipped with a vapor collection system that is evident by the piping running along the top and wrapping around the end of the tank. The lading retention system may feature a multi-compartment design in which compartments are separated by double bulkheads and a vented/drained airspace (CCPS 1995). The manhole is either recessed into the cargo tank or is equipped with rollover protection.

The tank is equipped with bottom stop valves that are generally grouped together on the underside of the tank to assist with unloading. Piping connects the compartments to the bottom valves and is protected from breakage by accident protection devices or shear sections (CCPS 1995). Additionally, an emergency valve remote closure device is located more than 10 feet from the stop valves. A rear bumper provides additional protection to pipes and valves in the event of a rear-end collision.

Minimum thicknesses for tank head/bulkhead/baffle and tank shell as specified in 49 CFR 178.346 are shown in Tables 1 and 2, respectively, based on the type of material and the cargo tank motor vehicle rated capacity, in gallons.

MC 307/DOT 407—Low-Pressure Cargo Tank

With a maximum allowable working pressure between 25 psig (49 CFR 178.347) and 40 psig (CCPS 1995), MC 307/DOT 407 cargo tanks typically transport between 2,000

Table 1. Specified minimum head thickness of MC 306/DOT 406 cargo tank (or bulkhead and baffle when used as tank reinforcement).

	Minimum Head Thickness (inches)		
Volume Capacity (gallons per inch of length)	Mild Steel	High Strength Low Alloy Steel & Austenitic Stainless Steel	Aluminum
14 or less	0.100	0.100	0.160
Over 14 to 23	0.115	0.115	0.173
Over 23	0.129	0.129	0.187

Table 2. Specified minimum shell thickness of MC 306/DOT 406 cargo tank.

	Minimum Shell Thickness (inches)		
Cargo Tank Motor Vehicle Rated Capacity (gallons)	Mild Steel	High Strength Low Alloy Steel & Austenitic Stainless Steel	Aluminum
More than 0 to at least 4,500	0.100	0.100	0.151
More than 4,500 to at least 8,000	0.115	0.100	0.160
More than 8,000 to at least 14,000	0.129	0.129	0.173
More than 14,000	0.143	0.143	0.187

and 8,000 gallons of flammable liquids and mild corrosives with vapor pressures not more than 40 psi at 70°F. Figure 2 illustrates an MC 307/DOT 407 cargo tank.

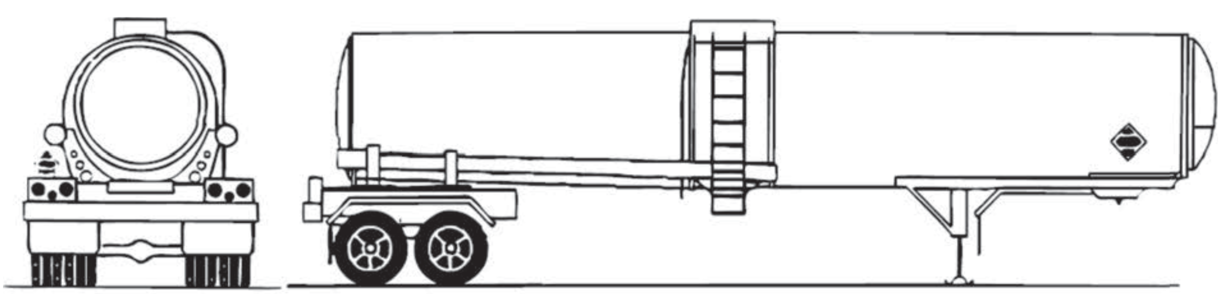
MC 307/DOT 407 low-pressure cargo tanks are typically made of steel with a double shell and may be lined. The lading retention system may have a multi-compartment design in which compartments are separated by double bulkheads and a vented/drained airspace (CCPS 1995). The manhole, which can withstand an internal fluid pressure of at least 40 psi, is either recessed into the cargo tank or is provided with roll-over protection. Additionally, stiffening rings add structural strength to the tank.

The tank is equipped with bottom stop valves that are generally grouped together on the underside of the tank to assist with unloading. Piping connects the compartments to the bottom valves and is protected from breakage by accident protection devices or shear sections (CCPS 1995). Additionally, an emergency valve remote closure device is located more than 10 feet from the stop valves.

Minimum thicknesses for tank heads/bulkhead/baffles and tank shell as specified in 49 CFR 178.347 are shown in Tables 3 and 4, respectively, based on the type of material and the cargo tank motor vehicle rated capacity, in gallons.

MC 312/DOT 412 Corrosive Cargo Tank

MC 312/DOT 412 cargo tanks are characterized by a narrow cylindrical shape and are typically lined with a homogeneous corrosive resistant material to transport high density liquids and corrosives such as acetyl chloride and hydrochloric acid (CCPS 1995). The cargo tanks have a multi-compartment design; are usually constructed of steel, stainless steel, or



Source: U.S. Department of Transportation et al. 2012.

Figure 2. MC 307/DOT 407 low-pressure chemical tank.

Table 3. Specified minimum head thickness of MC 307/DOT 407 cargo tank (or bulkhead and baffle when used as tank reinforcement).

Volume Capacity (gallons per inch of length)	Minimum Head Thickness (inches)			
	Mild Steel	High Strength Low Alloy Steel	Austenitic Stainless Steel	Aluminum
10 or less	0.100	0.100	0.100	0.160
Over 10 to 14	0.100	0.100	0.100	0.160
Over 14 to 18	0.115	0.115	0.115	0.173
Over 18 to 22	0.129	0.129	0.129	0.187
Over 22 to 26	0.129	0.129	0.129	0.194
Over 26 to 30	0.143	0.143	0.143	0.216
Over 30	0.156	0.156	0.156	0.237

Table 4. Specified minimum shell thickness of MC 307/DOT 407 cargo tank.

Volume Capacity (gallons per inch of length)	Minimum Shell Thickness (inches)			
	Mild Steel	High Strength Low Alloy Steel	Austenitic Stainless Steel	Aluminum
10 or less	0.100	0.100	0.100	0.151
Over 10 to 14	0.100	0.100	0.100	0.151
Over 14 to 18	0.115	0.115	0.115	0.160
Over 18 to 22	0.129	0.129	0.129	0.173
Over 22 to 26	0.129	0.129	0.129	0.194
Over 26 to 30	0.143	0.143	0.143	0.216
Over 30	0.156	0.156	0.156	0.237

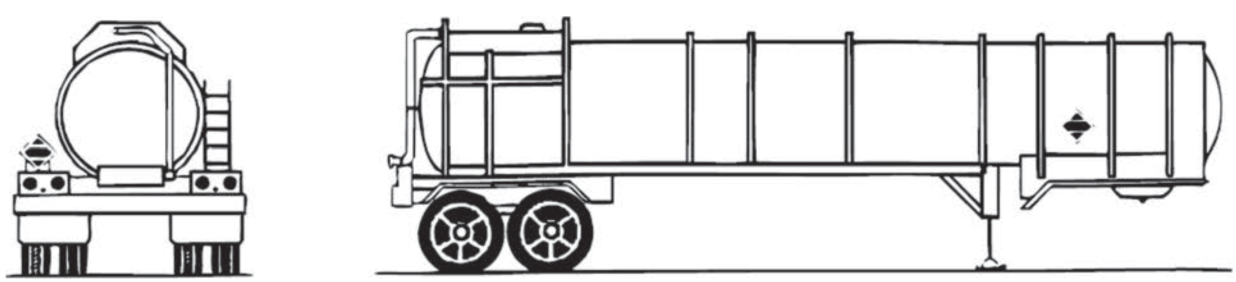
aluminum; and are equipped with rollover protection and splashguards that also provide rollover protection. Figure 3 illustrates an MC 312/DOT 412 cargo tank.

The manhole is located at either the center or the rear of the tank. The loading area is typically covered with corrosive resistant material; piping, hoses, and connections may be made of non-metallic materials to resist corrosion as well (49 CFR 178.348). These cargo tanks are typically equipped with the ability to be unloaded from the top using air pressure and are provided with valves both at the discharge point and inside the tank to prevent siphoning in the event of a valve failure (CCPS 1995). Discharge piping is shown in Figure 3 at the rear of the tank.

Minimum thicknesses for tank head/bulkhead/baffle and tank shell as specified in 49 CFR 178.347 are shown in Tables 5 and 6, respectively, based on the type of material, the cargo tank motor vehicle rated capacity, in gallons, and the lading density at 60°F.

MC 331 High-Pressure Gas Cargo Tank

MC 331 cargo tanks are typically used to transport liquefied pressurized gases (49 CFR 178.337). With a maximum allowable working pressure between 100 and 500 psig, MC 331 cargo tanks are made of steel or aluminum using seamless or welded construction. Aluminum tanks are insulated



Source: U.S. Department of Transportation et al. 2012

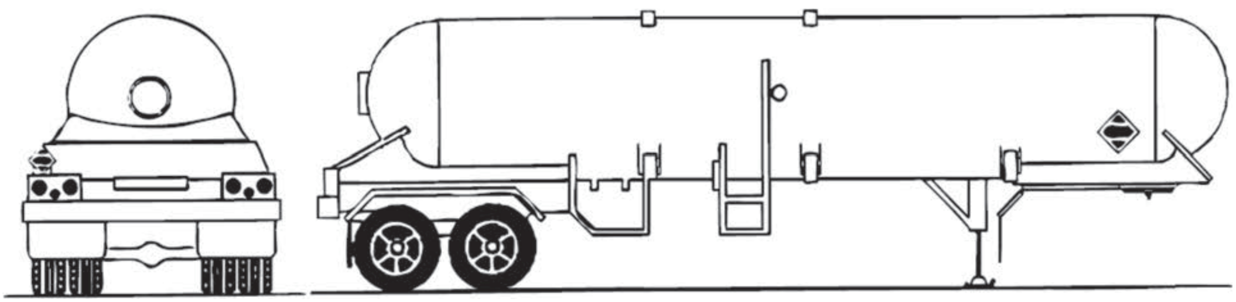
Figure 3. MC 312/DOT 412 corrosive cargo tank.

Table 5. Specified minimum head thickness of MC 312/DOT 412 cargo tank (or bulkhead and baffle when used as tank reinforcement).

Volume Capacity (gallons per inch)	Lading Density (pound per gallon at 60°F)	Minimum Head Thickness (inches)	
		Steel	Aluminum
10 or less	10 lb and less	0.100	0.144
	Over 10 to 13 lb	0.129	0.187
	Over 13 to 16 lb	0.157	0.227
	Over 16 lb	0.187	0.270
Over 10 to 14	10 lb and less	0.129	0.187
	Over 10 to 13 lb	0.157	0.227
	Over 13 to 16 lb	0.187	0.270
	Over 16 lb	0.250	0.360
Over 14 to 18	10 lb and less	0.157	0.227
	Over 10 to 13 lb	0.250	0.360
	Over 13 to 16 lb	0.250	0.360
Over 18	10 lb and less	0.157	0.227
	Over 10 to 13 lb	0.250	0.360
	Over 13 to 16 lb	0.312	0.450

Table 6. Specified minimum shell thickness of MC 312/DOT 412 cargo tank.

Volume Capacity (gallons per inch)	Lading Density (pounds per gallon at 60°F)	Distances Between Heads (and bulkheads, baffles, and ring stiffeners when used as tank reinforcement)	Minimum Shell Thickness (inches)	
			Steel	Aluminum
10 or less	10 lb and less	60 in. or less	0.100	0.144
	Over 10 to 13 lb	60 in. or less	0.129	0.187
	Over 13 to 16 lb	60 in. or less	0.157	0.227
	Over 16 lb	60 in. or less	0.187	0.270
Over 10 to 14	10 lb and less	54 in. or less	0.100	0.144
		Over 54 in. to 60 in.	0.129	0.187
	Over 10 to 13 lb	54 in. or less	0.129	0.187
		Over 54 in. to 60 in.	0.157	0.227
	Over 13 to 16 lb	54 in. or less	0.157	0.227
		Over 54 in. to 60 in.	0.187	0.270
	Over 16 lb	54 in. or less	0.187	0.270
		Over 54 in. to 60 in.	0.250	0.360
Over 14 to 18	10 lb and less	36 in. or less	0.100	0.144
		Over 36 in. to 54 in.	0.129	0.187
		Over 54 in. to 60 in.	0.157	0.227
	Over 10 to 13 lb	36 in. or less	0.129	0.187
		Over 36 in. to 54 in.	0.157	0.227
		Over 54 in. to 60 in.	0.250	0.360
	Over 13 to 16 lb	36 in. or less	0.157	0.227
		Over 36 in. to 54 in.	0.187	0.270
		Over 54 in. to 60 in.	0.250	0.360
Over 18	10 lb and less	36 in. or less	0.129	0.187
		Over 36 in. to 54 in.	0.157	0.157
		Over 54 in. to 60 in.	0.187	0.270
	Over 10 to 13 lb	36 in. or less	0.157	0.227
		Over 36 in. to 54 in.	0.250	0.360
		Over 54 in. to 60 in.	0.250	0.360
	Over 13 to 16 lb	36 in. or less	0.187	0.270
		Over 36 in. to 54 in.	0.250	0.360
		Over 54 in. to 60 in.	0.312	0.450



Source: U.S. Department of Transportation et al. 2012

Figure 4. MC 331 high-pressure gas cargo tank.

and covered with a steel jacket while steel tanks need to be insulated and covered with a steel jacket only when carrying a flammable gas. Insulation must be non-combustible if used for tanks carrying nitrous oxide refrigerated liquid and must be corkboard, polyurethane foam, or ceramic fiber/fiberglass if used for tanks carrying chlorine. If the cargo tank is not insulated, it is painted white, aluminum, or a similar reflecting color on the upper two-thirds of the container. Structural members, the suspension sub-frame, accident protection structures, and external circumferential reinforcement devices are typically used for attachment of appurtenances and other accessories. Figure 4 illustrates an MC 331 cargo tank with vents located on top of the cargo tank and a manhole located on the rear head.

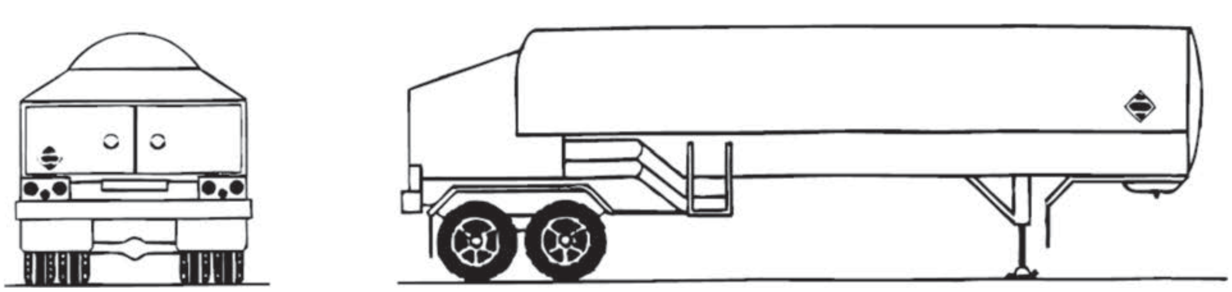
Non-chlorine cargo tank openings include gauging devices, thermometer wells, pressure relief valves, manhole openings, product inlet openings, product discharge openings, and other openings that have been closed with a plug, cap, or bolted flange. Backflow check valves or internal self-closing stop valves are located inside the cargo tank or inside a welded nozzle that is an integral part of the cargo tank. Additionally, non-chlorine cargo tanks have remote closure valves in at least two diagonally opposite locations (CCPS 1995). Chlorine cargo tanks have only one opening on the top of the tank, which is fitted with a nozzle, an internal excess flow valve, and an external stop valve, and protected by either a manway cover or a dome cover plate (49 CFR 178.337).

The minimum thickness for MC 331 tanks is based on the structural requirements of the tank and 25% of the tensile strength of the material used. Sulfur dioxide and chlorine tanks are made of steel and designed to incorporate a corrosion allowance of the lesser of an additional 20% or an additional 0.100 inches. Chlorine tanks are required to be at least 0.625 inches, including the corrosion allowance. All other MC 331 steel tanks should exceed 0.187 inches, and MC 331 aluminum tanks should exceed 0.270 inches (49 CFR 178.337).

MC 338 Cryogenic Liquid Cargo Tank

MC 338 cargo tanks are designed to prevent heat transfer to the lading and consist of an inner tank enclosed within an outer tank. This provides a thermos-bottle-type design where the interstitial space can be evacuated of air (vacuum). Additionally, an insulation material may be provided between the inner and outer tanks. Depending on the insulation provided, each tank is rated for a specific holding time before the tank pressure exceeds the set pressure of a pressure relief valve. The insulation must also meet certain fire rating standards based upon the type of lading for which the tank was designed (49 CFR 178.338). Figure 5 illustrates an MC 338 cryogenic liquid cargo tank.

The manhole, typically located on the top or rear of the tank, must be provided with a means of entrance and exit through



Source: U.S. Department of Transportation et al. 2012

Figure 5. MC 338 cryogenic liquid cargo tank.

Table 7. Specified minimum jacket thickness of MC 338 cargo tank.

	Jacket Evacuated		Jacket Not Evacuated	
Type Metal	**Gauge**	**Inches**	**Gauge**	**Inches**
Stainless steel	18	0.0428	22	0.0269
Low carbon mild steel	12	0.0946	14	0.0677
Aluminum	–	0.1250	–	0.1000

– = not applicable

the jacket, or the jacket must be marked to indicate the manway location on the tank. Tanks designed for flammable ladings have a discharge opening located at the bottom centerline of the tank and are equipped with a closure that is leak tight at the tank's maximum allowable working pressure.

Accident damage protection for all valves, fittings, pressure relief devices, and other accessories is typically provided through a collision-resistant housing located at the rear of the tank. Additionally, pressure relief devices are protected so that they are not obstructed in the event of a collision. MC 338 cargo tanks typically have a remote means of automatic closure located at the end of the cargo tank that is furthest from the loading/unloading connection area.

The tank is typically constructed of steel alloys suited for the low-temperature environment to which the tank is subjected. The minimum thickness of the steel tank is 0.187 inches or 0.110 inches if the tank is vacuum insulated or double walled with a load-bearing jacket carrying a proportionate amount of structural loads. The minimum thickness for an aluminum tank is 0.270 inches.

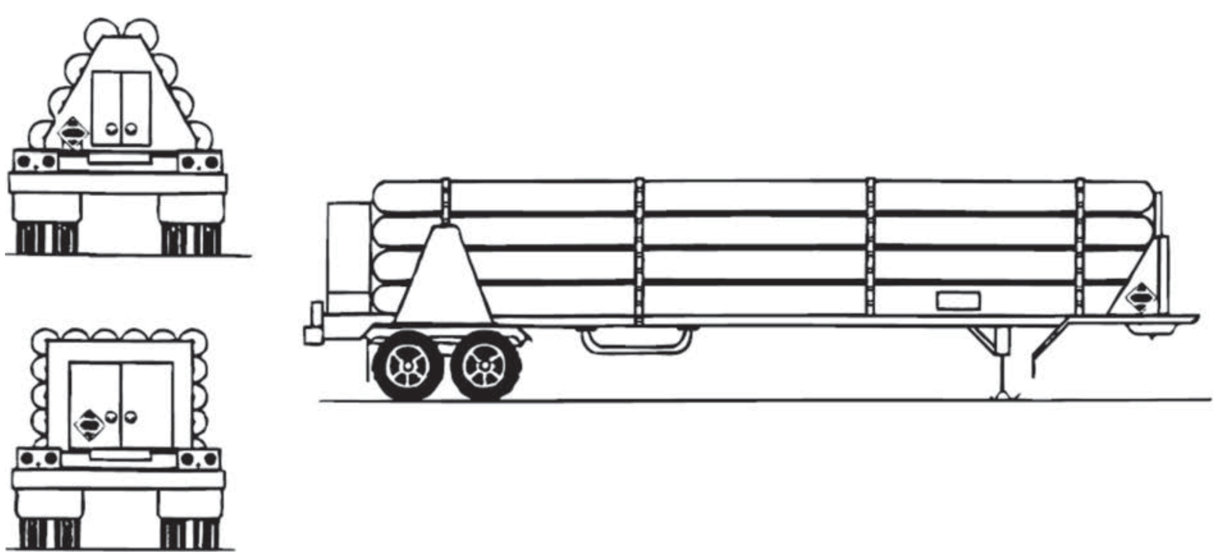
The minimum thickness requirements for the jacket are shown in Table 7.

Compressed Gas Tube Trailer

Tube trailers transport bulk non-liquefied compressed gases such as helium, hydrogen, nitrogen, and oxygen at pressures ranging between 3,000 and 5,000 psi. A group of cylinders, meeting standards outlined in 49 CFR 178.35 are stacked and banded together in a modular or nested shape. Each cylinder is constructed using a material without seams, cracks or laminations, or other defects. Figure 6 illustrates an example configuration of cylinders in a tube trailer, and Table 8 displays some properties associated with cylinders used for tube trailers.

Non-Pressurized UN Portable Tank

Non-pressurized UN portable tanks are used to transport liquid and solid hazardous materials. These tanks are designed to withstand temperatures between –40°C and 50°C (–40°F and 122°F) or greater than the maximum temperature of its lading. Tanks are generally made out of steel; however, some shells may be constructed using aluminum. Additionally, tanks may be lined with a homogeneous corrosion-resistant material that is compatible with the lading. Minimum thick-



Source: U.S. Department of Transportation et al. 2012

Figure 6. Compressed gas tube trailer.

Table 8. Specified seamless cylinder properties.

Cylinder Type	Max. Water Capacity (lb)	Cylinder Dimensions (where max. water capacity is not provided)		Min. Service Pressure (psig)	Max. Service Pressure (psig)	Material Type
		Max. Diameter (inches)	Max. Length (feet)			
3A	1,000	N/S	N/S	150	N/S	Open-Hearth or Electric Steel
3AX	1,000	N/S	N/S	500	N/S	Open-Hearth or Electric Steel
3AA	1,000	N/S	N/S	150	N/S	Open-Hearth, Basic Oxygen, or Electric Steel
3AAX	1,000	N/S	N/S	500	N/S	Open-Hearth, Basic Oxygen, or Electric Steel
3B	1,000	N/S	N/S	150	500	Open-Hearth or Electric Steel
3BN	125	N/S	N/S	150	500	Nickel
3E	N/S	2	2	N/S	1,800	Open-Hearth or Electric Steel
3HT	150	N/S	N/S	900	N/S	Open-Hearth or Electric Furnace Steel
3T	1,000	N/S	N/S	1,800	N/S	Open-Hearth, Basic Oxygen, or Electric Furnace Steel
3AL	1,000	N/S	N/S	150	N/S	Aluminum

Note: N/S = Not Specified

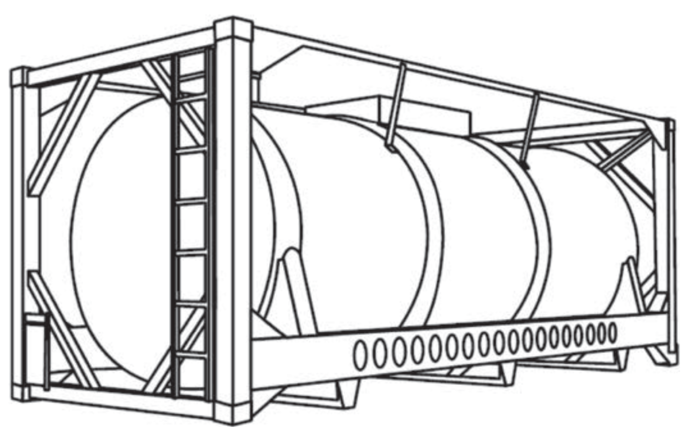
nesses are specified based on the type of material used as well as the tank diameter and are exclusive of corrosion allowance. Table 9 shows the required minimum thicknesses of non-pressurized UN portable tanks as specified in 49 CFR 178.275.

All UN portable tanks (see Figure 7) are constructed with supports that provide a secure base during transportation. Longitudinal bars may be used to provide additional lateral support. Reinforcement rings or bars fixed across the frame, an ISO frame, or an insulation jacket may be used to provide additional protection against overturning. A bumper or rear frame may also be equipped to protect against rear impacts (49 CFR 178.275).

A pressure relief device is located within the vapor space on top of the shell, near the longitudinal and transverse center. Accident damage protection is provided to ensure the pressure relief device continues to function in the event of a collision. Stop valves, or other suitable means of closure, are located close to the shell at all openings except for openings leading to venting or pressure relief devices. If the tank is insulated, a spill collection reservoir with suitable drains will surround top fittings. Bottom fittings, if provided, shall have either two or three independent shut-off valves located both close to the shell and at the end of the discharge pipe (49 CFR 178.275).

Table 9. Specified minimum thicknesses for non-pressurized UN portable tanks.

Tank Diameter	Minimum Thickness [mm (in)]	
	Reference Steel	Absolute
Up to 1.8 meters	5 (0.197)	3 (0.100)
1.8 meters and above	6 (0.200)	3 (0.100)



Source: U.S. Department of Transportation et al. 2012

Figure 7. Portable tank.

Pressurized UN Portable Tank

Pressurized UN portable tanks are used to transport non-refrigerated liquefied gases. Tanks have a circular cross-section and are made of steel with a minimum thickness of 4 millimeters (0.2 inches). If insulated, the insulation either covers between the upper third and upper half of the shell surface or completely covers the shell and is separated from the shell by an air space. Like all UN portable tanks, the tank is constructed with supports that provide a secure base during transportation. Longitudinal bars may be used to provide additional lateral support. Reinforcement rings or bars fixed across the frame, an ISO frame, or an insulation jacket may be used to provide additional protection against overturning. A bumper or rear frame may also be provided to protect against rear impacts (49 CFR 178.276).

A pressure relief device is located within the vapor space on top of the shell, near the longitudinal and transverse center. Accident damage protection is provided to ensure the pressure relief device continues to function in the event of a collision. All other openings greater than 1.5 millimeters (0.100 inches) have at least three mutually independent shut-off devices in series. Types of shut-off devices can include stop valves, excess flow valves, integral excess flow valves, external stop valves, blank flanges, thread caps, and plugs (49 CFR 178.276).

Cryogenic UN Portable Tank

Cryogenic UN portable tanks are used to transport refrigerated liquefied gases. The tank is constructed of steel and designed to hold at least 450 liters (118.9 gallons). Consisting of an inner shell enclosed in a jacket, the tank is insulated by either an intermediate layer of solid, thermally insulating material or by vacuum (49 CFR 178.277).

Like all UN portable tanks, the tank is constructed with supports that provide a secure base during transportation. Longitudinal bars may be used to provide additional lateral support. Reinforcement rings or bars fixed across the frame, an ISO frame, or an insulation jacket may be used to provide additional protection against overturning. A bumper or rear frame may also be provided to protect against rear impacts. All filling and discharge openings have at least two mutually independent stop valves and one blank flange or equivalent device in series. Two independent reclosing pressure relief devices are provided for every shell. Pressure relief devices are designed to resist dynamic forces and to open automatically when pressures exceed the maximum allowable working pressure by 10% (49 CFR 178.277).

Cargo Tank Motor Vehicle Assembly and Repair

Besides container design specifications, industry practices may influence the performance of cargo tanks in an accident scenario. To understand this aspect further, information was obtained from the FMCSA report entitled *Guidelines for the Operation, Assembly, Repair, Testing, and Inspection of Hazardous Material Cargo Tanks* (Bowman et al. 2009). The report identifies factors that affect the service life of a cargo tank based on industry comments, regulatory documents, and professional organizations' guidance. The report also provides recommendations to minimize the effects of those factors, thus extending the service life of a cargo tank. Industry input was gathered through direct observation, interviews, and focus groups. These focus groups consisted of 63 administrators and maintenance/inspection personnel from (1) commercial fleets carrying hazardous materials and (2) certified inspection/repair facilities. Industry comments were then supplemented with recommended procedures from industry-related associations and engineering societies, resulting in a list of industry-recommended practices.

The following sections discuss the report in more detail and provide further information on cargo tank motor vehicle assembly and repair.

Cargo Tank Assembly

The following three types of frames to which cargo tanks may be mounted are identified by Bowman et al. (2009):

- A full-sized semi-trailer frame.
- A front, fifth-wheel mounting frame and a rear wheel mounting frame or bogie (used when the cargo tank serves as the load-bearing structure).
- A straight truck chassis or "bobtail" (used when the cargo tank serves as the load-bearing structure).

Bowman et al. (2009) recommend that the following attachments be examined for material compatibility in order to avoid galvanic corrosion:

- Supports designed to prevent excessive localized stresses.
- Round, oval, or rectangular reinforcing plates used between a support or the chassis and the tank.
- Saddles extending over at least one-third of the circumference.
- Stiffening rings.
- Longitudinal stringers at the top of the tank.
- Gussets.

Bowman et al. (2009) also provide a review of the installation guidelines for manhole assemblies, accident damage protection, pressure relief valves, tank outlets, and gauges for DOT 406/407 and 412 specification cargo tanks and for MC 330 and MC 331 specification cargo tanks. Information is also provided concerning emergency discharge control equipment, engine fuel lines, liquid level gauging devices, pumps and compressors, and the installation of linings and coatings.

Cargo Tank Repair

Bowman et al. (2009) provide recommended practices for the repair of cargo tanks based on existing regulations, codes, and standards. The report also provides recommendations for the following conditions requiring repair:

- **Corrosion.** It is recommended that operators be aware of corrosion and that a corrosion mitigation plan be developed that establishes the process for determining the type of corrosion and the proper repair procedures needed for that type. If the wall thickness has not been compromised, pitting corrosion, line corrosion, and general corrosion can be repaired using a weld overlay. Otherwise, the repair will consist of a flush patch. Galvanic corrosion is mitigated by eliminating the cause or by removing the incompatible material. Other types of corrosion include erosion/corrosion, crevice corrosion, and passivation.
- **Weld defects.** It is recommended that welding quality control policies and procedures be established that not only ensure that consistent welding techniques are used by all company personnel but also identify all weld defects and the procedures for rectifying such defects before placing cargo tanks back into service. Weld cracking, undercutting, excessive reinforcement, insufficient reinforcement, and incomplete fusion are some examples of weld defects.
- **Cargo tank distortion.** Flush patch repair is required if dents with a weld exceed 0.5 inches or if dents without a weld exceed 1 inch or a depth greater than one-tenth of the greatest dimension of the dent. Gouges may be repaired by blending and re-evaluated for service.
- **Cracking.** It is recommended that policies for identifying and correcting material cracking be established. Recommended policies should include properly trained personnel and proper procedures. Types of cracking include fatigue cracks, structural overload, non-ductile fracture, stress-corrosion cracking, transgranular stress, and hydrogen embrittlement.
- **Bulkhead and baffle defects.** It is recommended that bulkheads and baffles be attached and joined appropriately to ensure structural integrity. Bowman et al. (2009) indicate that there are two forms of construction: fillet welding the flange of the baffle to the shell and welding the edge of the baffle without a flange directly to the shell. Using flanged construction is more desirable.
- **Omitted or undersized welding pads.** It is recommended welding pads be used appropriately to prevent cargo tank shell defects. Bowman et al. (2009) indicate that omitting or using undersized pads is a major contributor to defects in attachment of shell to frame, rollover-protection devices, or rear-end structures.

Bowman et al. (2009) anticipated the current regulation that requires National Board certification of facilities and inspectors involved in the certification of repairs to cargo tanks. Individuals with National Board Inspection Code certification are ideal candidates for providing information as to the location and extent of damage sustained by the lading retention system of vehicles involved in accidents.

Container Performance Studies

Container performance studies were reviewed to determine how existing crash data have been used in past studies. For highway cargo tanks, a number of analyses have been performed to evaluate the performance of front heads and container performance in rollover scenarios. Key factors required to perform similar statistical analyses of container performance are identified.

In *Safety Performance of Tank Cars in Accidents: Probabilities of Lading Loss* (Treichel et al. 2006), the safety performance of tank cars in accidents is analyzed using multivariate logistic regression to examine the probability of lading loss from railway tank cars involved in accidents. The underlying database, the RSI-AAR TCAD, is the result of long-term industry effort to record detailed tank car accident damage information. Treichel et al. (2006) determined which cars should be included in their analysis by detailing inclusion criteria that would ensure that the probability estimates developed would be relevant and resulting container performance comparisons meaningful. The variables considered in the regression analysis include pressure car versus non-pressure car, head thickness, head shield type, shell thickness, presence of a jacket, presence of shelf couplers, presence of bottom fittings, presence of bottom fitting protection, and location of accident (yard versus mainline). Variables were evaluated to determine whether they had a significant effect on the probability of lading loss, and a coefficient was developed for each significant factor. Using these coefficients, regression equations to calculate the conditional probability of release were determined for specific tank car components, namely the head, shell, and top and bottom fittings.

Improving Crashworthiness of Front Heads of MC-331 Cargo Tank Motor Vehicles (Selz and Heberling 2000) evaluates design alternatives to improve MC 331 cargo tank head crashworthiness. Selz and Heberling (2000) used drop tests to develop a computer model capable of predicting deformations and rupture of a cargo tank. The model was refined using data from an accident that occurred in White Plains, New York, in 1994. Two additional accidents were selected for similar analysis; however, the accident reports lacked sufficient data. Elements of the accident report that were required to develop an analytical correlation included the following:

- Speed of the trailer.
- Characteristics of the object struck (i.e., shear capacity and weight of portion sheared).

- Combined weight of the vehicle and cargo.
- Response of the cargo tank to the crash (i.e., amount of deformation and size of rupture).

The model enabled prediction of the interaction of steel, propane, foam, and roadway structures in a crash scenario. Several possible head configurations were tested including bare head design, incorporation of a secondary head, and incorporation of energy-absorbing material between two heads. The model indicated that the bare head design would not be able to withstand an impact above 30 miles per hour. The secondary head increased the crashworthiness of the tank except in the most severe crash scenarios. The addition of energy-absorbing material (foam) between the primary and secondary heads further improved the crashworthiness of the container.

The critical velocity of a train part striking the head of a European liquefied petroleum gas (LPG) railway tank car is calculated in *LPG Rail Tank Cars Under Head-On Collisions* (Lupker 1990). The analysis used scaled models and finite difference calculations to show that non-symmetrical deformation begins to occur when the deformation is one order of magnitude greater than the shell thickness. The analytical approach used indicated that indentations greater than 30 times the shell thickness would result in penetration of the tank car.

Cargo Tank Roll Stability Study (Pape et al. 2007) features an analysis of the factors causing cargo tank rollover events through a review of 966 rollover accident records from the MCMIS, 89 cargo tank accident records from the Large Truck Crash Causation Study (LTCCS), 1,837 cargo tank accident records from the TIFA database, and 197 rollover crashes from the GES databases. Using the information obtained from these databases, the following four complementary approaches to reducing the incidence of cargo tank rollovers were evaluated:

- Improved driver training.
- Electronic stability aids.
- Modified vehicle designs to increase vehicle stability.
- Modified highway design.

The following factors were identified in various databases as providing a contributing cause to rollover events:

- Crosscutting factors including the primary reason or critical event and the pre-crash event or maneuver.
- Vehicle factors including the body type, hazardous material involvement, load, mechanical problems, and cargo tank specification.
- Roadway and environment factors including road type, population area, roadway surface condition, roadway curvature, and location relative to an interchange.
- Driver factors including driver age, vehicle speed, and driver errors or distractions.

The analysis resulted in some unexpected findings. Namely, the majority of truck rollover crashes involved a single vehicle in dry pavement conditions and were due to driver error. Speeding, presence of an interchange, and truck configuration had little significance on causality. Pape et al. (2007) recommended the use of driving simulators to train drivers on how to avoid pre-rollover events, electronic stability aids to ensure proper speeds on curves, lower center of gravity vehicle designs, and proper signage where unusual curves, grades, or traffic patterns exist.

In *The Dynamics of Tank-Vehicle Rollover and the Implications for Rollover-Protection Devices* (Winkler et al. 1998), two tank truck and five combination vehicle (tractor and semi-trailer) rollover computer simulations are developed. The simulations were intended to calculate the range of initial conditions of input for three scenarios:

- The vehicle falls on its side and engages the rollover-protection devices.
- The vehicle becomes airborne and the rollover-protection devices directly impact the ground at a speed of 6 to 18 feet per second and up to 30 feet per second in severe cases.
- The vehicle lands on its side and slides into a vertical barrier oriented parallel to the roadway.

In particular, the following maneuvers were tested:

- Intersection turn where the vehicle attempts to follow a 100-foot radius curve at speeds ranging between 20 and 55 miles per hour.
- Highway/exit ramp turn where the vehicle attempts to follow a 500-foot radius curve at speeds between 50 and 70 miles per hour.
- Curb-strike maneuver where the vehicle strikes a 6-inch curb while attempting to travel in a 500-foot radius curve between 35 and 55 miles per hour. Various angles of impact between 5 and 30 degrees were tested.
- Guardrail-strike maneuver similar to curb-strike but occurring when a vehicle strikes a guardrail 16 to 36 inches above the ground.
- Spiral turn where the steering wheel angle is increased at a rate of 2 degrees per second while traveling at 40 miles per hour.
- High-speed avoidance maneuver where the vehicle, traveling at 50 miles per hour, turns slightly to the right and severely overcorrects left.
- Step-turns where the steering wheel is “cranked” to a predetermined angle while traveling at speeds between 30 and 70 miles per hour.

The simulations identified several dynamic parameters present in rollover scenarios including roll, pitch, and yaw attitude upon ground strike and vertical, lateral, and roll impact velocity.

The computer simulation indicated that a load 400 times the weight of the vehicle results from an input velocity of 24 feet per second (16.4 miles per hour) striking the ground at an angle between 10 and 15 degrees and having a crush allowance of 1 foot. As the impact force results in high-profile, bulky rollover-protection measures, the authors indicate that tank designs allowing more tank deformation may be desirable. Winkler et al. (1998) provided two alternatives to achieving increased deformation: increasing the allowable deformation of the tank (i.e., when the strength of protective devices exceeds the strength of the tank) or increasing the allowable deformation of the accident protection devices. In all designs, the focus should be on energy dissipation that is ideally achieved through a constant crush force. Existing and modified rollover-protection devices, such as various staple designs or flat rail designs with a variety of dams, were analyzed. Results indicated that designs such as staple designs typically result in higher crush forces and are less able to support these forces because of their geometry.

In *Full-Scale Rollover Testing of Commercial Cargo-Tank Vehicles* (Winkler 2009), single unit cargo tank trucks and combination cargo tank vehicles (tractor-semi-tanker) were analyzed to determine crashworthiness of the cargo tank and verify the results of a previous simulation study (Winkler et al. 1998). The purpose of the experiment was to determine the attitude and velocities at the moment of impact rather than the amount of damage sustained by the lading retention system. Since the single unit vehicle was being tested multiple times in progressively more severe maneuvers, the cab was equipped with close-fitting roll bars. On the other hand, no additional rollover protection was used on the combination vehicle as it was only being tested once in a very severe maneuver. Total mass and static rollover threshold were determined for both vehicles. Initial vehicle speeds of the single unit vehicle prior to the critical movement ranged from 49.9 kilometers per hour (31 miles per hour) to 80.6 kilometers per hour (50.1 miles per hour) for all tests resulting in a rollover. The combination vehicle was tested at 73.4 kilometers per hour (45.6 miles per hour) and, as is typical of rollover maneuvers, the trailer rolled prior to the tractor cab. Winkler (2009) attributes the rolling of the trailer prior to the tractor cab to the low center of gravity and torsion-compliant design of the tractor and also indicates that the trailer had rolled 104 degrees by the time it struck the ground because of the narrow MC 312 profile and heavy-side tires. The amount of deformation sustained by the trailer or truck, as well as the potential for lading loss, was not reported.

Cargo Tank Accident Investigations

Accident investigations were also reviewed to identify key factors for inclusion in a database enabling statistical analyses of container performance. The following sources represent serious, relatively unique accidents that could have been avoided. Similar accidents should be easily identified by the proposed database.

In *Safety Advisory: Chlorine Transfer Hose Failure* (U.S. Chemical Safety and Hazard Investigation Board 2002) an incident occurring on August 14, 2002, in which a chlorine railcar transfer hose ruptured catastrophically and released 48,000 pounds of chlorine into nearby areas was reviewed. The U.S. Chemical Safety and Hazard Investigation Board determined that the hose was made of an incorrect material and issued a Safety Advisory recommending that chlorine handlers using non-metallic-lined chlorine transfer hoses ensure that these hoses are constructed with the appropriate structural braiding layer.

"Collision of Cargo Tank Truck and Automobile and Subsequent Fire, Upper Pittsgrove Township, New Jersey, July 1, 2009," an NTSB *Hazardous Materials Accident Brief* (2009), documented the investigation of the collision of an MC 306 cargo tank semi-trailer and an automobile in which the automobile became wedged beneath the cargo tank truck and was dragged about 500 feet. As a result of the crash, loading line four was ruptured. Because the cargo tank's loading lines contained gasoline, about 13 gallons were released and ignited. Similar accidents had occurred in Yonkers, New York, on October 9, 1997, and in Wilmington, Delaware, on February 15, 1998. The NTSB recommended that carrying of hazardous materials in cargo tank external piping should be prohibited.

Another *Hazardous Materials Accident Brief,* "Release of Hazardous Materials from Cargo Tank, Middletown, Ohio, August 22, 2003" (NTSB 2004), documented the investigation of an MC 331 cargo tank in which the front head cracked open while the cargo tank was being loaded, releasing anhydrous ammonia, a poisonous and corrosive gas. The cargo tank head had a 16-inch-long, through-wall crack next to the radial weld as well as two other cracks that did not lead to lading loss. The cracks formed as a result of stress-corrosion cracking occurring when carbon steel, in the presence of a caustic material, is exposed to tensile stresses. It is recommended that anhydrous ammonia containing less than 0.2 percent water by weight should not be loaded into cargo tanks manufactured of quenched and tempered steel (marked QT).

In the *Hazardous Materials Accident Brief* titled "Catastrophic Structural Failure of MC-307 Cargo Tank, South Charleston, WV, January 5, 2002" (NTSB 2003), the investigation of a catastrophic structural failure between the front and center tanks of an MC 307 cargo tank consisting of three independent but connected tanks was documented. The incident resulted in the closure of an intersection for 7 hours, and, although no hazardous materials were released, the total cost of damage, clean-up, and lost revenues was estimated to be $18,000. The catastrophic structural failure was determined to be the result of extensive corrosion. It was recommended that all similar tanks be inspected for corrosion and that inspection continue to occur periodically.

Industry Knowledge and Opinion

A successful accident damage database requires the collection of relevant information at minimal cost and with full cooperation or participation from the key industry stakeholders including package manufacturers, carriers, shippers, and repair facilities. Several companies from each stakeholder group were visited and interviewed to determine what information is currently recorded regarding bulk package design and/or accident damage.

Through these stakeholder interviews, it was ascertained that, due to the large differences in bulk package use and accident performance associated with different specification containers, a process to engage a larger number of stakeholders was required. Therefore, a set of stakeholder surveys were developed and distributed. This distribution occurred, where possible, through respective stakeholder industry associations. Stakeholders who were not members or affiliates of industry associations received individual survey invitations.

The following sections describe the survey process and information collected regarding the current use of accident damage protection and accident prevention measures, tank parts and appurtenances of interest, and proposed accident data fields.

Site Visits

The research team visited a single-stage manufacturing facility (Facility A), a final-stage manufacturing and repair facility (Facility B), and a repair facility (Facility C) to achieve the following objectives:

- Learn about design, manufacturing, and repair processes that are unique to cargo tank trailers and cargo tank motor vehicles.
- Identify additional data fields that should be considered for inclusion in a possible accident damage database.

Budget constraints prevented visits to facilities for ISO/UN portable tanks, as they tend to be located outside of the United States. The following subsections summarize what was learned at each site.

Facility A—Single-Stage Manufacturer

Facility A is a single-stage trailer manufacturing facility in which the tank is manufactured and mounted on a truck chassis or trailer frame. Facility A produces an average of 7,000 tanks per year (over the past 30 years) of which approximately three-quarters are DOT 406 containers. For each tank produced, this facility records the following information in a regularly maintained database:

- Tank identification number.
- Original owner.
- Date of manufacture.
- Design type.
- Model.
- Total trailer capacity.
- Gross axle weight.
- Number of axles.
- Number of compartments.
- Compartment size.
- Number of bulkheads.
- Load corresponding to compartment size.

Additionally, certificates of compliance are kept on file and drawings for each model have been retained for the past 50 years. Therefore, design information is still available for most tanks manufactured by this supplier that continue to be operated.

The representatives at Facility A are proponents of improving the roll stability of their trailers by including a trailer-mounted roll stability control (RSC) system and mounting the tanks on a "wide-track" where dual wheels are spaced at 77.5 inches, as opposed to "narrow track" where dual wheels are spaced at 71.5 inches. Representatives at Facility A indicated that these two measures are among the most influential measures for reducing rollovers; however, these measures are often difficult to implement for two reasons:

- Some states do not allow wide-track trailers.
- Insurance companies do not provide reduced premium incentives for roll stability devices; therefore, it is difficult to convince tank owners to incur the extra cost of installation of these systems.

Facility A representatives indicated that Form DOT F 5800.1 would be useful; however, it is their belief that the reported data are neither accurate nor complete. Furthermore, the form is not capable of identifying whether the tank itself ruptured or whether lading loss occurred solely because of non-accident causes such as closures that have not been properly secured. It was suggested that an accident damage database would benefit from the inclusion of basic information recorded on the name plate and specification plate affixed to each tank as well as the following information:

- Length of the trailer and all containers.
- Length and dimensions of the ruptured tank.
- Location of the ruptured tank (within the trailer).
- Shape of the tank (round or oval).
- Gross vehicle weight.

Additionally, this facility suggested that design breakthroughs or regulatory accommodations are needed to offset the weight of damage prevention measures. Unless weight-offsetting measures are identified and implemented, the managers at Facility A concluded that additional strategies would not be voluntarily adopted because of the difficulty in simultaneously increasing state weight limits.

Facility B—Final-Stage Manufacturing and Repair Facility

Facility B is a final-stage manufacturing and repair facility that focuses on the assembly, repair, and inspection of truck-mounted atmospheric and low-pressure aluminum bulk packages. Testing includes annual and 5-year inspections as well as biannual ultrasonic thickness testing at approximately 160 points around the bulkhead and in areas that have high stresses (structural areas). Facility B includes top safety performance in their goals, provides expertise at the scene of hazardous materials tank truck crashes, and trains DOT officers in techniques for investigating crash sites.

Facility B representatives identified two main causes of lading loss:

- Rollover accidents in which the structural support for the tank influences whether or not lading loss occurs. Tanks lacking an underbelly structure often twist in rollover accidents. When this occurs, the bulkheads are typically torn at the seams, resulting in a leak that fills the void space between bulkheads (if there are multiple compartments in a tank). The product then fills the void space and exits the tank through specification vents.
- Accidents involving another vehicle in which incorrectly repaired piping is compromised. Facility B representatives indicated that they have noticed piping repairs performed by other repair facilities in which a crack that initiated in the shear plane has been welded closed. The shear plane is designed to allow appurtenances such as external piping to break free so that the tank is not compromised in an accident scenario. This means that welding near the shear plane may result in rupture of the bulk package if it is involved in an accident.

Additionally, when fatigue cracks develop in the shell, such as what might occur around support appendages, the influence of repair, maintenance, and qualification practices on the performance of cargo tanks that are later involved in crashes deserves more analysis.

In addition to examining tank maintenance practices and structural integrity histories in an accident damage database, Facility B representatives indicated that it would be useful to include the year the trailer was manufactured as well as whether the vehicle was equipped with RSC.

Facility C—Repair Facility

Facility C is part of a national chain of repair facilities that primarily conduct inspections and scheduled maintenance on atmospheric pressure (MC 306 and DOT 406), low-pressure chemical (MC 307 and DOT 407), corrosive material (MC 312 and DOT 412), and liquefied high-pressure gas (MC 331) bulk packages. Of the tanks inspected at this facility, it was reported that approximately 30 percent are cracked (typically around dolly legs or the rear bulkhead) or leaking (typically in pipes that are clamped together as opposed to one-piece bent piping). Facility C's representative indicated that even MC 331 bulk packages are susceptible to structural discrepancies (such as corrosion in the shell) that may make the shell less able to withstand a crash.

Facility C repairs tanks that have been involved in an accident approximately once a month. Accident damage is typically in the form of either dents in the tank shell or piping that has sheared away from the bulk package.

Facility C representatives indicated that the only information they would be interested in obtaining from a database is information regarding who had performed a previous repair. Furthermore, although inspection forms are filled out on a computer, the facility maintains only hard copies of repair information and would prefer faxing information pertaining to a possible accident damage database in the future (particularly if participation was voluntary).

Surveys

Due to the potential differences in the use of bulk package accident performance data, five surveys, targeting package manufacturers, carriers, shippers, repair facilities, and researchers, were developed. One of the objectives of the surveys was to gain insight on what information different stakeholders believed would be most useful in an accident damage database. Questions were tailored to draw on each survey group's industry expertise. Copies of the surveys, as well as an explanation of the survey questions, can be found in Appendix A.

Table 10. Survey response rates.

Stakeholders	Estimated Number of People Surveyed	Number of Responses Received	Approximate Response Rate
Manufacturers	20	3	15%
Repair Facilities	70	8	11%
Carriers	360	29	8%
Shippers	32	7	22%
Researchers	38	8	21%

As part of the survey process, the following industry organizations were asked to encourage their members to participate by filling out a survey:

- Truck Trailer Manufacturers Association (TTMA).
- International Tank Container Organization (ITCO).
- National Tank Truck Carriers Inc. (NTTC).
- American Chemistry Council (ACC).
- American Petroleum Institute (API).
- Compressed Gas Association (CGA).
- American Trucking Associations (ATA).
- American Transportation Research Institute (ATRI).

Response Rates

The response rates for the surveys (see Table 10) were on par with response rates of previous industry surveys. Since the number of responses is considered a small sample size (less than 30), generalization of responses to a particular stakeholder group may include biases that are unable to be detected. However, by pooling survey responses together, industry preferences may be accurately portrayed.

Demographics of Survey Responders

Survey responders were asked several demographic questions in order to be able to relate their opinions to the opinions of other stakeholder groups. Two of the manufacturers were single-stage manufacturers while one was an incomplete vehicle manufacturer. They mostly manufactured trailer-mounted tanks although some MC 306/DOT 406 and MC 331 tanks were truck-mounted. Similarly, the majority of repair facilities repair trailer-mounted bulk packages with the exception of two facilities that repair mostly truck-mounted bulk packages.

The number of survey respondents manufacturing, repairing, or using different bulk packages, as shown in Tables 11 through 17, show that with the exception of the manufacture of cryogenic liquid cargo tanks (MC 338) and compressed gas tube trailers, most types of U.S. DOT-specification bulk packages are represented to some degree by survey responses. In contrast, Table 19 shows that the portable tank industry is underrepresented by survey responses. Furthermore, survey responses convey opinions of portions of the industry working with other types of tanks including non-specification tanks used for combustible materials (see Table 18), food grade packages, and vacuum packages (see Table 20). Comparing Tables 11 through 20, the top three bulk packages used by the carrier survey respondents are low-pressure cargo tanks (built to MC 307 or DOT 407 specifications), atmospheric pressure cargo tanks (built to MC 306 or DOT 406 specifications) and corrosive cargo tanks (built to MC 312 or DOT 412 specifications). The top three bulk packages used by the shipper survey respondents are low-pressure cargo tanks (built to MC 307 or DOT 407 specifications), corrosive cargo tanks (built to MC 312 or DOT 412 specifications), high-pressure gas cargo tanks (built to MC 331 specifications), and pressurized UN portable tanks.

Table 11. Number of respondents working with atmospheric pressure cargo tanks (MC 306 or DOT 406).

Stakeholder	Number of Stakeholder Companies	% of Stakeholder Respondents	Quantity of Tanks per Year
Bulk Tank Manufacturers	2	67%	100–1,000
Repair Facilities	5	63%	1–199 (< 50% damaged in accidents)
	1	13%	200–499 (< 25% damaged in accidents)
	1	13%	> 1,000 (< 25% damaged in accidents)
Carriers	17	59%	
Shippers	2	29%	

A blank cell indicates that the field is not applicable.

Table 12. Number of respondents working with low-pressure cargo tanks (MC 307 or DOT 407).

Stakeholder	Number of Stakeholder Companies	% of Stakeholder Respondents	Quantity of Tanks per Year
Bulk Tank Manufacturers	2	67%	100–1,000
Repair Facilities	4	50%	1–199 (< 25% damaged in accidents)
	1	13%	500–1,000 (< 25% damaged in accidents)
	1	13%	> 1,000 (< 25% damaged in accidents)
Carriers	23	79%	
Shippers	5	71%	

A blank cell indicates that the field is not applicable.

Table 13. Number of respondents working with corrosive cargo tanks (MC 312 or DOT 412).

Stakeholder	Number of Stakeholder Companies	% of Stakeholder Respondents	Quantity of Tanks per Year
Bulk Tank Manufacturers	2	67%	10–99
Repair Facilities	4	50%	1–199 (< 25% damaged in accidents)
	1	13%	200–499 (< 25% damaged in accidents)
Carriers	15	52%	
Shippers	5	71%	

A blank cell indicates that the field is not applicable.

Table 14. Number of respondents working with high-pressure gas cargo tanks (MC 331).

Stakeholder	Number of Stakeholder Companies	% of Stakeholder Respondents	Quantity of Tanks per Year
Bulk Tank Manufacturers	1	33%	10–99
Repair Facilities	4	50%	1–199 (< 25% damaged in accidents)
Carriers	9	31%	
Shippers	5	71%	

A blank cell indicates that the field is not applicable.

Table 15. Number of respondents working with cryogenic liquid cargo tanks (MC 338).

Stakeholder	Number of Stakeholder Companies	% of Stakeholder Respondents	Quantity of Tanks per Year
Bulk Tank Manufacturers	0	0%	
Repair Facilities	2	25%	1–199 (< 25% damaged in accidents)
Carriers	3	10%	
Shippers	2	29%	

A blank cell indicates that the field is not applicable.

Table 16. Number of respondents working with asphalt cargo tanks.

Stakeholder	Number of Stakeholder Companies	% of Stakeholder Respondents	Quantity of Tanks per Year
Bulk Tank Manufacturers	1	33%	10–99
	1	33%	100–1,000
Repair Facilities	1	13%	1–199 (< 25% damaged in accidents)
	1	13%	200–499 (< 25% damaged in accidents)
Carriers	3	10%	
Shippers	0	0%	

A blank cell indicates that the field is not applicable.

Table 17. Number of respondents working with compressed gas tube trailers.

Stakeholder	Number of Stakeholder Companies	% of Stakeholder Respondents	Quantity of Tanks per Year
Bulk Tank Manufacturers	0	0%	
Repair Facilities	2	25%	1–199
Carriers	3	10%	
Shippers	3	43%	

A blank cell indicates that the field is not applicable.

Table 18. Number of respondents working with non-specification tanks for combustible materials.

Stakeholder	Number of Stakeholder Companies	% of Stakeholder Respondents	Quantity of Tanks per Year
Bulk Tank Manufacturers	2	67%	10–99
Repair Facilities	0	0%	1–199 (< 25% damaged in accidents)
Carriers	5	17%	
Shippers	0	0%	

A blank cell indicates that the field is not applicable.

Table 19. Number of respondents working with portable tanks.

Stakeholder	Number of Stakeholder Companies	% of Stakeholder Respondents	Type of Portable Tank
Bulk Tank Manufacturers	0	0%	
Repair Facilities	0	0%	
Carriers	1	10%	Pressurized UN Portable Tank
	1	10%	Cryogenic UN Portable Tank
Shippers	3	43%	Non-Pressurized UN Portable Tank
	4	57%	Pressurized UN Portable Tank
	2	29%	Cryogenic UN Portable Tank

A blank cell indicates that the field is not applicable.

Table 20. Number of respondents working with other types of bulk packages.

Stakeholder	Number of Stakeholder Companies	% of Stakeholder Respondents	Package Type	Quantity of Tanks Per Year
Bulk Tank Manufacturers	1	33%	Food Grade Package	> 1,000
	1	33%	Vacuum Package	100–1,000
Repair Facilities	0	0%		
Carriers	4	14%	Other	
Shippers	1	14%	Other	

A blank cell indicates that the field is not applicable.

Chemical/petroleum carriers were also asked questions concerning the number of trips made per year. In general, there was a wide range in the reported number of bulk tank deliveries of hazardous materials made per year. Four carriers make between 100 and 999 deliveries per year, eleven make between 1,000 and 9,999 deliveries per year, five reported making between 10,000 and 50,000 deliveries per year, and nine reported making over 50,000 deliveries per year. The seven shipper respondents represented shipping operations of various sizes. The majority of shipper respondents reported that their companies made between 10,000 and 50,000 highway shipments of hazardous materials using bulk tanks in North America, while one shipper reported making between 1,000 and 9,999 shipments, and two others reported making over 50,000 shipments. The types of hazardous materials shipped by these companies represent all classes of materials.

Table 21 illustrates the hazardous material classes transported by 29 carriers and 7 shippers. The majority of carriers who responded to the survey transport materials classified as Class 3—flammable and/or combustible liquids (transported by 90% of respondents); Class 8—corrosive substances (transported by 83% of respondents); and Class 9—miscellaneous hazardous materials/products, substances, or organisms (transported by 72% of respondents).

Table 21. Hazardous material classes transported by respondents to carrier and shipper surveys.

Hazardous Material Class	Number of Carriers	% of Carrier Respondents	Number of Shippers	% of Shipper Respondents
Class 2	23	79%	5	71%
Division 2.1 – Flammable gases	9	31%	3	43%
Division 2.2 – Non-flammable, non-toxic gases	11	38%	4	57%
Division 2.3 – Toxic gases	3	10%	3	43%
Class 3 – Flammable liquids (and combustible liquids)	26	90%	4	57%
Class 4	3	10%	4	57%
Division 4.1 – Flammable solids	0	0%	0	0%
Division 4.2 – Spontaneously combustible materials	2	7%	2	29%
Division 4.3 – Water-reactive substances/dangerous when wet materials	1	3%	4	57%
Class 5	13	45%	1	14%
Division 5.1 – Oxidizing substances	10	34%	1	14%
Division 5.2 – Organic peroxides	3	10%	1	14%
Class 6	13	45%	2	29%
Division 6.1 – Toxic substances	13	45%	2	29%
Division 6.2 – Infectious substances	0	0%	0	0%
Class 8 – Corrosive substances	24	83%	5	71%
Class 9 – Miscellaneous hazardous materials/products, substances, or organisms	21	72%	3	43%

Note: More than one class of material may be hauled by carriers or shipped by chemical/petroleum shippers.

Table 22. Bulk package ownership (as reported by carrier respondents).

	Ownership Split		
Number of Respondents	**% Carrier Owned**	**% Shipper Owned**	**% Lessor Owned**
10	100%	0%	0%
11	80% – 99%	0 – 19%	0%
3	80% – 99%	0%	0 – 19%
2	60% – 79%	20% – 39%	0%
1	0% – 19%	80% – 99%	0%
1	0% – 19%	0%	80% – 99%
1	0%	0%	100%

Furthermore, both carrier and shipper respondents agree that the majority of the bulk packages are owned by carriers, a sizable number of bulk packages are owned by shippers, and a few are owned by lessors (see Tables 22 and 23).

Hazardous material bulk package researchers were also asked a series of demographic questions. The primary topics of the respondents' research included risk analysis of hazardous materials transportation by alternate modes (including rail and waterways), risk assessment of the safety of hazardous materials transportation, and bulk package performance research (including procedures to determine package integrity; examination of tank behavior; and manufacturing characteristics that affect tank integrity and the dynamic safety of tank trucks, tank design, baffles design, and anti-slosh). Related bulk package research involving the respondents included the following:

- All aspects of cargo tank performance.
- The relationship between accident environments and cargo environments or how the conveyance protects the cargo from severe accidents.
- The effect of infrastructure quality on accident probability.
- Accident likelihood.
- Consequences given that an accident has occurred.
- Rollover, stability, and control.
- Bulk package risk assessment.

Researcher experience ranged from 3 years to 35 years, with a median of 20 years. Only one of the researcher survey respondents was employed by an organization that maintained data regarding cargo tank accident performance measures. Additionally, to relate hazardous material researchers' responses to other stakeholder groups, researchers were asked to indicate which types of bulk tanks they are most interested in. Figure 8 illustrates the reported interests of the hazardous materials researcher groups.

Types of Accident Damage Protection and Accident Prevention Measures Implemented

Manufacturers, carriers, and shippers were asked questions concerning the implementation of accident damage protection and accident prevention measures to gauge the types of strategies currently adopted by the industry and also to determine who might be key motivators in adopting future strategies. A summary of the survey results is provided in Table 24.

From the manufacturers that replied to the survey, the incorporation of accident damage protection measures beyond federal standards into standard tank designs is not a generally adopted practice in the bulk package manufacturing industry. There was one response for each of "never," "occasionally—only at the request of our customers," and "usually—a standard

Table 23. Bulk package ownership (as reported by shipper respondents).

	Ownership Split		
Number of Respondents	**% Carrier**	**% Shipper**	**% Lessor**
1	100%	0%	0%
1	80%–99%	0%–19%	0%
1	60%–79%	20%–39%	0%–19%
1	60%	40%	0%
1	40%	60%	0%
1	20%–39%	60%–79%	20%–39%
1	0%	100%	0%

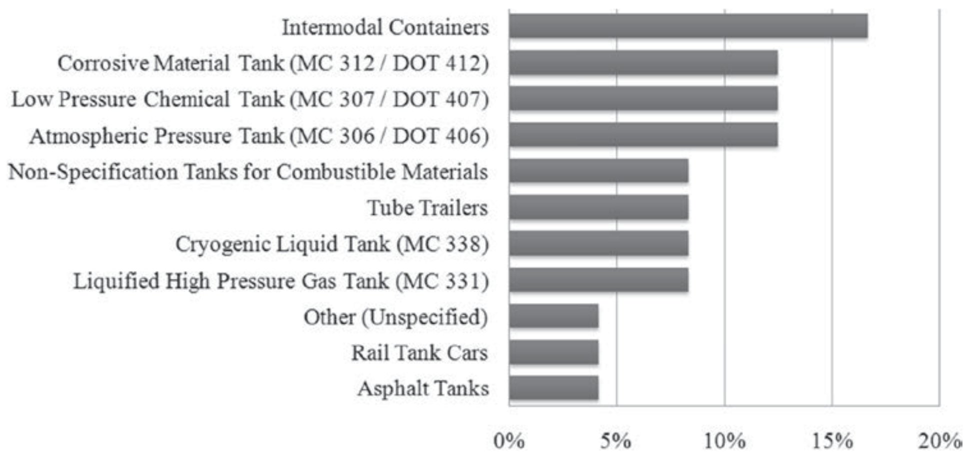


Figure 8. Researcher interest in specific bulk packages.

feature on our bulk tanks" for the following accident damage protection measures:

- Fitting protection beyond federal standards.
- Additional shell protection.
- Increased tank wall thickness.

The accident prevention measures that have been incorporated into standard tank design by at least one manufacturer include lowered center of gravity, electronic stability control or trailer-mounted RSC, and truck conspicuity and enhanced lighting/signaling beyond what is required by regulation. The other accident measures included in the survey (wider wheel

Table 24. Number of companies (by stakeholder group) that have incorporated accident damage protection and prevention measures beyond federal standards.

	Bulk Package Manufacturers	Carriers	Shippers
No additional measures specified	1	8	1
Accident damage protection measures			
Fittings protection beyond federal standards	2	8	2
Additional shell protection	2	1	0
Increased tank wall thickness	2	5	1
Other	0	2	5
Accident prevention measures			
Lowered center of gravity	1	10	3
Wider wheel-base	2	8	2
Electronic stability control	2	13	1
Truck-mounted RSC	2	13	2
Trailer-mounted RSC	2	12	3
Improved brakes (including disc and hybrid drum-disc brake configurations)	2	8	1
Electronic data recorders (EDRs)	N/A	10	2
Tire pressure monitors	2	15	2
Automated transmissions	N/A	9	1
Speed limiters	N/A	21	3
Truck-specific navigation (including global positioning system [GPS] navigation aids)	N/A	10	2
Truck conspicuity (devices that make the truck more visible) and enhanced lighting/signaling beyond that which is required by regulations	2	9	0

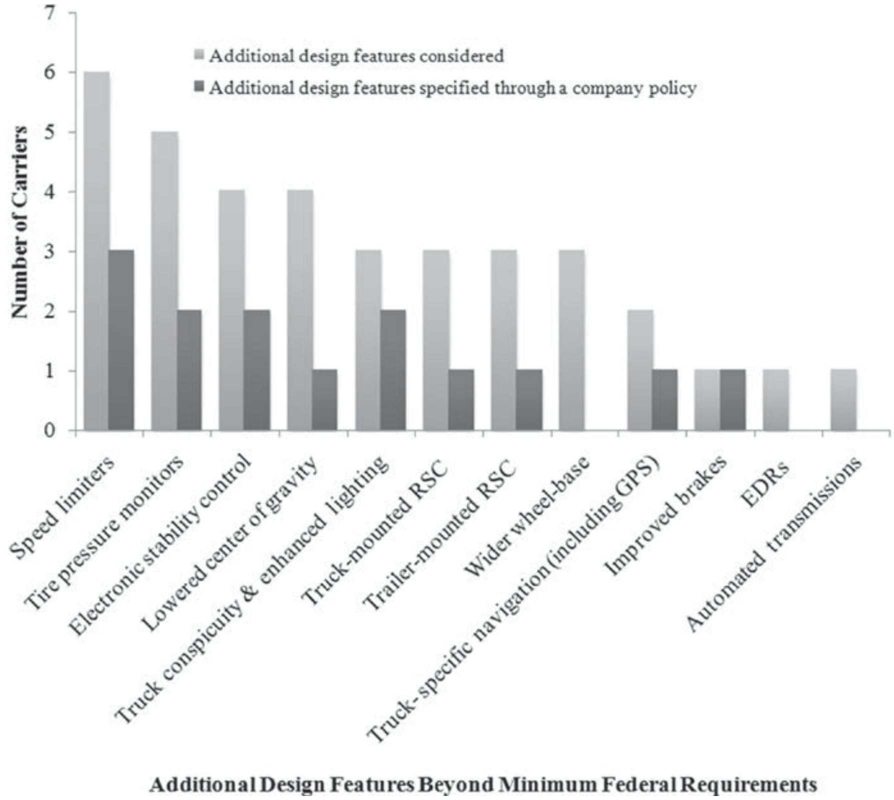


Figure 9. Accident prevention design features that exceed the minimum federal requirements specified or considered for carrier-owned bulk packages.

track, advanced braking technology such as disc and hybrid drum-disk brake configurations, and tire pressure monitors) tend to only be included at the request of a customer.

Of the carriers that replied to the survey, 41% indicated that they would consider additional design features offered while 28% indicated that they have a company policy that identifies additional requirements. The additional design features considered or specified primarily include fittings protection beyond federal standards and, to a lesser extent, increased tank wall thickness. Only one carrier identifies additional shell protection as a company-specified accident damage protection measure required for the vehicles/cargo tanks used in their deliveries. A number of different accident prevention design features are incorporated into bulk packages owned by carriers (see Figure 9). However, there is no generally accepted accident prevention measure used by all carriers who specify or consider additional design features that exceed the minimum federal requirements for bulk packages used to transport hazardous materials. Furthermore, 28% of carrier survey respondents reported that they do not specify additional design features that exceed the minimum federal requirements for bulk tanks used to transport hazardous materials.

The majority of shipper respondents have a company policy that identifies additional design features that exceed the minimum federal requirements for bulk tanks used to transport hazardous materials. These additional requirements include the following accident damage protection:

- Fitting protection beyond federal standards.
- Elimination of bottom outlets for certain products.
- Thicker shell.
- Higher test pressure.

In addition, several shippers reported that they require a variety of accident prevention measures. The accident prevention measures most often required include lowered center of gravity, trailer-mounted RSC, and speed limiters.

Best Ways to Reduce Conditional Probability of Release

All of the stakeholder groups were asked questions concerning the most effective means to improve accident damage performance of bulk packages. In addition to responding to the questions asked, several survey respondents also provided suggestions for reducing the probability of accident occurrence. Suggested accident prevention measures and protection devices are summarized in Table 25.

Table 25. Measures to reduce the risk of a spill and/or the volume of lading released in a crash.

	Identified By:				
Measure	Bulk Package Manufacturer	Repair Facility	Carrier	Shipper	Researcher / Government
For Improved Accident Protection					
Top-fitting protection enhancements (enlarge and increase robustness of "spill boxes")	✓		✓		✓
Improved bottom fittings protection / protective cages around any piping		✓	✓	✓	
Remove bottom fittings					✓
Locate manual valves close to the tank				✓	
Use the trailer frame to provide valve and piping protection			✓	✓	
Provide fitting securement of all closures				✓	
Reduce unnecessary fittings				✓	
Ensure piping, vents, piping protection, dolly legs, and rear tires do not extend beyond the profile of the tank			✓		
Use a "wheels back" trailer design to add additional protection in rear-end collisions				✓	
Install under-ride protection			✓		
Continuous frame rails		✓			
Better dome lids		✓	✓		
Better internal valves		✓			
Self-closing stop valves / Emergency valves	✓				
Stronger bulkheads		✓			
Increase material thickness (shell and head)		✓	✓	✓	✓
Use stainless steel whenever possible			✓		
Use rupture-resistant material and/or self-sealing materials					✓
Use compartmented tanks				✓	
Incorporate an isolation layer					✓
Add side impact protection (perhaps designing "airbags")			✓		
Use U.S. DOT-specification tanks even for non-regulated materials				✓	
Strap together tube tanks on trailers				✓	
Proper maintenance of equipment, valves, and domes			✓		
Employ an effective inspection and maintenance program				✓	
Make sure load is secure and valves and manholes are properly closed and secure			✓		
Maintain spill kits and provide training on how to use them			✓		
To Prevent Accidents					
Accident avoidance technology	✓				
Increase roll/yaw stability limits through tank designs and mountings, baffles, or stability control devices					✓
Driver / personnel training	✓				
Road design	✓				
Identifying operational factors	✓				
Reduce speed limit					✓

Manufacturers. With regard to the most effective means to improve accident damage protection, the general opinion is summarized in the words of one manufacturer, "the current requirements of 49 CFR 178-345-8 are very effective in protecting against accident[s]." Nonetheless, top-fitting protection enhancements were identified as beneficial.

Repair facilities. In addition to identifying the measures/devices shown in Table 25, repair facilities rated existing measures/devices for their effectiveness. The repair facilities indicated that lowered center of gravity, electronic stability control (ESC), and improved brakes (including disc and hybrid drum-disc brake configurations) were the most effective accident prevention measures, followed by wider wheelbase and speed limiters.

Carriers. In addition to identifying the measures/devices in Table 25, it was also suggested that a redesign may be necessary to improve safety because "without a complete redesign of tanks as they are today, safety in design is at its current limit."

Shippers. Shippers suggested that the most effective means to improve accident damage protection was to ensure that appurtenances attached to cargo tanks are kept within the profile of the tank, strap together tube tanks on trailers, apply enhancements to a tank's damage protection system, and increase the shell thickness.

Researchers. Researchers also suggested reducing the energy delivered to the container by properly designing the conveyance.

Tank Parts and Appurtenances to Include in the Proposed Database

Identification of bulk package design performance measures is the main goal of an accident damage database. To achieve this goal, tank parts and appurtenances that may influence bulk package performance should be included. To determine which parts of the tank are usually damaged, the stakeholders were asked to consider three types of accidents that may or may not result in lading loss: the first type of accident consists of incidents in which the bulk package experiences a rollover; the second type consists of incidents in which there are one or more additional vehicles involved in the crash; and the third type consists of incidents in which the vehicle transporting hazardous materials is the only vehicle involved and it does not roll over. Of the parts of the tank most likely to be damaged in each of the accident scenarios, the stakeholders were also asked to identify which damages parts would most likely result in a release of lading. Survey responses pertaining to the three types of accidents are summarized in Tables 26 through 28, respectively.

Another consideration when determining variables to include in an accident damage database is how manageable

Table 26. Tank parts usually damaged or resulting in loss of lading when the bulk package overturns.

	Identified By:				
Tank Part	Bulk Package Manufacturer	Repair Facility	Carrier	Shipper	Researcher / Government
Tank shell	✓	✗	✗	✓	✗
Tank heads		✗	✗	✓	
Support structure: rings, bolsters, baffles, and bulkheads		✓	✗		
Jacket material		✓	✓		
Top fittings: valves, pipe nozzles, piping, hydraulic assemblies, pressure relief devices, clean out caps, domes, etc.	✗	✗	✗	✗	✗
Rupture disc (on cryogenic trailers)			✗	✗	
Bottom fittings / piping			✗	✓	
Rear fittings / piping				✓	
Vapor recovery system		✗	✗		
Rollover protection		✗	✓	✓	
Frame rails		✓	✓	✓	
Ladders, fenders, hose trays, tool boxes		✓	✓	✓	
Axles, suspension, landing gear, fifth-wheel plate		✓	✓	✓	
Wheels, rims, and tires		✓	✓	✓	

Note: ✓ denotes tank parts likely to be damaged and ✗ denotes tank parts most likely to result in a release if damaged.

Table 27. Tank parts usually damaged or resulting in loss of lading when there are one or more additional vehicles involved in the crash.

	Identified By:				
Tank Part	Bulk Package Manufacturer	Repair Facility	Carrier	Shipper	Researcher / Government
Tank shell	✓	✗	✗	✓	✗
Tank heads		✗	✗	✓	
Support structure: rings, bolsters, baffles, and bulkheads		✓	✗		
Jacket material		✓	✓		
Top fittings: valves, pipe nozzles, piping, hydraulic assemblies, pressure relief devices, clean out caps, domes, etc.	✗	✗	✗	✗	✗
Rupture disc (on cryogenic trailers)			✗	✗	
Bottom fittings / piping			✗	✓	
Rear fittings / piping				✓	
Vapor recovery system		✗	✗		
Rollover protection		✗	✓	✓	
Frame rails		✓	✓	✓	
Ladders, fenders, hose trays, tool boxes		✓	✓	✓	
Axles, suspension, landing gear, fifth-wheel plate		✓	✓	✓	
Wheels, rims, and tires		✓	✓	✓	

Note: ✓ denotes tank parts likely to be damaged and ✗ denotes tank parts most likely to result in a release if damaged.

Table 28. Tank parts usually damaged or resulting in loss of lading when the vehicle transporting hazardous materials is the only vehicle involved and it does not roll over.

	Identified By:				
Tank Part	Bulk Package Manufacturer	Repair Facility	Carrier	Shipper	Researcher / Government
Tank shell	✗	✗	✗	✗	✗
Tank heads	✓	✗	✗	✓	
Support structure: rings, bolsters, baffles, and bulkheads		✓	✗		
Rupture disc			✗		
Front bumper, fairing, and radiator			✓	✓	
Frame rails		✓	✓		
Jacket material		✓	✗	✗	
Underride and rear-end protection		✓	✓	✓	
Top fittings: vents, valves, pipe nozzles, piping, hydraulic assemblies, pressure relief devices, clean out caps, manways, etc.		✗	✗	✗	✗
Bottom fittings / piping		✗	✗	✗	✗
Rear fittings / piping			✗	✗	✗
Internal valves			✗	✗	✗
Ladders, fenders, hose trays, tool boxes			✓		
Axles, suspension, landing gear, fifth-wheel plate			✓		

Note: ✓ denotes tank parts likely to be damaged and ✗ denotes tank parts most likely to result in a release if damaged.

the data collection will be. Therefore, manufacturers, carriers, shippers, and researchers/government officials were asked to indicate their interest in having the following tank parts evaluated in terms of their contribution to a reduction in the probability and severity of a hazardous material spill resulting from a crash involving a bulk package (see Table 29):

- Roll stability devices (e.g., ESC or RSC devices).
- Accident prevention devices (e.g., improved brakes and increased nighttime visibility devices).
- Accident protection devices (e.g., rollover damage protection device, rear-end tank protection, stop valves, and shear sections).
- Wet lines.
- Valve design and location.
- Tank shape.
- Tank wall thickness and material strength/toughness.
- Baffle and bulkhead location.

Repair facilities were asked to evaluate the difficulty of providing the bulk tank design information associated with the above tank parts and to identify additional design features that should be evaluated for accident damage performance.

Manufacturers. Of the items suggested for evaluation in a possible database, evaluations of roll stability devices and accident prevention devices were of most interest to the bulk package manufacturers who responded to the survey. Evaluations of accident protection devices, valve design and location, tank shape, tank wall thickness and material strength/toughness, and baffle and bulkhead locations were also identified as useful.

Table 29. Stakeholder interest in tank part evaluation.

	Rated Interest / Relevance				Average Difficulty in Providing Information (as assessed by repair facilities)
Tank Part	Bulk Package Manufacturer	Carrier	Shipper	Researcher / Government	
Roll stability devices (e.g., ESC or RSC devices)	66%	75%	71%	57%	39%
Accident prevention devices (e.g., improved brakes, increased nighttime visibility devices)	83%	75%	81%	N/A	N/A
Accident protection devices (e.g., rollover damage protection device, rear-end tank protection, stop valves, shear sections)	33%	70%	71%	62%	44%
Wet lines	N/A	35%	28%	46%	55%
Valve design and location	33%	65%	66%	41%	44%
Tank shape	33%	60%	47%	57%	39%
Tank wall thickness and material strength/toughness	33%	65%	57%	57%	39%
Baffle and bulkhead location	17%	54%	42%	47%	39%

Notes:

For bulk package manufacturers, interest in the evaluation of tank parts was averaged in the following manner: (# of companies most interested x 100% + # of companies that would also find the evaluation useful x 50%) / total number of companies.

For carriers and shippers, interest in the evaluation of tank parts was averaged in the following manner: (# not interested x 0 % + # somewhat interested x 33% + # interested x 66% + # very interested x 100%) / (# not interested + # somewhat interested + # interested + # very interested).

For researchers/government officials, relevance of the evaluation of tank parts was averaged in the following manner: (# not relevant x 0% + # somewhat relevant x 33% + # relevant x 66% + # very relevant x 100%) / (# not relevant + # somewhat relevant + # relevant + # very relevant).

To evaluate the difficulty in providing information, the following calculation was used: (# of repair facilities responding "very easy" x 0% + # of repair facilities responding "easy" x 33% + # of repair facilities responding "difficult" x 66% + # of repair facilities responding "very difficult" x 100%) / (Total number of repair facilities responding to the question).

N/A = Not available

Repair Facilities. Repair facility respondents indicated that existing venting requirements should be evaluated by the possible accident damage database. Additionally, type and thickness of accident damage material and stressed areas and bulges/indentations between baffles of the tank should be included.

Carriers. The majority of carrier respondents indicated that they were either interested or very interested in all of the items suggested above with the exception of wet lines. Lowered center of gravity and corrosion resistance were also identified as performance measures to evaluate.

Shippers. The majority of shipper survey respondents indicated that they were either interested or very interested in the evaluation of roll stability devices, accident prevention devices, accident protection devices, valve design and location, and tank size. Shipper opinions ranged between "not interested" and "very interested" when considering the evaluation of tank shape, tank wall thickness and material strength/toughness, and tanks with a lowered center of gravity. In comparison, shippers were less interested in the evaluation of baffle and bulkhead location and wet lines.

Researchers. In general, researchers' opinions on which package design information was useful to their research differed greatly from researcher to researcher. Those who were interested in bulk tank performance and conditional probability of release indicated that the most useful package design information is type(s) of accident protection devices followed by type(s) of roll stability devices, tank shape, tank wall thickness, and baffle and bulkhead location. Presence of wet lines, type of wet line construction, and valve design and location were data fields judged to be not as useful to researchers focusing on bulk package performance. Additional package design information to consider included the presence and type of top fittings protection, package capacity, type of mounts, and design center of gravity height. For other researchers, including those who study risk associated with routing and evaluate hazardous material risks for other modes, package design information is less useful.

Accident Data to Include in the Proposed Database

The stakeholders were asked to indicate how useful the following accident information is for their business (see Table 30):

- Crash root cause (e.g., driver condition and location constraints).
- Crash description (e.g., time of crash and number of vehicles).
- Package design information (e.g., head thickness, cross-section shape, and dimensions).
- Package damage/rupture information (e.g., damage location, damage type, size and depth of damage, and wall thickness of damaged cargo tank).
- Injury/fatality information (e.g., number of fatalities due to released lading).
- Accident costs (e.g., repair costs and clean-up costs).

Table 30. Stakeholder interest in accident information evaluation.

	Rated Usefulness			
Accident Information	Bulk Package Manufacturer	Carrier	Shipper	Researcher / Government
Crash root cause (e.g., driver condition and location constraints).	78%	88%	81%	90%
Crash description (e.g., time of crash and number of vehicles).	66%	79%	62%	78%
Package design information (i.e., head thickness, cross-section shape, and dimensions).	66%	56%	71%	95%
Package damage/rupture information (e.g., damage location, damage type, size and depth of damage, wall thickness of damaged cargo tank).	66%	67%	71%	90%
Injury/fatality information (e.g., number of fatalities due to released lading).	44%	68%	52%	85%
Accident costs (e.g., repair costs and clean-up costs).	44%	77%	39%	62%

Notes:

Interest in the usefulness of accident information was averaged in the following manner: (# responding "not useful" x 0% + # responding "somewhat useful" x 33% + # responding "useful" x 66% + # responding "very useful" x 100%)/ total number of responders (per stakeholder group).

Manufacturers. The bulk package manufacturers who responded to the survey had varying opinions on what would be most useful; however, they all agreed that the categories of information listed above would be at least somewhat useful. Injury and fatality information as well as accident costs were rated the least useful overall.

Carriers. Throughout the survey, carriers stressed the importance of including root cause information in such a database. This desire for a process to evaluate crash root cause was confirmed by 97% of survey respondents indicating that this was either useful or very useful. Other accident information that the majority of carriers said they find useful or very useful include crash description (90% of survey respondents), accident costs (86% of survey respondents), package damage/rupture information (76%), and injury and fatality information (69%). Package design information was regarded as only somewhat useful by a majority of survey respondents. One carrier indicated that the type of hazardous material, age of vehicles, and equipment manufacturer would also be very useful for their business.

Shippers. Crash root cause, crash description, package design information, and package damage/rupture information were identified as the most useful accident information for shippers. Opinions varied as to whether the other types of accident information were useful or not. The least useful information was accident costs. Additionally, shippers believed that contributing causes (not just root cause), onboard video data, years of driver experience, and type of roadway/roadway class were all very useful accident information for their business.

Researchers. The majority of researcher survey respondents were interested in crash root cause, package design, and package damage/rupture information while less interest was expressed regarding the collection of crash description, injury and fatality information, and accident costs. Interest was also expressed in the collection of the following types of accident data:

- Accident reconstruction data (i.e., initial speeds, masses, etc.).
- Evacuation information.
- Business disruption information.
- Number of shipments of the package type.
- Type of cargo.
- Whether the package was loaded or empty.
- Type of maneuver.
- How much material was released.
- Road and environment condition.

Researchers were also asked to rate how relevant several package damage/rupture information descriptors are to their research. Overall the following information was identified as relevant or very relevant by the majority of respondents:

- Location of damage resulting in the most hazardous materials spilled.
- Location of damage resulting in a hazardous material spilled.
- Location of damage that did not result in a spill.
- Dimensions of the crack, gouge, puncture, or rupture where the most hazardous material spilled.
- Dimensions of cracks, gouges, punctures, or ruptures where hazardous material spilled.

The following package damage or rupture information was identified as at least somewhat relevant by all but one respondent:

- Location of initial point of impact.
- Cause(s) of lading loss.
- Dimensions of damage at non-spill locations.
- Whether the crack or tear occurred because of damage to the fitting or appurtenance.
- Location of damaged fitting.
- Type of damaged fitting.

The following data are, in general, the least relevant package damage/rupture information:

- Dimensions of dent, crack, puncture, or rupture at initial point of impact.
- Shell or head thickness at initial point of impact, the location where the most hazardous material was spilled, locations resulting in a hazardous materials spill, and non-spill damage locations.
- Whether the damage occurred near a previous repair.
- Whether the previous repair influenced the structural integrity of the tank.
- Whether the cargo tank was repaired to specification, repaired to non-specification, or scrapped.

Finally, researchers were asked what additional aspects a cargo tank performance database could easily accommodate. The following is a list of the additional fields that should be considered:

- Accident cause:
  - Vehicle speed.
  - Type of maneuver being undertaken at the time of the accident.
  - Road and environment conditions (dry, wet, ice/snow, visibility).
- Material-related consequences:
  - Hazardous material type (UN/NA number, proper chemical name, and CAS #).

  - Hazardous material state (gas, liquid, or solid).
  - Load or fill volume.
  - Release amount.
  - Area affected.
  - Timeframe affected.
  - Topography or road slope characteristics at the incident site.
  - Type of response including number of units/personnel involved.
- Maintenance information:
  - Tank retest dates.
  - Repair description.
  - Repair location (on tank).
  - Name of inspection facility.
  - Name of repair facility.
- Driver experience.
- Location of accident (latitude and longitude).
- Whether the tank rolled for a significant distance.
- Common accident identifier so that the proposed tank performance database can be matched with information on the same accident from other databases.

Effectiveness of Existing Databases in Addressing Industry Issues

The manufacturers and repair facilities that indicated familiarity with the MCMIS, the Hazardous HMIRS, and the Fatality Analysis Reporting System (FARS) also indicated, in general, that these databases were only somewhat useful in addressing industry issues. On the other hand, the majority of carriers indicated that they were familiar with MCMIS and HMIRS and thought that these two databases were useful in addressing industry issues. Ten carriers were also familiar with the LTCCS and also found that database to be useful in addressing industry issues. With regard to the researchers who responded to the survey, three of the four researchers familiar with MCMIS indicated that it is somewhat effective in addressing industry issues, while five of the six respondents familiar with HMIRS indicate that it is effective. Similarly, all of the respondents familiar with FARS, TIFA, and LTCCS think that these databases are effective in addressing industry issues.

Information Collected by Existing Databases

Several existing accident and hazardous materials data collection processes collect information that could be used to evaluate bulk package accident performance. These include the following:

- FMCSA's MCMIS.
- PHMSA's HMIRS.
- UMTRI's TIFA.
- NHTSA's NASS GES.

Additionally, the RSI-AAR's TCAD is an existing data collection process used for a comparable purpose in railroad transport. It is anticipated that similar information would be collected by a database developed to evaluate highway cargo tanks' and portable tanks' performances in accidents.

This section provides a comprehensive review of information collected by existing databases. The information collected by each database was grouped into the following five categories:

- **Administrative variables.** These include identification numbers, information concerning the individual or agency submitting the report, and internal report tracking and validation information.
- **Accident descriptors.** These include accident location, time, and date, as well as external variables that may contribute to the root cause of the accident, such as weather conditions at the time of the accident.
- **Driver descriptors.** These include driver identification information, employer information, and driver performance information.
- **Pre-crash vehicle descriptors.** These include general vehicle/package, carrier, and cargo information.
- **Post-crash vehicle descriptors.** These include variables describing the accident, accident severity, and damage sustained by the vehicle or lading retention system.

Administrative Variables

Database Report Identifier

All of the databases examined assign a unique identifier to each incident report submitted.

Other Agency Identifiers

Both HMIRS and MCMIS record identifiers assigned by other agencies. For example, HMIRS indicates that if another report is filled out by another federal agency, such as the FMCSA, the report number should be provided. On the other hand, FMCSA provides a field to record the DOT number, a unique report number designated by the state. HMIRS provides fields identifying whether a police report was filed and, if so, what the police report number was. Similar fields are provided for fire/EMS responder reports.

Reporting Requirements

While HMIRS provides an indication of what type of incident occurred (hazardous material spill, undeclared shipment, or a non-release accident), MCMIS only provides an indication of whether or not the incident is federal or state recordable.

From Whom/Where the Report Was Obtained

Providing a trace to the original source of the information allows missing or incorrect data fields to be completed or corrected. The HMIRS and MCMIS databases provide a way to link back to the individual who completed the report, while the RSI-AAR TCAD links back to the reporting railroad but not the individual completing the report. Since the GES database is meant to be a sample that is not connected to an actual event, the GES database links back to the police jurisdiction and also includes fields pertaining to each sampling stage. Case weight information is also recorded so that the importance of each case can be adjusted such that it is appropriately representative of its population.

Report Tracking and Validation Information

Two of the strategies for making data available for analysis employed by existing databases include the following:

- Processing the data before inclusion in the database. This strategy ensures that the data used in subsequent analyses have been validated; however, data only become available after a certain lag period. This is the strategy used by GES.
- Adding raw incident reports to the database and verifying the reports after information has been added. By adding reports prior to verification, data can be used for preliminary analyses. In such cases, the status of the report (raw/validated) as well as the date that the status last changed should be recorded. This is the strategy used in MCMIS and TCAD.

Accident Descriptors

Geographic Location Identifiers

Identifiers such as state, county, city, and highway number—recorded by TIFA, HMIRS, and MCMIS—provide links to actual crashes; however, this location information is not accurate enough to provide roadway information. Providing fields for crash location coordinates (latitude and longitude) allows additional information, such as number of lanes or divided highway, to be determined. Coordinate information should be readily available as most operators or police officers use devices that provide location information. Additional fields that may be useful to include are the ones that indicate whether the crash occurred in a construction zone, on a bridge, or under an overpass.

Relational Location Descriptors

While the GES database does not provide location identifiers in the crash record, descriptions of the location of the accident in relation to the roadway and nearest junction are recorded. TIFA records contain a geographic code, type of route signing (e.g., interstate, U.S. highway, state highway, county road), traffic-way identifiers, mile point to the nearest 0.1 mile, and latitude and longitude in decimal degree format. Additionally, the accident's relation to a junction (e.g., at an intersection) and relation to a roadway (e.g., on a shoulder) are recorded.

Similarly, the RSI-AAR TCAD records include the location of the nearest railroad station, the state or province, and the type of track. Information concerning the roadway design is also recorded.

Time Descriptors

Providing the date of the incident facilitates referencing a particular crash across multiple databases if report numbers are not provided. Recording the year of the crash is important for a variety of reasons, including understanding what regulatory requirements might be in place, what technology is in use, and to monitor trends. Additionally, the amount of traffic on the road often depends on the month, day of week, and hour. Therefore, if the denominator used is annual average daily traffic (AADT), adjustments can be made to account for peak or off-peak traffic. Furthermore, information concerning the date, hour, and minute of the crash enables light levels to be determined and recorded.

Roadway Descriptors

GES includes roadway variables such as access control, number of travel lanes, alignment, profile, traffic control device, and speed limit. TIFA records include type of land use, roadway function class, number of travel lanes, roadway speed limit, roadway profile, alignment and surface type, traffic control device (if applicable), whether the crash occurred on the National Highway System or within a special jurisdiction, whether the trafficway was divided, and whether the traffic controls were functioning. While not appropriate for direct use, highway package performance may be influenced by variables such as highway class, level of service, type of pavement, type of median, and type of lane markers. On the other hand, the RSI-AAR TCAD only records the railroad responsible for track maintenance.

Population Density

GES includes variables describing the population density. This information provides an indication of both roadway design and the amount of traffic anticipated to be on the road.

Driving Conditions

Driving conditions influence highway risk because poor driving conditions can affect the performance of a driver or vehicle. For example, driving on dry roads is preferable to driving on wet or icy roads, but is not always possible. The type of crash occurring on wet or icy roads has different characteristics than the type of crash occurring under dry road driving conditions. The following roadway conditions are currently recorded:

- **Light conditions.** The general light conditions at the time of the crash, including roadway illumination fixtures, are recorded in MCMIS and GES (both obtained from police accident reports).
- **Temperature.** The RSI-AAR TCAD records the temperature at the time of the crash.
- **Weather condition.** The GES, MCMIS, and HMIRS record weather (general atmospheric) conditions at the time of the crash.
- **Road surface condition.** The road surface condition, recorded in GES and MCMIS databases, indicates whether the road was dry or wet or covered in snow, slush, ice, sand, dirt, or oil at the time of the crash. These conditions influence the amount of friction between tires and road surface.
- **Work zone.** Driving in construction zones may affect the risk of transporting hazardous materials by introducing factors such as altered driving patterns, smaller lane sizes, uneven lanes, and loose stones/construction debris scattered along the roadway surface. GES includes a variable for a work zone.
- **School bus.** The presence of a school bus can change traffic patterns and cause vehicles to stop relatively unexpectedly. Therefore, hazardous materials risk may be affected. This variable is included in the GES database.

Number of Vehicles Involved

GES, TIFA, and MCMIS include a set of variables recording the number of vehicles involved in the accident. The number of vehicles includes all trucks, buses and other vehicles, such as cars and bicycles, involved in the crash. The RSI-AAR TCAD records the number of railcars in the consist, the number of cars derailed, the location (in the train) of the first car involved, and the number of tank cars derailed. Generally, the greater the number of rail cars involved, the more severe the accident.

Number of People Involved

GES, TIFA, and MCMIS also include a set of variables recording the number of motorists as well as the number of non-motorists involved in the crash. If the number of injuries or fatalities is used as a measure of the severity of the accident, the total number of people involved in the accident could be used as the denominator to establish the rate of injury for a given accident.

Event Descriptions

The crash or collision of motor vehicles is typically described in police accident reports as one of the following accident types on the basis of the pre-crash situation (NTSB 2009):

- Single driver:
  - Right side or left side road departure includes driving off the road, loss of control, loss of traction, or attempting to avoid a collision with another vehicle/pedestrian/animal.
  - Forward impact includes striking a parked vehicle, stationary object, pedestrian or animal, or driving off the road as the road ends.
- Multiple vehicles, same trafficway/same direction:
  - Rear-ending includes striking a stopped vehicle, a slower moving vehicle or a decelerating vehicle.
  - Forward impact includes striking a vehicle due to loss of control/traction or due to an attempt to avoid a collision with another vehicle/object.
  - Sideswipe angle includes striking a vehicle in a different lane or striking a vehicle that is attempting to enter the lane.
- Multiple vehicles, same trafficway/opposite direction:
  - Head-on collision due to a lateral move.
  - Forward impact includes striking a vehicle due to loss of control/traction or due to an attempt to avoid a collision with another vehicle/object.
  - Sideswipe collision due to a lateral move.
- Multiple vehicles, changing trafficway/vehicle turning:
  - Turning across path when originating from opposite direction (i.e., left-hand turn into oncoming traffic) or when originating from same direction.
  - Turning into path in the same direction or in the opposite direction.
- Multiple vehicles, intersecting paths (T-bone collisions).
- Multiple vehicles, backing into a vehicle or other object.

Both GES and MCMIS record the above-mentioned descriptions. HMRIS also records a description of events as well as plans for further examination of the incident in a narrative format. TIFA records contain more refined data including the first event causing injury/property damage and the manner of collision. Similarly, the RSI-AAR TCAD includes fields for accident type.

Vehicle Role

GES examines each vehicle involved and identifies the following variables:

- Travel speed of each vehicle involved.
- Travel path of the vehicle involved both before and after a driver made a corrective action to avoid an accident.
- The critical event leading to the vehicle's first impact in the crash.
- Vehicle's action prior to the critical event.
- Corrective action the driver attempted to avoid the crash.
- Whether the vehicle was in control during various phases of the crash sequence including
  - Prior to the corrective action.
  - Following the corrective action.
  - Prior to the critical event.
- The initial point of impact that produced property damage or personal injury.
- The event resulting in the most severe property damage or injury.
- Similarly, TIFA records the truck's travel speed, the first event causing injury or property damage, vehicle maneuver prior to accident, crash avoidance maneuver, the most harmful event, the events related to the record's motor vehicle, and whether the vehicle struck another vehicle or was struck by another vehicle (if applicable).

Driver Descriptors

Driver Contact Information

FMCSA records driver name and contact information in MCMIS but does not make this information available to the public. Therefore, driver contact information is not used for risk analysis. GES records the driver's zip code, which allows driver performance to be evaluated based on geographic region.

Driver's License

MCMIS also records the driver's license number, but this information is not available to the public. While the whole license number may not be necessary or available, in a database constructed for risk assessment it may be useful to record license class. Therefore, adverse effects of drivers operating cargo tank motor vehicles without the proper license could be offset. TIFA records the non-commercial license state and type.

License Status

In addition to the license information itself, TIFA records include information concerning the status of the license, compliance (whether it is appropriate for the type of vehicle driven), endorsements, and previous convictions, including license restrictions, number of previous crashes, and number of previous suspensions/revocations, driving while intoxicated convictions, speeding convictions, and other harmful moving violations convictions. The dates of the first and last crash/suspension/conviction are also recorded.

Employer

While GES records include employer information for the driver of each vehicle, HMIRS and MCMIS record carrier information for the hazardous material cargo tank truck involved in the crash. TIFA records include both employer information for the driver of each vehicle and a description of the operating authority (e.g., private, for hire). The inclusion of these fields in a database designed for risk analysis enables the degree of risk associated with each carrier to be determined. In terms of package performance, employer information can be used to correlate maintenance practices.

Driver Description

TIFA records include driver height and weight. This enables field of vision and other factors within the vehicle to be approximated.

On Duty

Information on whether the cargo tank was attended or not would enable the analysis of parked cargo tank motor vehicles in a crash scenario. Any spills occurring when the cargo tank is unattended would likely be larger than spills occurring when the employee is near the tank because emergency shut-off valves could not be activated in a timely fashion.

Occupants

GES and TIFA record the number of occupants (including driver) per vehicle. The presence of individuals other than the driver in a hazardous material cargo tank motor vehicle may indicate driver distraction. On the other hand, the presence of a passenger may increase driver alertness particularly when traversing long distances.

Alcohol Involvement

GES, TIFA, and the RSI-AAR TCAD record the involvement of alcohol in the crash. GES also records whether the driver was drinking in the vehicle. Both GES and MCMIS record whether violations were charged as well as the severity of those charges.

Driver Condition

In addition to alcohol, driver performance can be influenced by the presence of drugs or other factors such as physical/mental impairment. GES records both driver presence and driver physical/mental impairment, and MCMIS records driver condition. TIFA records include an indication of the general driver condition if it is a contributing factor to the crash and any violations charged.

External Factors

Factors external to the vehicle can also influence driver performance; therefore, GES records what, if anything, obscured the driver's vision or distracted the driver.

Driver Input

TIFA and GES record the driver's action in the crash. This field may vary from the action taken by the vehicle if equipment fails. GES also records the object a driver tried to avoid.

Hours Worked

The presence of this field in a motor carrier crash database is important because fatigue can also lead to poor driver performance. The current maximum number of hours motor carrier employees can work is 14 hours per day, 11 hours driving.

Pre-Crash Vehicle Descriptors

Pre-crash vehicle descriptors may include the manufacturer of a vehicle and vehicle identification and specification. Each database reviewed has a slightly different structure. GES records characteristics for each vehicle involved in a crash independently, while HMIRS and FMCSA contain one record per crash. Because railroad tank cars operate in trains rather than as single vehicles, the RSI-AAR TCAD records each tank car involved individually in a separate table that can be linked to the accident information table.

Mode of Transport

PHMSA records information for multiple modes (highway, rail, air, and water) so HMIRS requires a field identifying the mode in which the incident occurred.

Vehicle Identification

Vehicles in the GES database are recorded both by vehicle identification number (VIN), if available, and by a number assigned in the police accident record. MCMIS not only records the VIN, but also contains fields for vehicle license number and state. TIFA records include VIN, truck fuel code, weight code, series, and length. The RSI-AAR TCAD records every tank car's unique reporting mark and number.

Vehicle Use

Emergency vehicles such as ambulances and vehicles with non-emergency special uses such as hearses and farm equipment are identified in a GES accident report. MCMIS provides a field identifying whether the vehicle carries passengers or cargo. Furthermore, GES records a trailer being towed behind the vehicle at the time of the crash, and GES, HMIRS, and MCMIS record the type of cargo trailer being towed.

Vehicle Description

GES, MCMIS, and TIFA focus on the performance of motor vehicles and therefore include descriptions of the motor vehicle. In the case of highway transportation of hazardous materials, the vehicle described is the tractor or chassis. GES includes variables such as vehicle make and model, body type, number of axles, and model year. The MCMIS database records the number of axles, vehicle configuration, and a rough categorization of the gross rated weight. TIFA records the unit type (whether in-transport, not-in-transport within the trafficway, not-in-transport outside the trafficway, or construction or utility motor vehicle); vehicle make; model, body type; model year; cab style; whether the vehicle has trailing units; the vehicle's configuration; straight truck body style (if applicable); power unit make and year; the number of power unit axles; and a rough categorization of the gross rated weight. Additionally, the presence of accident prevention measures is recorded. These include headway detection/forward crash warning, side/object detection, lane departure warning, rollover warning, ESC, power unit tracking, trailer tracking, and speed limiter devices.

Cargo Tank Designs

TIFA records basic descriptions of the cargo body type, style, the number of axles on the trailer, and the vehicle configuration (e.g., straight truck and full trailer). Since HMIRS focuses on the performance of cargo tanks, its records include designs for the hazardous material cargo tank involved. Related data fields include:

- Material of construction.
- Head type.
- Package capacity.
- Quantity of hazardous material in the package.
- Number of containers in the shipment.

- Design pressure.
- Shell thickness.
- Head thickness.
- Service pressure.
- Valve or device type (if failed).
- Manufacturer name.
- Manufacture date.

The RSI-AAR TCAD expands on the above fields by including the following fields:

- Year car was built.
- Tank class specification.
- Category of car types.
- Original certificate of construction number.
- Tank test pressure.
- Tank specification identifier.
- Stenciled car specification.
- Tank shell material specification.
- Tank shell material grade.
- Tank shell minimum thickness.
- Tank shell maximum thickness.
- Tank shell inside diameter at center.
- Tank head material specification.
- Tank head material grade.
- Tank head material thickness.
- Tank inside diameter at head.
- Tank capacity.
- Truck capacity.
- Tank insulation or thermal protection type.
- Tank insulation thickness.
- Center sill type.
- Coupler type.
- Head shield type.
- Heater type.
- Presence of bottom fittings.

Bulk Cargo Tank Hazardous Material Placard

Hazardous material placards identifying the quantity of hazardous material must be displayed on cargo tanks carrying a variety of hazardous materials. Other markings such as proper shipping names and material identification numbers are required on cargo tanks carrying materials poisonous by inhalation, marine pollutants, and elevated temperature materials. Since emergency responders must be able to identify the hazardous material placards, the placards are easily identifiable. The presence of placards is recorded by TIFA, GES, and MCMIS databases but is not recorded by the HMIRS database because the placards are assumed to be present on all cargo tanks included in the database. In addition to recording the presence of a hazardous material placard, the GES and HMIRS databases also record hazardous material placard numbers.

Hazardous Material Descriptors

While other motor vehicle databases record whether the vehicle carried hazardous material or not, TIFA and HMIRS records also include various properties of the hazardous material being transported. The hazard class of a hazardous material and the hazardous material identification number are recorded. Additionally, in HMIRS, fields are provided to record packing group and identification markings such as toxic by inhalation, serious marine pollutant, radioactive indicators, hazardous material waste numbers, and material shipment approval numbers, if applicable. Similarly, the RSI-AAR TCAD records the type of cargo, lading name, lading classification, and Standard Transportation Commodity Code (STCC). For tank cars that are empty, the RSI-AAR TCAD records last lading in car tank, previous lading name, and previous lading classification.

Post-Crash Vehicle Descriptors

Type of Accident

HMIRS provides several "Yes" or "No" fields indicating whether or not the following events occurred:

- No release.
- Spillage.
- Material loss.
- Serious bulk release.
- Fire.
- Explosion.
- Water sewer involved.
- Gas dispersion.
- Environmental damage.
- Vehicle overturn.

Although some of the accident types listed above may generally be more serious than others, these fields do not provide information regarding the severity of the accident. Further information is required to determine risk associated with each event. Additionally, the occurrence of a fire is recorded by GES, and the occurrence of a hazardous material release is recorded by both GES and MCMIS. TIFA records whether a rollover occurred and where it happened (on roadway, etc.), whether a jackknife occurred and the event order in which it happened, whether an underride or override occurred, the involvement of hazardous materials in the accident and whether those materials released.

Table 31. "What Failed" codes for cargo tank motor vehicles in HMIRS.

Code	What Failed	Code	What Failed
101	Air Inlet	136	Locking Bar
105	Bolts or Nuts	137	Manway or Dome Cover
106	Bottom Outlet Valve	138	Mounting Studs
107	Check Valve	139	O-Ring or Seals
110	Cover	141	Piping or Fittings
115	Discharge Valve or Coupling	142	Piping Shear Section
116	Excess Flow Valve	143	Pressure Relief Valve or Device – Non-reclosing
117	Fill Hole	144	Pressure Relief Valve or Device – Reclosing
118	Flange	145	Remote Control Device
119	Frangible Disc	146	Sample Line
120	Fusible Pressure Relief Device or Element	148	Sump
121	Gasket	150	Tank Shell
122	Gauging Device	151	Thermometer Well
123	Heater Coil	152	Threaded Connection
124	High Level Sensor	153	Vacuum Relief Valve
125	Hose	154	Valve Body
126	Hose Adaptor or Coupling	155	Valve Seat
127	Inlet (Loading) Valve	156	Valve Spring
131	Lifting Lug	157	Valve Stem
132	Liner	158	Vapor Valve
133	Liquid Line	159	Vent
134	Liquid Valve	160	Washout
135	Loading or Unloading Lines	161	Weld or Seam

Source: PHMSA 2004

Hazardous Material Release

In addition to identifying accidents in which a hazardous material release occurred, HMIRS records the quantity of hazardous materials released. This information provides an indication of the severity of the incident. However, it should be noted that HMIRS records all incidents regardless of whether or not a crash occurred (non-accident releases).

Vehicle/Package Damage Descriptors

Damage descriptors are to be used to determine vehicle or package performance in accidents. GES focuses on vehicle damage while HMIRS focuses on package damage. Damage can be described in terms of the following:

Damage component. HMIRS provides codes to be used to indicate damage component for different bulk and non-bulk containers. Table 31 lists codes for cargo tank component failure.

Damage type. HMIRS also records how a failure occurred. Table 32 shows the codes used for cargo tanks.

Damage cause. GES records what vehicle factors may have contributed to the cause of the crash. The factors recorded are shown in Table 33. TIFA also records route causes that may have contributed to the crash. These include roadway conditions, vehicle defects, and other special circumstances. On the other hand, HMIRS records causes of lading retention system failure. The factors shown in Table 34 are associated with hazardous material releases regardless of whether or not a crash occurred.

Damage location. GES includes a field to record the most severely damaged area as well as up to five specific areas

Table 32. "How Failed" codes for cargo tank motor vehicles in HMIRS.

Code	How Failed	Code	How Failed
301	Abraded	307	Gouged or Cut
302	Bent	308	Leaked
303	Burst or Ruptured	309	Punctured
304	Cracked	310	Ripped or Torn
305	Crushed	311	Structural
306	Failed to Operate	312	Torn Off or Damaged

Source: PHMSA 2004

Table 33. The GES vehicle crash causes.

Code	Cause	Code	Cause
0	None	10	Wipers
1	Tires	11	Wheels
2	Brake System	12	Mirrors
3	Steering System—Tie Rod, Kingpin, Ball Joint, etc.	13	Driver Seating and Control
4	Suspension—Springs, Shock Absorbers, McPherson Struts, Control Arms, etc.	14	Body, Doors
5	Power Train—Universal Joint, Drive Shaft, Transmission, etc.	15	Trailer Hitch
6	Exhaust System	50	Hit-and-Run Vehicle
7	Headlights	97	Vehicle Contributing Factors—No Details
8	Signal Lights	98	Other Vehicle Contributing Factors
9	Other Lights	99	Unknown if Vehicle Has Contributing Factors

Source: NHTSA 2010

of damage. TIFA records include the principal impact point in terms of degrees around the vehicle and bulk package (no distinction is made between the vehicle and trailer) and the extent of the damage. In the HMIRS, a description of package failure such as size and location of holes or cracks is requested in narrative format in Form DOT F 5800.1. In the RSI-AAR TCAD, codes are used in some database fields to specify damage location on tank head (e.g., below, on, or above center line) and shell (e.g., end or center, bottom or top). Codes are used in other fields to record puncture location, shape, and geometry on tank head and shell. Another set of codes is used to record rupture types by specifying the total number of

Table 34. HMIRS lading loss causes.

Code	Cause	Code	Cause
501	Abrasion	521	Inadequate Preparation for Transportation
502	Broken Component or Device	522	Inadequate Procedures
503	Commodity Self-ignition	523	Inadequate Training
504	Commodity Polymerization	524	Incompatible Product
505	Conveyer or Material Handling Equipment Mishap	525	Incorrectly Sized Component or Device
506	Corrosion—Exterior	526	Loose Closure, Component, or Device
507	Corrosion—Interior	527	Misaligned Material, Component, or Device
508	Defective Component or Device	528	Missing Component or Device
510	Deterioration or Aging	529	Overfilled
511	Dropped	530	Overpressurized
512	Fire, Temperature, or Heat	531	Rollover Accident
515	Human Error	532	Stub Sill Separation from Tank (Tank Cars)
517	Improper Preparation for Transportation	533	Threads Worn or Cross Threaded
518	Inadequate Accident Damage Protection	536	Vandalism
519	Inadequate Blocking and Bracing	537	Vehicular Crash or Accident Damage
520	Inadequate Maintenance		

Source: PHMSA 2004

circumferential fractures and number of tubs. For top and bottom fittings and other attachments, codes are used to specify damage component, type, and cause.

Property Damage

In addition to vehicle damage, vehicular crashes often result in non-vehicle property damage. Actual property damage estimates and costs associated with initial emergency response, clean-up, and remediation are recorded in HMIRS. Similarly, the RSI-AAR TCAD records track wayside equipment, track structure property damage estimates, and an estimate of the total reportable damage.

Evacuation

Certain hazardous material releases require evacuation of the surrounding neighborhood. Occasionally, evacuations occur for non-release events when the danger of a release event remains. HMIRS records whether an evacuation took place, the total number of employees and members of the public evacuated, total evacuated, and the number of hours the evacuation lasted. Similarly, the RSI-AAR database records the total number of persons evacuated.

Road Closure

Since Form DOT F 5800.1 is required in the event of a road closure, HMIRS contains a field indicating whether a major artery was closed as a result of the incident and how long it was closed.

Injury/Fatality

Another measure of crash severity is the number of injuries and fatalities resulting from the crash. GES records the most severe injury level involved in the crash overall and in each vehicle, including fatalities. The number of people requiring medical attention is also recorded. TIFA records include the number of casualties by degree of injury (none, C, B, A, K, and unknown); additionally, individual occupant injury/fatality information is recorded. MCMIS, HMIRS, and the RSI-AAR TCAD record the number of fatalities separately from the number of injuries. HMIRS records additional detail concerning the fatalities and injuries associated with an incident. The fields provided regarding fatalities include the following:

- Whether the incident resulted in a fatality.
- The number of employee fatalities due to a hazardous material release.
- The number of responder fatalities due to a hazardous material release.
- The number of general public fatalities due to a hazardous material release.
- The number of non-hazardous material fatalities.

The fields recording information pertaining to injuries include the following:

- Whether the incident resulted in a serious injury.
- The number of employee hospitalized injuries due to a hazardous material release.
- The number of responder hospitalized injuries due to a hazardous material release.
- The number of general public hospitalized injuries due to a hazardous material release.
- The number of non-hazardous material hospitalized injuries.

The RSI-AAR TCAD also includes the following fields to provide more information about injuries and fatalities:

- The number of fatalities by reporting railroad.
- The number of fatalities for all railroads involved.
- The number of total fatalities.
- The number of employee fatalities.
- The number of passenger fatalities.
- The number of other fatalities.
- The number of injuries by reporting railroad.
- The number of injuries for all railroads involved.
- The number of total injuries.
- The number of employee injuries.
- The number of passenger injuries.
- The number of other injuries.

Data Limitations of Existing Databases

In order to perform package performance studies to estimate the conditional probability of release in accidents for bulk packages with various design elements, detailed data on the nature of damages suffered by packages involved in accidents are also necessary. This is an area where the existing Form DOT F 5800.1 form reporting process already records various details of damage to packages and design features that resulted in releases in HMIRS. From this information, the number of incidents in which various types of damage occurred can be calculated. However, the current process does not record information in sufficient detail to address some of the pertinent questions. HMIRS records the "what" and "why" associated with a package failure. Indicating failure locations (the "where") may be a potential avenue to improve. Experience from the RSI-AAR TCAD shows that the following additional information, grouped as pre- and post-crash package descriptors, may be useful.

Pre-Crash Package Descriptors

Suitable adaptations of the following fields are some possible additional data to collect in HMIRS:

- Tank shape (e.g., cylindrical, oval, etc.).
- Tank inside diameter or cross-section length for non-cylindrical.
- Insulation/thermal protection type and thickness.
- Structural reinforcement information:
- Ring reinforcement.
- Jacket material and thickness.
- Head shield material and thickness.
- Top fittings protection or recessed design.
- Bottom fittings protection or absence of bottom fittings.
- Location of fittings, manway, and other appurtenances.

In addition, a bulk package "certificate of construction," a form created by truck manufacturing facility that contains specific design configuration data, may be requested to ensure the accuracy of the data collected.

Post-Crash Package Descriptors

To record additional damage data in HMIRS, new fields and codes might be implemented that

- Indicate damage location on tank head and shell.
- Record puncture type and geometry on tank head and shell.
- Record rupture type and configurations.
- Indicate indentation location, diameter, and depth on tank head and shell in non-release accidents.

Identification of Data Needs

To define the data needed for an effective bulk package accident performance study, the larger context in which a package's accident performance can be evaluated, namely its conditional probability of release given involvement in an accident, was considered. Figure 10 is an influence diagram that summarizes the relationship of major factors affecting hazardous materials transportation safety. Hazardous materials transportation risk is a function of

- **The probability of a crash occurring.** This is influenced by route choice, driving maneuvers, vehicle condition (i.e., brakes), and vehicle and package design characteristics (i.e., roll stability).
- **The probability of a hazardous materials release given an accident.** This is influenced by two elements:
  - The package's resistance to damage, which is affected by package design and package condition.
  - The impact type and severity, which can be described by the accident characteristics.
- **The consequences given a crash and a hazardous materials release.** These are also influenced by route choice and environmental conditions, (i.e., proximity to population centers or areas sensitive to the effects of a release) and the type of hazardous material.

In addition to collecting data indicating whether or not there was a release of product and, if so, the quantity and other details about the release, the most important types of data to be collected for analysis of bulk package accident performance are

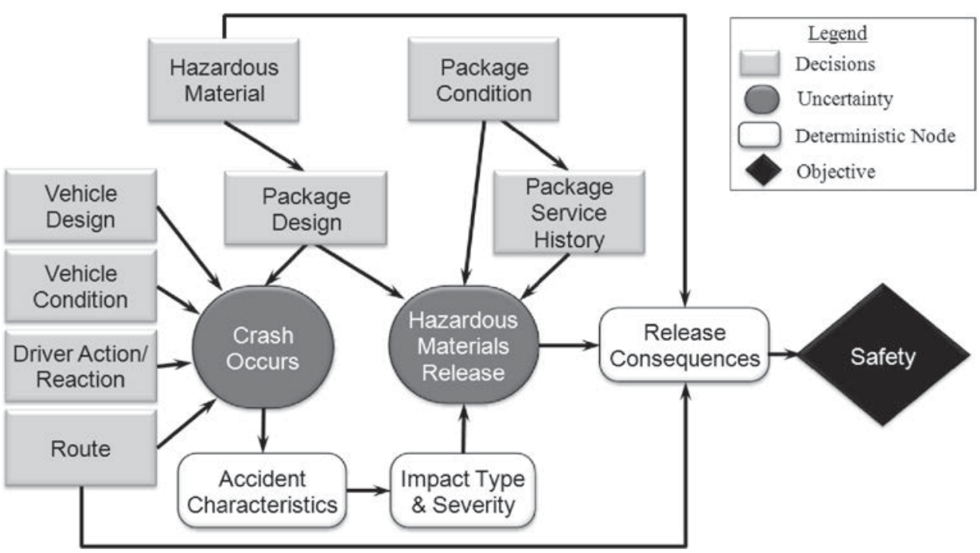


Figure 10. Hazardous materials transportation risk influence diagram.

- Package design characteristics,
- The circumstances of accidents in which packages are involved, and
- The nature of the damage packages experience.

These factors are explored in greater detail in Figure 11. Service history and condition may also influence bulk package performance, although to a lesser degree.

In Figure 11, the majority of variables are included in one of the following groups: commodity characteristics, package design, package condition, and crash characteristics. Several additional variables that do not fit into these groups but should be considered for inclusion in a possible accident damage database include the following:

- Trailer/truck frame design.
- Attachment to trailer/truck frame.
- Vehicle speed prior to crash avoidance maneuver.
- Whether a release occurred.
- Amount of commodity spilled.

Commodity Characteristics

All regulated materials are not equally hazardous and, ideally, container specifications and packaging requirements are commensurate with the degree of risk posed by the product. In practice, hazardous materials physicochemical properties (e.g., corrosiveness, vapor pressure at temperatures expected during transit, etc.) influence the type of cargo tank used for their transportation. The proper shipping name, hazard class/division code, and identification number can be used in a risk-based decision-making approach to determine whether additional accident damage protection measures, such as a more damage-resistant specification container, might be appropriate for a particular type of commodity. The quantity of product being transported was also grouped with commodity characteristics. The inclusion of the quantity of hazardous material being transported would aid in the calculation of the expected quantity released and could be used as a metric for developing estimates of release severity.

Package Design Characteristics

The specification of the bulk package chosen to transport a hazardous material influences (directly and indirectly) package resistance to damage. Additionally, several package design characteristics influence package stability and crash characteristics, which, in turn, influence the impact type and severity.

Design Characteristics Affecting Package Resistance to Damage and Tank Stability

Package Specification. The inclusion of bulk tank specification enables the evaluation of specification-specific conditional probability of release. This would account for some of the variability between different types of cargo tanks.

Package Cross-Section Shape. The package cross-section shape (round, oval, etc.) may be a significant factor affecting performance of bulk packages in accidents. Its influence is propagated through a series of package design characteristics as well as crash characteristics (by affecting package stability) to affect the package's resistance to damage, and impact type and severity. Bulk packages are principally designed as pressure vessels to safely contain product under normal operating conditions, and the criteria relating to accident conditions is limited. The inclusion of this variable in a possible accident damage database would enable the following questions to be addressed:

- Do different cross-section shapes affect accident performance in general?
- If so, in what manner?

Number, Capacity, and Order of Compartments in Package. The number and capacity of compartments in the package provide an indication of its length and also influence the number and location of voids between compartments. Therefore, both the number and capacity of compartments in the bulk package are likely significant factors in the estimation of the conditional probability of release. Questions that could be addressed by including these variables in an accident damage database are the following:

- Does the number of compartments in a bulk package affect package performance?
- Does compartment capacity influence component-specific conditional probability of release?
- Does the order in which compartments are placed affect package performance?

Cross-Section Maximum and Minimum Height and Width and Center of Gravity. The cross-section height and width and the overall loaded center of gravity are the remaining variables that describe the package dimensions. Since package height and width can vary along the length of the package, which is typical for lower center of gravity designs, the maximum and minimum height and width should be recorded for each compartment. The following questions

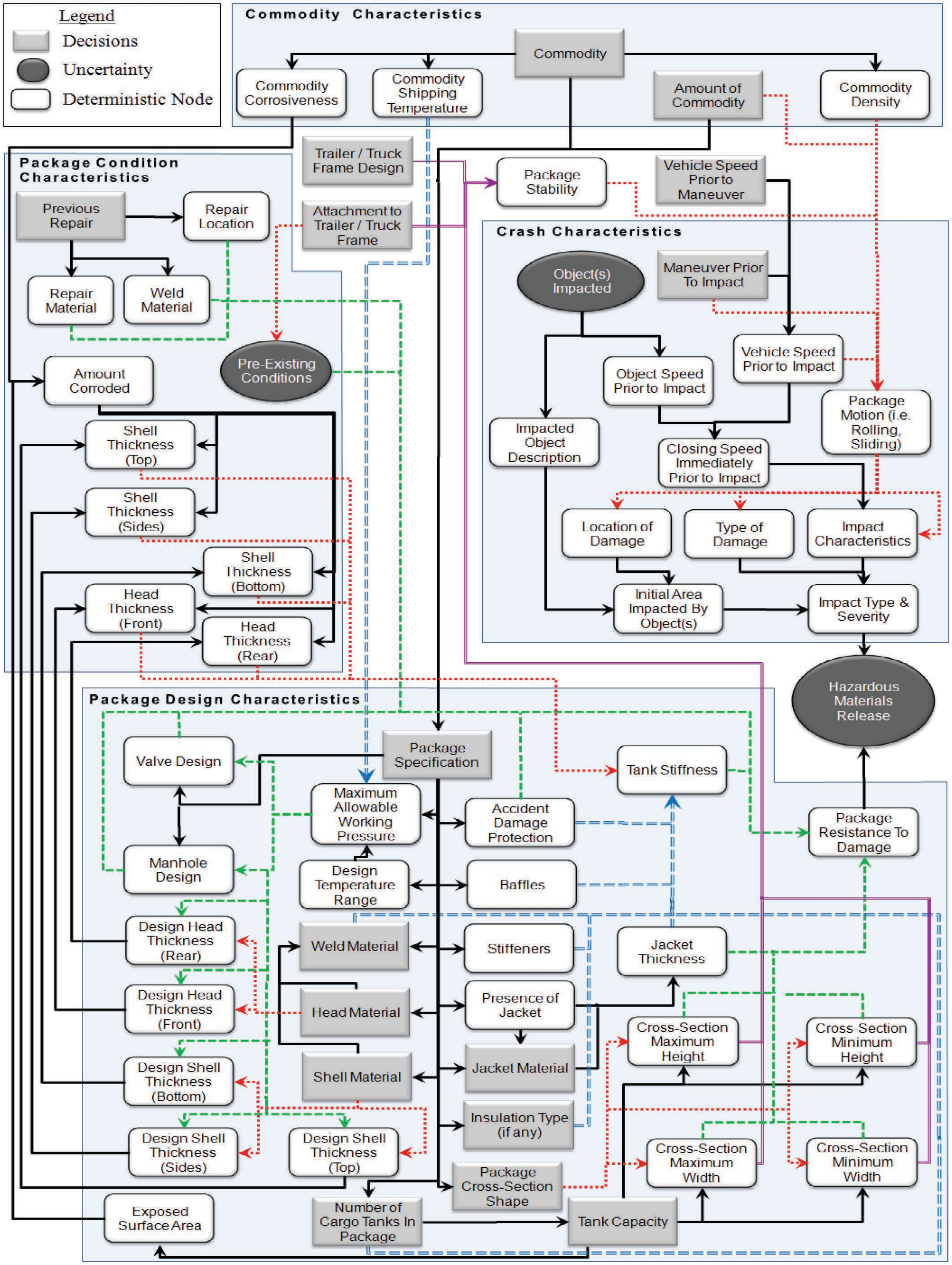


Figure 11. Conditional probability of release influence diagram.

could be addressed with the inclusion of these variables in an accident damage database:

- Does a lower center of gravity affect bulk package accident performance?
- What affect does varying cross-section height and width have on package performance?

Design Characteristics Affecting Package Resistance to Damage Only

Accident Damage Protection. Two categories of accident damage protection are provided in 49 CFR §178.345-8: accident damage protection for the "upper 2/3 of the tank circumference," which mainly provides protection in rollover accidents, and accident damage protection for the "lower 1/3 of the cargo tank circumference," which mainly provides protection for multiple-vehicle, non-rollover accidents.

Currently, bottom accident damage protection is required to "extend no less than 6 inches beyond any component that may contain lading in transit" (49 CFR §178.345-8[b][1]) or, if provided for a lading discharge opening equipped with an internal self-closing stop valve, may be "provided by a sacrificial device located outboard of each internal, self-closing stop valve and within 4 inches of the major radius of the tank shell or within 4 inches of a sump, but in no case more than 8 inches from the major radius of the tank shell" (49 CFR §178.345-8[b][2]). If an accident damage protection device is impacted during the accident, recording which design (non-sacrificial or sacrificial) was used would enable a statistical analysis to evaluate the relative performance of these two approaches.

Rollover accident damage protection devices are provided in the upper two-thirds of a cargo tank for those opening closures (i.e., valves, manholes) that do not achieve 125% of the strength that would be provided by the accident damage protection device. One or more of these devices may be used. By recording the provision of continuous rollover protection or for individual appurtenances, the design criteria in federal regulation could be evaluated.

Number and Placement of Baffles. In addition to providing longitudinal deceleration protection, baffles may be used as circumferential reinforcements if welded to the cargo tank shell over more than 50% of the total circumference of the tank. Use of baffles as stiffeners can increase the structural integrity of the tank; however, use of baffles also may result in local inconsistencies in tank performance in the event of an accident. In combination with recording the number and placement of other circumferential reinforcements, recording the number and placement of baffles would allow the following questions could be addressed:

- How does spacing of baffles affect bulk package performance?
- How does the performance of baffles or baffle attachment rings compare in accident scenarios?

Additionally, recording the proximity of shell failure to a baffle might enable a statistical analysis of the impact of baffles on shell integrity during an accident.

Number and Placement of Stiffeners. In addition to using baffles as stiffeners, ring stiffeners are used alone or in combination with other stiffening measures. Therefore, questions similar to those concerning baffles may also be addressed with regard to stiffeners.

Presence of Jacket. Previous studies involving railroad tank cars have found that, all other things being equal, jacketed tank designs have a lower conditional probability of release than non-jacketed tank designs (Anderson & Kirkpatrick 2006). In order to evaluate the same effect for highway tanks, the presence of a jacket on the tank should be recorded. The amount of jacket deformation incurred in an accident could be used in conjunction with jacket design characteristics, to describe the energy absorption capabilities of a package. Saccomanno, Stewart, and Shortreed (1993) suggested that energy absorption characteristics are a critical element in estimating the risk of hazardous materials transportation.

Jacket Material and Thickness. Recording the jacket material and thickness in an accident damage database could enable the following questions to be addressed:

- Do different types of jacket material perform differently and, if so, how?
- How does jacket thickness affect bulk package accident performance?

Insulation Type. A layer of insulation is often provided between the jacket and the tank to reduce temperature changes of the lading while in transit. The insulation may provide additional energy absorption in the event of an accident. For these reasons, recording the presence and type of insulation would enable assessment of these effects on bulk package performance.

Head Material and Design Thickness(es). The head material and design thicknesses are listed on the cargo tank name plate and therefore should be simple to record in an accident damage database. They should be included in an accident damage database since these factors explain a substantial amount of the variability in the conditional probability of release for railroad tank cars (Treichel et al. 2006). Because strength, toughness, and the design thickness depend, in part, on the type of material, it should be included in the accident damage database. These variables would enable a statistical analysis to be performed to address the following questions:

- Do different types of head material perform differently and, if so, how?
- What are the relationships between head thickness and material and CPR?

Shell Material and Design Thickness(es). Similar to the head parameters, shell material and design thicknesses should be simple to record in an accident damage database. Since shell thicknesses can vary from the top of the tank to the bottom, thicknesses should be recorded for all three locations (top, side, and bottom). Questions that could be addressed by recording these variables include the following:

- Do different types of shell material perform differently and, if so, how?
- What are the relationships between shell design thickness and material and bulk package performance?

Weld Material. Rollover accidents often result in twisting the cargo tank. If this twisting exceeds the strength of the joint material, the bulkheads in a multiple-compartmented bulk package may be torn at their seams, resulting in a leak that fills the void space between bulkheads. The material then can be released through specification vents. Therefore, while weld material information is not listed specifically on the name plate or specification plate, recording the weld material is important because its strength may be a factor affecting CPR in rollover accidents.

Design Temperature Range. The design temperature range is listed on the cargo tank's name plate and therefore should be simple to record in the accident damage database. Recording the design temperature range would enable the following question to be addressed: Does design temperature range affect bulk package performance?

Maximum Allowable Working Pressure. The maximum allowable working pressure is also listed on the cargo tank's name plate. It refers to "the maximum pressure allowed at the top of the tank in its normal operating position" (49 CFR 178.320 [a]). Therefore, the maximum allowable working pressure is a proxy for the overall pressure the bulk package can sustain. Recording the maximum allowable working pressure would enable the following question to be addressed: Is there a relationship between maximum allowable working pressure and the conditional probability of release?

Pressure Relief Valve Design. Pressure relief valves enable venting of gaseous materials in order to maintain a specified pressure and temperature within the bulk package. Although interest in the evaluation of valve design and location is moderate, both small diameter fittings far from accident damage and "small" fittings on the vessel top centerline were identified as major sources of lading loss in rollover accidents. According to 49 CFR 178.345-10 (h), "each pressure relief device must be permanently marked with the following: (1) manufacturer's name, (2) model number, (3) set pressure in psig, and (4) rated flow capacity in standard cubic feet per hour (SCFH) at the rating pressure, in psig." When vents are used, "such vents must be set to open at not less than 1 psig and must be designed to prevent loss of lading through the device in case of vehicle overturn" (49 CFR 178.345-10 [b][2]). By recording these variables in conjunction with an estimate of the amount of lading loss from the vent, the following questions could be addressed:

- Is there a relationship between valve flow capacity and estimates of the conditional probability of release?
- Is there a relationship between set pressure and estimates of the conditional probability of release?
- Do valve/vent designs affect bulk package performance?

Additionally, recording the placement of the valve (particularly if it was included in the damaged area) in relation to other tank components, such as stiffening rings and baffles, would enable the following questions to be addressed:

- Is there a relationship between valve placement and safety performance of bulk packages?
- Is there a relationship between valve location relative to circumferential reinforcements and accident performance?

Void Space Vent Design. Vents within the void space between bulkheads in a multi-compartmented cargo tank, under normal operating conditions, ensure that there is no lading within the void space. However, in rollover accidents in which the bulkhead is torn from the shell of the tank, these open vents may enable lading to seep from the tank. Although the current void space vent specifications call for non-sealable vents, modifications to enable such vents to automatically seal in the event of a rollover may be considered in the future. If such a design change was implemented, even on a trial basis, recording the design of the vent as well as an estimation of the amount of lading loss from the vent, could allow the following question to be addressed: Does void space vent design have an effect on bulk package performance?

Manhole Design. In addition to valves, the surveys indicated that manhole assembly characteristics should be recorded in a possible accident damage database. This is of particular interest in rollover accidents. Regulations require that manholes be designed such that "shock impact due to a rollover accident on the roadway or shoulder where the fill cover is not struck by a substantial object" will not result in the cover opening (49 CFR 178-345-5[d]). The questions that could be addressed by recording manhole assembly test pressure (which, as of 2004 is required to be permanently marked on the outside of the manhole), shape, and placement include the following:

- How does round manhole performance compare to oval manhold performance?
- Does test pressure of a manhole assembly affect the performance of bulk packages in accidents?
- Does the placement of manhole assemblies affect bulk package performance?

Surface Area Susceptible to Corrosion. The exposed surface area is a function of the compartment capacity of the cargo tank. It directly influences the amount of material corroded, particularly at the typical meniscus location when the tank is full and at the edge of fluid when the tank has only residue lading. If corrosion occurs, the actual shell and head thicknesses are reduced compared to design shell and head thicknesses, thereby affecting tank stiffness and the package's resistance to damage. Recording variables describing the surface area susceptible to corrosion would enable the following question to be addressed: Is package performance related to conditions found in areas susceptible to corrosion?

Package Maintenance Characteristics

Amount Corroded/Actual Thickness(es)

Corrosion of the shell or head can affect tank stiffness and resistance to damage. However, determining and recording the overall amount of corroded material is time consuming in comparison to recording the presence and depth of corrosion at the location of the damage. As an alternative, the actual shell or head thickness at the rupture location would enable statistical analysis to address the following questions:

- Does tank corrosion affect CPR in accidents?
- If there is an effect, is there a functional relationship between corrosion depth and CPR?

Presence of Pre-existing Stress Flaw(s)

In some cases, stress fractures have been found in the vicinity of a bulk package's attachment to the trailer or chassis frame. If the presence of existing stress fractures or other such flaws are recorded, the following questions could be addressed:

- Does the presence of pre-existing stress flaws affect bulk package performance?
- Is there a relationship regarding the proximity of stress fractures or other flaws to accident damage with regard to susceptibility of lading loss?

Previous Repair Location Size and Materials

Repairs to the cargo tank that involve replacement of a section of the tank shell might result in higher stresses adjacent to repair welds. These higher stresses may affect the CPR. Consequently, information concerning the repair location, repair size, repair material, and weld material should be recorded in an accident damage database. Recording these variables would permit the following questions to be addressed:

- Is package performance affected by the presence and/or location of past repairs?
- Does the proximity of repairs to damage affect accident performance?
- Does repair size affect package performance?

Crash Characteristics

The crash characteristics identified in Figure 11 can be subdivided into three categories: impacted object characteristics, bulk package motion characteristics, and the resultant impact characteristics.

Impacted Object

The impacted object characteristics can be described by identifying the object impacted. By recording which objects damaged the lading retention system, the following question could be addressed: Is there a relationship between the type of object impacted and cargo tank performance?

Bulk Package Motion Variables

The bulk package motion characteristics can be described by the choices made by the driver of the bulk package vehicle. These include bulk package speed prior to the maneuver, maneuver prior to impact (e.g., braking and/or swerving), bulk package speed immediately prior to impact, and package motion (e.g., rolling and/or sliding). By recording these variables, one would be able to address the following questions:

- What is the nature of the relationship between the closing speed of the bulk package relative to the impacted object and the CPR?

- What is the nature of the relationship between package motion and the CPR? For example, if a package is both rolling and sliding along the ground, is it more susceptible to lading loss than if it were only rolling or only sliding?

Impact Variables

Impact characteristics can be described by damage type, shape, size, and location on the bulk package, as well as components damaged and location of lading loss (on the bulk package). These variables represent factual data that can be consistently recorded. Along with closing speed immediately prior to impact, they can be used as proxy variables in lieu of recording impact energy and forces, both of which are difficult to determine during data collection.

Type of Damage

As discussed in Section 4.2.5.3 of Form DOT F 5800.1, the type of damage is recorded only if the bulk package fails. Labeled "Failure Type," Form DOT F 5800.1 allows for the following options: abraded, bent, burst or ruptured, cracked, crushed, failed to operate, gouged or cut, leaked, punctured, ripped or torn, structural, and torn off or damaged. However, when the type of damage is recorded only for instances that resulted in lading loss, the probability of a particular type of damage resulting in lading loss cannot be determined. Instead of reporting failure type, an accident damage database should record the types of damage sustained by the lading retention system, and for each type of damage, provide an indication as to whether it resulted in lading loss. Including the type of damage in the accident damage database would enable analysis to address the following question: What is the relationship between different types of damage and conditional probability of release?

Damage Shape and Size

The area of damage refers to the geometric shape and size of the damage. In conjunction with the closing speed of the bulk package and the object(s) impacted in the crash, the area of damage is an important factor in determining the force of the impact. Therefore the area of damage plays a vital role in determining the CPR. Area of damage has been used as a variable in Selz and Heberling's *Improving Crashworthiness of Front Heads of MC-331 Cargo Tank Motor Vehicles* (2000) where amount of deformation and size of damage was considered and Lupker's *LPG Rail Tank Cars Under Head-On Collisions* (1990) where non-symmetrical deformation began to occur when the deformation was one order of magnitude greater than the shell thickness. By recording the damage shape and size, statistical analyses can be performed to confirm the findings of Selz and Heberling (2000) as well as answer the following questions:

- Is there a particular way a cargo tank deforms, made evident by the deformation shape, which is more susceptible to lading loss?
- How large can the indentation be before non-symmetrical indentation occurs?
- How large can the indentation be before the bulk package ruptures?

Shape and Size of Failure

Similarly, the shape and size of the hole in the lading retention system should be recorded in an accident damage database. While these variables will not contribute directly to the probability of whether a release occurs, they can be used to estimate the amount of lading loss.

Location of Damage/Failure

The location of damage is one of the variables collected by the RSI-AAR TCAD that has proven to be helpful in developing estimates for the CPR and is likely to be useful in release estimates for bulk packages. Because of the large number of shapes and sizes of cargo tanks and portable tanks, recording location information would be facilitated by use of a diagram based on the package dimensions previously entered (length, height and width, container shape, and package capacity) in the accident damage report and cordoning sections of the cargo tank similar to those recorded in the RSI-AAR TCAD (see Figure 12) where

- 1 represents tank car head damage below the centerline,
- 2 represents tank car head damage on the center line,
- 3 represents tank car head damage above the centerline,
- 4 (not shown) represents head destroyed,
- 5 (not shown) represents shell destroyed,
- 6 represents shell damage at either end on the bottom half of the tank car,
- 7 represents shell damage at the center on the bottom half of the tank car,

Source: RSI-AAR TCAD 2005

Figure 12. Tank car damage locations.

- 8 represents shell damage at either end on the top half of the tank car,
- 9 represents shell damage at the center on the top half of the tank car, and
- 10 (not shown) represents damage in the vicinity of the sump.

Unlike tank cars, cargo tank trucks and trailers are not symmetric in their design; therefore, the identification of the location of damage is more complex. The following location-identification scheme could be used (see Figure 13):

- 1 represents cargo tank front head damage below the centerline.
- 2 represents cargo tank front head damage on the centerline.
- 3 represents cargo tank front head damage above the centerline.
- 4 (not shown) represents front head destroyed.
- 5 represents cargo tank rear head damage below the centerline.
- 6 represents cargo tank rear head damage on the centerline.
- 7 represents cargo tank rear head damage above the centerline.
- 8 (not shown) represents rear head destroyed.
- 9 represents damage at the bottom front driver-side of the cargo tank.
- 10 represents damage at the bottom middle driver-side of the cargo tank.
- 11 represents damage at the bottom rear driver-side of the cargo tank.
- 12 represents damage at the top front driver-side of the cargo tank.
- 13 represents damage at the top middle driver-side of the cargo tank.
- 14 represents damage at the top rear driver-side of the cargo tank.
- 15 represents damage at the bottom front passenger-side of the cargo tank.

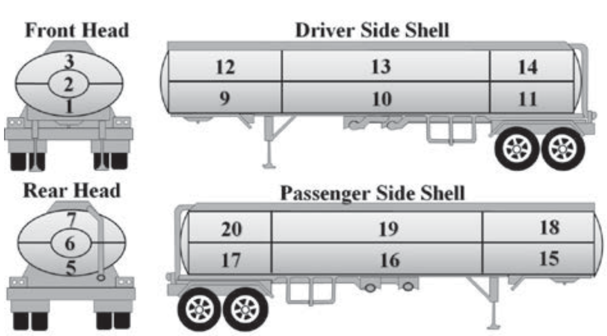


Figure 13. Possible cargo tank damage location-identification scheme using a DOT 406 container as an example.

- 16 represents damage at the bottom middle passenger-side of the cargo tank.
- 17 represents damage at the bottom rear passenger-side of the cargo tank.
- 18 represents damage at the top front passenger-side of the cargo tank.
- 19 represents damage at the top middle passenger-side of the cargo tank.
- 20 represents damage at the top rear passenger-side of the cargo tank.
- 21 (not shown) represents damage to the piping and/or undercarriage below the cargo tank.

Questions that could be addressed by collecting the location of damage include the following:

- Is there a relationship between location and damage vulnerability?
- What is the performance of the lading retention system(s) relative to withstanding forces involved in accidents?
- What is the CPR for each area?

Components Damaged

In addition to the location of damage, a list of the components damaged within the area should be collected and an indication provided as to whether they failed. For example, if "7," the rear head above the centerline, was listed as the location of damage, the vapor recovery system should be identified if it also sustained damage. If the damage to the vapor recovery system resulted in lading loss, an indication of failure should be provided. In addition to questions regarding damage location, recording which components were damaged within the identified location would enable a statistical analysis to address the following:

- Does placement of cargo tank components affect the CPR (i.e., does any particular location for a manhole significantly reduce the CPR)?
- Are there location-specific effects in terms of component design damage resistance?

Variable Evaluation

Each variable was evaluated, based on survey and interview feedback, for its importance in an accident damage database and for ease of obtaining the information (see Table 35). In Table 35, in the column titled "Importance of Inclusion in Accident Damage Database," variables rated "E" are considered essential. Variables not rated as essential are rated on a scale of 1 to 10 where 1 indicates "very important to include" and 10 indicates "somewhat important to include." In the

Table 35. Variable evaluation.

Variable[a, b]	Importance of Inclusion in Accident Damage Database[c]	Ease of Obtaining Information[d]
Commodity Characteristics		
Proper Shipping Name	**E**	1
Hazardous Class/Division Code	**E**	1
Identification Number	**E**	1
Amount	**E**	1
Package Design Characteristics		
Package Specification	**E**	1
Package Cross-Section Shape	3	2
Number of Compartments in Package	**E**	1
Capacity of Each Tank	**E**	1
Tank Outage	2–4	5
Order of Tank Placement in the Package	2–4	1
Cross-Section Maximum Height	2–4	4
Cross-Section Minimum Height	2–4	4
Cross-Section Maximum Width	2–4	6
Cross-Section Minimum Width	2–4	6
Overall Loaded Center of Gravity	1	8
Bottom Accident Damage Protection	E	1
If Not Sacrificial, Extension Beyond Lading Retention Components	3	2
If Sacrificial, Distance from the Major Radius of the Cargo Tank Shell	3	2
Rollover Accident Damage Protection	E	1
Number of Baffles	2	1 if not jacketed, 8 if jacketed
Placement of Baffles	2	1 if not jacketed, 8 if jacketed
Number of Ring Stiffeners	2	1 if not jacketed, 8 if jacketed
Placement of Ring Stiffeners	2	1 if not jacketed, 8 if jacketed
Presence of Jacket	E	1
Jacket Material	E	1
Jacket Thickness	E	6
Insulation Type	E	6
Head Material	E	1
Front Head Design Thickness	E	1
Rear Head Design Thickness	E	1
Shell Material	E	1
Top Shell Design Thickness	E	1
Side Shell Design Thickness	E	1
Bottom Shell Design Thickness	E	1
Weld Material	5–7	1
Design Temperature Range	5–7	1
Maximum Allowable Working Pressure	1	1
Pressure Relief Valve Design	1	2
Pressure Relief Valve Placement	5–7	1
Pressure Relief Valve Distance From Bulk Package Stiffeners	5–7	6
Void Space Vent Design	10	2
Manhole Test Pressure	5–7	1
Manhole Shape	5–7	1
Manhole Placement	5–7	1

Table 35. (Continued).

Variable[a, b]	Importance of Inclusion in Accident Damage Database[c]	Ease of Obtaining Information[d]
Maintenance/Repair Characteristics		
Amount Corroded	6–8	8
Actual Front Head Thickness	6–8	8
Actual Rear Head Thickness	6–8	8
Actual Top Shell Thickness	6–8	8
Actual Side Shell Thickness	6–8	8
Actual Bottom Shell Thickness	6–8	8
Presence of Pre-existing Stress Flaw(s) in Damage Location	6–8	6
Presence of Pre-existing Stress Flaws(s) at Rupture Location	6–8	6
Previous Repair Location	6–8	6
Previous Repair Distance from Rupture	6–8	6
Previous Repair Size	6–8	6
Previous Repair Material	6–8	1
Previous Repair Weld Material	6–8	1
Presence of Corrosion at Rupture Location	6–8	6
Depth of Corrosion at Rupture Location	6–8	6
Crash Characteristics		
Impacted Object	1	1
Impacted Object Speed	2	1 if stationary object, 5 if moving object
Bulk Package Speed Immediately Prior to Impact	2	1 if event recorder data is available, otherwise 5
Closing Speed at Moment of Impact	2	1 if "Impact Object Speed" and "Bulk Package Speed Immediately Prior to Impact" is also recorded, otherwise 5
Bulk Package Motion Immediately Prior to Impact	2	1 if decelerating (braking) or rolling over, 5 otherwise
Type of Damage*	E	1 if subjective evaluations are used
Whether the Type of Damage Sustained Resulted in Failure*	E	1
Damage Shape	2	4
Damage Size	2	4
Rupture/Puncture Shape	2	3
Rupture/Puncture Size	2	3
Damage Location (on the cargo tank)	E	1
Damaged Components*	E	1
Whether Damage Sustained by the Component Resulted in a Release*	E	1
Release Occurred	E	1
Amount of Commodity Spilled	E	4
Others		
Trailer/Truck Frame Design	5	1
Attachment to Trailer/Truck Frame	5	1
Package Stability	5	8
Vehicle Speed Prior to Crash	**E**	1 if event recorder data is available, 5 otherwise
Avoidance Maneuver	1	1

[a]Variables shaded gray are recorded by Form DOT F 5800.1.

[b]Variables denoted with an asterisk are partially recorded by Form DOT F 5800.1.

[c] E = essential to include. 1–10 = scale on which 1 indicates "very important to include," and 10 indicates "somewhat important to include."

[d]1–10 = scale on which 1 indicates "very easy to obtain," and 10 indicates "difficult to obtain."

column titled "Ease of Obtaining Information" in Table 35, variables are rated once again on a 1 to 10 scale; however, in this column 1 indicates "very easy to obtain" and 10 indicates "difficult to obtain."

Variables identified as essential (12 in addition to variables recorded by Form DOT F 5800.1, 28 total) should be included in an accident damage database. Other variables may be considered for future inclusion if there is sufficient interest among stakeholders. Those variables currently required to be reported in Form DOT F 5800.1 are shaded in gray in Table 35 to illustrate the benefits of a greater compliance in reporting these variables.

Table 35 shows that, in addition to the variables collected in Form DOT F 5800.1, the following fields are required for developing a basic statistical understanding of cargo tank performance and for computing the component-specific CPR for highway bulk packages transporting hazardous materials:

- Bottom accident damage protection.
- Rollover accident damage protection.
- Presence of jacket.
- Jacket material.
- Jacket thickness.
- Insulation type.
- Head material.
- Front head design thickness.
- Read head design thickness.
- Shell material.
- Top shell design thickness.
- Side shell design thickness.
- Bottom shell design thickness.
- Type of damage (replaces "Type of Failure" on Form DOT F 5800.1).
- Whether the type of damage sustained resulted in failure.
- Damage location (on the bulk package).
- Damaged components (replaces "What Failed" on Form DOT F 5800.1).
- Whether the damage sustained by the component resulted in a release.
- Release occurred.
- Amount of commodity spilled.

Selected Level of Detail

The panel for HMCRP Project 07 asked to identify what degree of refinement was desired in the accident data reporting system. The various data fields outlined above were grouped into six levels (see Appendix B) ranging from Level 1, which included the variables needed for the most basic conditional probability of release calculation, to Level 6, which includes the variables required for assessment of detailed package and component design elements as well as various inferential statistics, including the effect of tank maintenance and repair history.

These differing levels represent increasingly detailed performance measures and a corresponding increase in the effort required by carriers to complete the reports. This illustrates the tradeoff between the value of the information collected and the level of effort required to collect such data. A decision regarding the most appropriate balance is crucial to the success of whatever data collection system might ultimately be developed for assessing accident performance of highway bulk packages.

The project panel suggested that a possible future database should contain fields corresponding to Level 4: Component-Specific CPR Statistics Accounting for the Influence of Accident Protection and Accident Characteristics. In addition, it was suggested that the research team include fields describing the extent of package damage and, if a release occurred, to quantify the dimensions of the breach.

SECTION 3

Data Collection Methodologies

The second objective of HMCRP Project 07, to identify possible methodologies for systematic collection of the necessary performance data, was achieved through a literature review, consideration of existing accident and hazardous materials data collection processes, and examination of accident severity thresholds. Industry surveys and interviews were used to identify preferable methodologies, and the most favorable methodology was explored through the development and implementation of a pilot study.

Strategies previously employed to collect data on various aspects of hazardous materials transportation were reviewed. The review includes literature that evaluates several existing databases and accident data collection processes that could either be modified to collect cargo tank and portable tank performance data or that could be emulated by this project's proposed database.

Accident definitions used by several different databases were reviewed for relevance in assessing highway bulk package accident performance. Unintentional releases were distinguished from intentional releases (i.e., criminal acts resulting in a release), and non-release events were distinguished from release events. The accident damage database proposed in this report will focus on collecting data on unintentional, accident-caused damage regardless of whether a release occurred. In addition, severity thresholds for inclusion or exclusion in existing databases were reviewed. The effect of specific severity threshold levels on the total number of accidents recorded in a database is illustrated using data from an existing accident database and the implications of different threshold levels are discussed. Finally, a basis is provided for defining the possible range of accidents to be included in the data collection program.

Industry interviews and surveys also collected opinions on the systematic collection of the necessary performance data. Three dichotomies are used in the survey: (1) voluntary versus mandatory data reporting, (2) an extension of Form DOT F 5800.1 versus a new program, and (3) a government-sponsored versus industry-sponsored program. A preliminary set of possible data collection protocols based on each approach were developed and prioritized based on their pros, cons, and ease of implementation. Four options are prioritized and further examined to address questions such as how data will be collected, where they will be housed, who will collect them, and how confidential data will be protected.

One of these data collection approaches, the possible implementation of a government-sponsored extension of Form DOT F 5800.1, with mandatory participation, was refined into a system with details about the elements of the data set to be collected. These elements are identified and grouped according to logical associations. Implementation considerations are then discussed. These include electronic data collection tools that offer logical response options based on previous responses, a possible prototype database management system, and security access control considerations.

Based on this approach, methodologies for collecting and analyzing the performance data were explored through the development and implementation of a pilot study. The purposes of the pilot study were to evaluate the quality of data expected from such a data collection process, identify improvements to the data collection system itself, demonstrate the types of analyses that could be facilitated by the database, and estimate the period of time required to collect incident data sufficient to support reliable statistical analyses. The pilot data collection tool was designed to enable bulk package accident damage information to be collected accurately and with minimal difficulty for pilot study participants.

Due to a low level of participation in the pilot study, an alternative method for gathering bulk package accident performance information was developed to supplement the accident reports gathered using the data collection tool. The pilot study added bulk package accident performance information from a manual review of NTSB reports and information gathered from multiple sources, including PHMSA HMIRS reports, FMCSA MCMIS reports, and news articles.

This process enabled identification of several improvements to the pilot data collection tool and generated a total of 50 accident records with varying degrees of completeness, particularly regarding bulk package design, the extent of the damage, and the dimensions of the breach.

The data collected as part of the pilot study were also used to estimate the amount of time for such a system to yield statistically significant accident performance measures. This was accomplished by comparing population-wide accident and release rates to minimum sample size requirements. The minimum sample size requirements were developed using a subset of pilot study accident records corresponding to hazardous materials transported in MC 306 or DOT 406 containers. Two conditions were used to establish minimum sample sizes: (1) a sufficient number of accident records to minimize Type I errors (where insignificant variables appear to have a significant effect) and Type II errors (where significant variables appear not to have an effect on the probability of a release) and (2) at least 10 events for each variable included in the regression equations.

Literature Review

Data collection strategies previously employed to analyze various aspects of hazardous materials transportation were evaluated for relevance to this project. There are several existing databases and accident data collection processes that could either be modified to collect cargo tank performance data or that could be emulated by this project's proposed database. The following studies provided an introduction to a variety of databases that will be examined in further detail.

HMCRP Report 1: Hazardous Materials Transportation Incident Data for Root Cause Analysis (Battelle Memorial Institute 2009) examines multiple existing databases including MCMIS, HMIRS, FARS, TIFA, LTCCS, the Railroad Accident/Incident Reporting System (RAIRS), and Marine Information for Safety and Law Enforcement (MISLE). Each of these databases was evaluated for the potential to perform a root cause analysis. In addition to providing an overview of the data collection process, the report discusses thresholds for exclusion/inclusion, examines accuracy and completeness of the data, and determines the degree of interconnectivity with other databases.

National Automotive Sampling System (NASS) General Estimates System (GES) Analytical User's Manual 1999–2008 (NHTSA 2010) discusses the purpose and design of the NHTSA GES database. The document describes the GES sample design process, provides a summary of the imputation process used, and documents the variable names and associated codes contained in the database.

Databases and Needs for Risk Assessment of Hazardous Materials Shipments by Trucks (Hobeika and Kim 1993) evaluates 12 hazardous material truck databases in terms of reliability and their associated risk assessment problems. While there are databases providing exposure (referent/denominator) information, this information is not usually obtained for a particular accident/crash incident. The dichotomy between crash databases and exposure databases, according to Hobeika and Kim (1993), reduces the reliability of hazardous material transportation risk analyses. Hobeika and Kim (1993) assert that the 12 databases analyzed in the paper lack sufficient information pertaining to incidents, exposure, or consequences needed to perform risk analysis. The paper discusses reporting requirements, compares national hazardous material statistics to state hazardous material statistics, and provides a brief discussion on the merits of using geographic information systems (GIS) and automatic vehicle identification (AVI) for the purposes of data collection.

Accident Definitions

In general, release incidents involving bulk packages in transit can be classified as caused by an accident or non-accident. Accidents are the result of unintentional application of external forces, including a crash between vehicles or impact with stationary objects, while non-accidents are due to causes such as improperly secured or defective valves, fittings and tank, and venting of non-atmospheric gases from safety-relief devices. Typically, non-accident-caused releases are more frequent than accident-caused releases (Barkan and Pasternak 1999) but have less severe consequences than accident-caused releases.

An accident damage database should contribute to transportation safety by enabling risk analyses to include the conditional probability of release given that a bulk package is involved in an accident. The analysis of data on unintentional, accident-caused releases will enable better-informed decisions regarding bulk tank design, accident protection technology, and operational strategies. On the other hand, there are a number of potentially useful security strategies that could be examined by recording intentional release events (i.e., criminal acts resulting in a release). However, the recording of intentional release events may require some different data that could affect the effectiveness and cost of the overall data collection process. Therefore, the proposed accident damage database will focus on collecting data from unintentional, accident-caused damage.

In order to estimate the conditional probability of release for bulk packages and their various design elements, detailed data on the nature of damages suffered by packages involved in accidents are necessary. Of particular importance relative to current highway accident databases is that data are needed on crashes involving hazardous material bulk packages, whether or not some or all of the contents leaked in accidents. This is an area where the existing Form DOT F 5800.1 already collects various details of damaged packages when a release has occurred or the damages to the bulk package cost more than $500. However, the current process does not record information in sufficient detail to address some of the pertinent questions concerning bulk package performance.

Furthermore, in terms of assessing portable and cargo tank performance, accidents in which a tank was involved but not damaged should be distinguished from accidents in which the tank did suffer damage, whether or not a release occurred. A similar distinction exists in the RSI-AAR tank car database with regard to recording derailed cars versus derailed cars that suffered damage to the tank or appurtenances. The former is an estimator of exposure of the vehicle to accidents whereas the latter is an estimate of the exposure of the tank itself to damaging events.

The implications of setting an accident severity threshold beyond which accidents should be recorded were examined using data from PHMSA's HMIRS. All en route or in transit incidents or accidents concerning cargo tanks, cylinders, or intermodal tanks between January 1, 2005, and May 1, 2010, yielded a total of 2,074 records involving cargo tanks that resulted in more than $500 in damage. These records were used to calculate the cumulative percentage of reported incidents with respect to the total cost of each event. The incident costs reported in Form DOT F 5800.1 ranged between $0 and $2,285,000, with 90% of the accidents incurring a cost less than $203,500 and 50% of the accidents incurring a cost less than $9,000 (see Figure 14). The relationship illustrated is more sensitive in the lower range of incident costs and indicates that higher severity cost thresholds lead to a lower number of recorded incidents.

By definition, low severity accidents are limited in the extent of damage incurred, rarely involve a release, and therefore pose little risk. The lower the threshold, the more accidents need to be recorded. The result is greater cost and time expended to collect the data, and a higher cost to maintain the database. Data on lower consequence accidents may be of less value in terms of the objectives of a database. On the other hand, lower consequence accidents may provide useful predictive information for lower frequency, higher consequence events. Furthermore, the larger sample size combined with the more rapid accumulation of data will enable more statistical power and enable inferences to be made sooner, especially in the early years of a new database. Consequently, there is a tradeoff to be considered in establishing thresholds. From a technical standpoint, standardized reporting criteria are important to understand because they provide a baseline rate upon which to base consistent risk estimates.

Reporting Thresholds of Existing Data Collection Strategies

Existing accident and hazardous materials data collection processes were reviewed for their ability to be adapted to evaluate cargo tank and portable tank performance in highway accidents. These existing programs include PHMSA's HMIRS, FMCSA's MCMIS, UMTRI's TIFA, and NHTSA's NASS GES. Additionally, several existing data collection processes used for a comparable purpose in other modes were examined. These include the RSI-AAR TCAD, the U.S. DOT/FRA's RAIRS, and the U.S. Coast Guard's MISLE.

Most similar accident database systems have some type of criteria that determine whether or not an event should be reported (for example, damage cost or quantity released). Furthermore, in some databases, there are tiered thresholds,

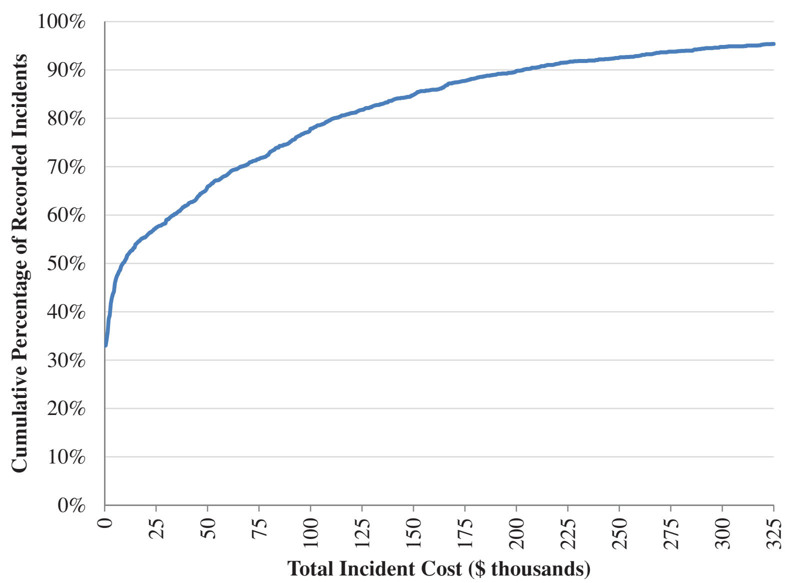


Figure 14. Cumulative percentages of reported incidents by total cost.

in which incidents of greater magnitude have more detailed reporting requirements. Reporting thresholds have both practical and analytical implications for the resultant database, and these should be understood when developing a new database.

This section summarizes accident definitions and accident severity thresholds for inclusion or exclusion in existing accident databases as discussed in *HMCRP Report 1: Hazardous Materials Transportation Incident Data for Root Cause Analysis* (Battelle Memorial Institute 2009). Additionally, the information recording process for each dataset is described.

Motor Carrier Management Information System (MCMIS)

MCMIS data collection starts with the local police compiling and submitting police accident reports to the appropriate state agency. From here, reports involving accidents that meet MCMIS criteria are also reported to FMCSA via an electronic filing system or manually using a Web interface. FMCSA then records the information in the MCMIS crash database, which contains four major files—Registration, Crash, Inspection, and Company Safety Profile. The most pertinent and relevant to this project is the Crash file.

The MCMIS Crash file is intended to record all serious crashes of trucks and buses involved in commerce. A crash is considered serious if there is

- A fatality.
- An injury requiring immediate medical attention away from the accident location.
- A vehicle that had to be towed from the accident location due to disabling damage.

Hazardous Materials Incident Reporting System (HMIRS)

Under 49 CFR 171.16, all road, rail, water, or air hazardous material carriers must submit a Form DOT F 5800.1 within 30 days of a reportable incident that falls under the following criteria:

- The National Response Center (NRC) is notified due to
  - An injury or fatality directly resulting from hazardous material exposure, an evacuation of more than an hour, a major artery road closed for more than an hour, or change of an operational flight pattern or aircraft routine.
  - A fire, breakage, or spillage involving radioactive materials.
  - A fire, breakage, or spillage involving infectious materials.
  - A marine pollutant release.
  - A situation that poses a continuous danger to life at the accident location.
- An unintentional hazardous material release or discharge of such materials occurs.
- An undeclared hazardous material is discovered.
- Any structural damage to the lading retention system or damage that requires repair to a system intended to protect the lading system of a hazardous material cargo tank with a minimum capacity of 1,000 gallons (even if there was no release) occurs.

For clarity, PHMSA's incident reporting guidelines provide the following examples of bulk package damage that require reporting (PHMSA 2004):

- Outlet valve damage affecting seating and requiring replacement.
- Lading retention system damage, including damage to charged outlet lines that could have resulted in loss of contents.
- Damage requiring professional inspection or recertification.
- Damage requiring repair due to compromised integrity.

A reportable incident can occur whenever a carrier is involved: during loading/unloading, in transit, or in temporary storage en route to final destination. For each incident, the cost of damages must be provided if total damage exceeds $500. The resulting database contains incident reports pertaining to non-accident-caused as well as accident-caused hazardous material releases and near misses.

Corrections and updates must be filed within a year of an incident by submitting Form DOT F 5800.1 again and checking the "A supplemental (follow-up) report" box on the form. Filing methods available include XML submissions, online Form DOT F 5800.1 reporting application, PDF attachment in email, and FAX. PHMSA performs newspaper searches and compares the list of incidents reported to NRC to identify unreported incidents. Carriers who fail to report incidents within the specified timeframe are notified by phone.

Trucks Involved in Fatal Accidents (TIFA)

The Center for National Truck and Bus Statistics at UMTRI manages the TIFA database. It is a subset of FARS focusing on all medium and heavy trucks with greater than 10,000-lb gross vehicle weight rating (GVWR) and expanded with supplemental survey data.

NHTSA has a contract with an agency in each state to provide information on fatal crashes using standard FARS forms. FARS analysts are state employees who attend formal training programs and receive on-the-job training. A supplemental phone survey is performed by the Center for National Truck and Bus Statistics at UMTRI to complete the TIFA database record for each accident.

TIFA has the same accident definitions and reporting criteria as FARS. Specifically, a crash is included if there is

- A fatality that occurs as a result of a crash.
- A fatality that occurs within 30 days of a crash.
- One motor vehicle in transport on a public road.

National Automotive Sampling System (NASS) General Estimates System (GES)

Maintained by NHTSA, GES is populated by data obtained from a nationally representative probability sample of police-reported crashes (NHTSA 2010). After selection of the police jurisdictions, the GES data collector organizes a select subsample of police accident reports into six strata depending upon vehicle type, injury severity, and vehicle tow status. A systematic sample of crashes is then selected based on different sampling ratios. Of particular interest to this study is Group 2, NASS crashes involving at least one medium or heavy truck in which a vehicle was towed due to damage or at least one person involved had an injury requiring medical treatment.

Large Truck Crash Causation Study (LTCCS)

FMCSA and NHTSA jointly undertook the LTCCS as a one-time initiative to compile a nationally representative sample of nearly 1,000 injury and fatal crashes involving large trucks that occurred between April 2001 and December 2003. Each crash involved at least one large truck with a GVWR greater than 10,000 lb and one fatality or serious injury, where a serious injury is either an incapacitating or non-incapacitating but evident injury.

RSI-AAR Tank Car Accident Database (TCAD)

The RSI-AAR TCAD provides an example of how a database designed for container performance could be structured, maintained, and operated. Compared to other accident databases, the RSI-AAR TCAD records more details about the parts of tank cars that failed in release accidents, but it also records data on accidents involving tank cars without a release, including certain details of the damage suffered in these accidents. This information provides denominator data that can be used to calculate a conditional probability of release statistic for specific designs of tank cars damaged in accidents. HMCRP Project 07 focused on methodologies to implement a program that would collect the same type of information as the RSI-AAR TCAD; however, there are a number of operational and institutional differences between the highway transport and rail industries that make such an implementation challenging. These differences are discussed in Appendix C.

As part of the RSI-AAR Railroad Tank Car Safety Research and Test Project, the TCAD is maintained by an independent contractor working for the project sponsors, RSI and AAR. Since 1970, data have been gathered and compiled from a variety of sources with the goal of recording accident circumstances, mechanical and design characteristics of each tank car involved in the accident, and details on the damage suffered by the tank cars during the accident. Accident information sources for the RSI-AAR project include the FRA RAIRS, railroads, tank car owners, news clip service and Associated Press articles, weekly accident summaries prepared by the University of Illinois based on Chemtrec reports, and government agencies' accident investigation reports. The contractor is responsible for gathering information from all these different sources, merging the information, resolving conflicting information, and pursuing missing data. Detailed damage data are usually provided by repair shops. Information on the design parameters of each car come from the rail industry's Universal Machine Language Equipment Register (UMLER), which is a registry of nearly all North American rolling stock that contains extensive information on individual tank cars' design parameters. Additional design information is provided by the tank car certificates of construction that must be completed for every tank car and updated when significant changes to a car are made throughout the course of its service life. The contractor is responsible for entering all relevant information into the database and ensuring its accuracy and integrity. For quality assurance (QA), quarterly reports are published for project director and project sponsor review.

Since its formation in 1970, more than 45,000 records of damaged tank cars and more than 29,000 accidents have been recorded in the database. This extensive database enables robust statistical analyses of the performance of the principal tank car components and development of quantitative answers to a variety of questions (CCPS 1995, Barkan and Pasternak 1999). The most basic questions include the following:

- What is the percentage of tank cars involved in accidents that released some or all of their contents?
- What is the safety performance of tank car transport of hazardous materials?
- How do different tank car specifications perform in accidents?
- How has tank car safety performance improved over time?

Meanwhile, more complex questions include the following:

- What is the likelihood of release from a particular component and what is the expected quantity of release from a particular component?
- How does the performance of a particular component differ with the incorporation of various design features?

- How effective are different design changes at improving safety?
- How has tank car safety improved as a result of some change in design or operation?
- What is the cost-effectiveness of various design changes?

In general, the database enables

- Quantitative understanding of the relative performance of different tank car designs in various accident circumstances.
- The ability to assess the risk of transporting various hazardous materials using a particular tank specification or a particular tank component.
- Estimation of the potential benefit of incorporating a particular safety measure or changing a particular design element.
- Combined with financial information, identification of the most efficient risk reduction measures.

Railroad Accident/Incident Reporting System (RAIRS)

The U.S. DOT's FRA requires that all railroad accidents in which damage to track and equipment exceeds a specified monetary threshold be reported to RAIRS. The threshold is adjusted periodically for inflation and, in 2011, was $9,400. Compliance with RAIRS reporting requirements appears to be quite high and RAIRS plays an important role in the rail industry's ability to monitor its performance and measure safety trends in general, as well as understand the circumstances of accidents involving tank cars in particular. Besides providing basic information about the circumstances of an accident, RAIRS has an extensive set of detailed accident cause codes that enable understanding of the relationship between accident cause and various outcomes, including tank car performance. RAIRS data frequently form the principal basis for understanding the circumstances of accidents involving tank cars reported in the RSI-AAR TCAD.

Marine Information for Safety and Law Enforcement (MISLE)

The U.S. Coast Guard maintains the MISLE system to support their Marine Safety and Operations Programs. As part of the system, the Marine Casualty and Pollution Database contains data related to marine casualty investigations reportable under 46 CFR 4.03 and pollution investigations reportable under 33 CFR 153.203. The database contains information collected by U.S. Coast Guard personnel concerning vessel and waterfront facility accidents and marine pollution incidents throughout the United States and its territories.

Limitations of Existing Databases

Insufficient Denominator Data

Perhaps the biggest limitation of the existing accident databases for package performance studies to estimate the conditional probability of release for bulk packages is insufficient understanding of the denominator data. In other words, how often are packages exposed to various accident conditions in which they might fail? Detailed damage information is needed for packages in accidents whether or not a release took place.

Since 2005, the restructured HMIRS has required reporting of non-release accidents if they involve a cargo tank with a minimum 10,000-gallon capacity and the lading retention system is damaged. These are classified as Type C records, as opposed to Type A for release incidents and Type B for undeclared hazardous material shipment. *HMCRP Report 1* (Battelle Memorial Institute 2009) suggests that there may be significant underreporting of Type C records, based on comparisons between HMIRS and MCMIS and TIFA. Substantial improvement to HMIRS for package performance statistical studies would be achieved if Type C record underreporting could be reduced or eliminated. Underreporting could be reduced by cross-checking accident records in HMIRS with (1) records of hazardous material fatal accidents in TIFA, (2) records of rollover accidents involving cargo tanks in MCMIS, and (3) information on repaired cargo tanks retrieved by auditing hazardous-material-authorized repair shops. Periodic audits would increase the number of incidents being reported and result in better statistical analyses.

Accident Underreporting

Underreporting is a term that describes the discrepancy between the total number of reportable incidents and the number of incidents actually reported. In *HMCRP Report 1,* Battelle Memorial Institute (2009) sought to "bound the probable HMIRS reporting rate" by comparing HMIRS reports resulting in a fatality with FARS records involving vehicles transporting bulk quantities of hazardous materials. Bulk hazardous materials accidents resulting in a fatality were found to be reported between 26.9% and 59.7% of the time. Since Form DOT F 5800.1 is only required to be filed if a fatality is related to the release of hazardous materials, the FARS data comparison is not a direct indication of underreporting.

To further quantify the amount of underreporting for all crashes resulting in damage to the lading retention system, PHMSA HMIRS records between March 1, 2011, and September 30, 2011, were matched to FMCSA MCMIS crash files and a news article data set primarily using location date and description of events. During this period, the PHMSA HMIRS database contained 123 reports of accidents, 98 of

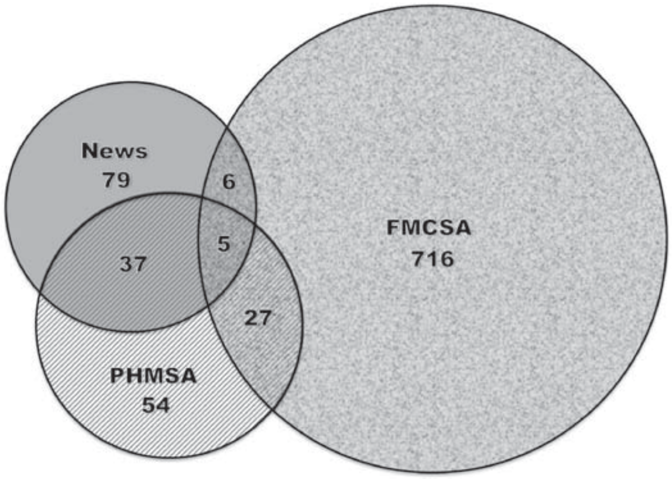


Figure 15. Venn diagram of hazardous materials accidents.

which resulted in lading loss. FMCSA MCMIS crash files contained 754 reports, 95 of which resulted in lading loss. It should be noted that not all 754 accidents resulted in damage to the lading retention system; however, at least 95 records (those resulting in lading loss) correspond to accidents in which the bulk package was damaged. The news article dataset was developed using news-source reported crashes identified through Google News Alert service. It included fields for date, time, location, state, a description of what events occurred and the consequences of those events, whether the bulk package overturned, and whether a release occurred. Between March 1, 2011, and September 30, 2011, 127 hazardous materials bulk package accidents were identified in news sources. Of these 127 accidents, 103 resulted in lading loss. The combined dataset consisted of 924 accidents (see Figure 15) of which 236 resulted in a release (see Figure 16).

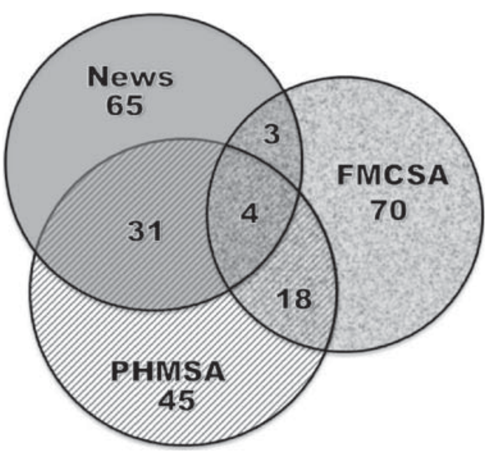


Figure 16. Venn diagram of hazardous materials releases.

This corresponds to an accident rate of 132 per month, of which 34 result in a release.

Since not all of the FMCSA MCMIS records are of accidents that resulted in damage to the lading retention system, the combined data set serves to identify the limits of underreporting. The lower bound considers only those FMCSA accidents in which a release occurred (all release accidents are required to be reported to PHMSA). Of the 278 records in which damage to the bulk package is confirmed, 155 accidents were not reported to PHMSA. This corresponds to an underreporting rate of 56%. The upper bound considers all FMCSA crash data involving a hazardous materials bulk package even though reporting all of these accidents may not be required. Of these 924 accidents, 801 are not reported to PHMSA. If all 924 accidents resulted in damage to the bulk package, the underreporting rate would be 87%. Therefore, between 13% and 44% of accidents in which a bulk package was damaged are reported to PHMSA.

Poor Quality of Reported Information

The reports submitted to PHMSA HMIRS have varying degrees of completeness and response consistency. Battelle's analysis of the HMIRS data showed that "some obvious Q/A checks are not being performed" (Battelle Memorial Institute 2009). A brief analysis of the accidents reported to PHMSA from January 1, 2006, to June 4, 2011, was undertaken to identify the percentage of accident reports that result in poor quality data (see Table 36). A total of 1,176 incidents were reported. Of these, the type of bulk container was identified for 997 incidents (85%). A description of what failed was identified for 961 incidents (82%). Reporting rates for bulk package design parameters such as package capacity, package amount, material of construction, design pressure, shell thickness, and head thickness range between 67% and 45%. Finally, a comparison of the number of reported incidents satisfying PHMSA's classification of a serious bulk release was compared to the number of incidents for which damages over $500 are reported. This analysis indicated that the cost of damages was incorrectly reported for at least 38 serious bulk releases (3%). Data checking and greater reporting compliance would result in better estimates of conditional probability of release.

Industry Experience

Several interviews were conducted with individuals having intimate knowledge of existing databases such as HMIRS, MCMIS, and TCAD. These interviews were conducted to determine potential challenges with data collection, understand how the data are analyzed, and gain insights into how the data could be used to enhance the industry's safety performance.

Table 36. Critical fields percentage reported for incidents in PHMSA HMIRS from January 1, 2006, to June 4, 2011.

Field	Number of Incidents	Percentage of Total Number of Incidents
Total Number of Reported Incidents	1,176	–
Container Specification/Non-Specification Container	997	85%
What Failed	961	82%
Package Capacity	745	63%
Package Amount	709	60%
Material of Construction	784	67%
Design Pressure	623	53%
Shell Thickness	543	46%
Head Thickness	528	45%

Note: "—" indicates this value is not applicable.

PHMSA's Hazardous Intelligence Portal (HIP) Designers Interview

The Hazardous Intelligence Portal (HIP) is PHMSA's current effort to provide a platform to collect and share hazardous material intelligence from several groups representing different transport modes within the U.S. Department of Transportation. HIP currently collects data from 15 sources, and it is anticipated that additional sources will be incorporated into the portal in the future. This effort was undertaken to organize a dashboard-type view of key data regarding the multimodal transportation of hazardous materials by company, enable comprehensive queries of data from multiple sources, and improve the prioritization and efficiency of inspections by regulatory agencies.

As part of this effort, HIP designers have worked closely with HMIRS data to update Form DOT F 5800.1. The main focus in updating Form DOT F 5800.1 is to improve data quality through both increasing data governance (only allowing acceptable answers) and replacing most free-form questions with drop-down list selection, yes/no, and check box answers. HIP designers indicate that the main limitations for using the PHMSA data for risk assessment include the following:

- Insufficient commodity flow data to provide cargo tank exposure estimates [for which the incorporation of radio frequency identification (RFID) tags on cargo tanks may be a solution].
- Incorrect and incomplete damage reporting.
- Inability to correct for this inconsistent reporting because PHMSA does not investigate cargo tank (highway) accidents.
- Significant underreporting of accidents with no follow-up to ensure accidents have been reported after initial notification has been provided.

In contrast with their ability to determine standard industry injury and fatality rates, PHMSA is unable to determine baseline rates for tank damage and hazardous material spills. Furthermore, based on their experience with the HMIRS, PHMSA identified the following future potential challenges:

- Reconciling differences between and performing analyses on combined data from old and new versions of data-reporting forms.
- The difficulty handling free-form answers when transferring accident reports from paper to digital format.
- Cleansing data so that new reports match previously submitted reports (again this typically arises with the presence of free-form answers).

FMCSA's Hazardous Materials Division Interview

In the interview with a representative of FMCSA the following three sources were identified that will enable cargo tank exposure estimates:

- The Motor Carrier Identification Report (Application for U.S. DOT Number) (MCS-150) currently collects information, including the annual number of miles traveled, from 60,000 carriers who transport some quantity of hazardous materials.
- The Combined Motor Carrier Identification Report and Hazardous Materials Permit Application (MCS-150B) also collects information, including the annual number of miles traveled, from motor carriers who transport certain types of hazardous materials requiring a safety permit. Note that those carriers who have registered with the MCS-150B are a subset of all carriers transporting hazardous materials as some hazardous materials are not part of the Hazardous

Materials Safety Permit program. For example, transporting liquid propane gas containing less than 85% methane does not require a safety permit.

- FMCSA's Unified Registration System (URS) will replace the MCS databases and, in addition to the annual number of miles traveled, will include the quantity and type (type and specification number) of cargo tanks that a motor carrier uses. However, only carriers who transport cargo tank trailers and cargo tank motor vehicles will be required to list the quantity and type of tank. Carriers who transport portable tanks will not be required to identify the quantity and type of portable tanks they transport.

In the interview, the possibility of local law enforcement officers providing much of the information needed for an accident damage database was also considered. Unfortunately there are not enough individuals with the appropriate training and expertise to reliably enter accurate and consistent accident damage information in a report. For example, although there are approximately 33,000 police jurisdictions across the United States, only 7,500 to 10,000 state level motor carrier inspectors are trained through the motor carrier safety assistance program. Furthermore, additional training would be required to obtain basic hazardous materials bulk package knowledge, and even fewer individuals have been trained to conduct post-crash root cause analysis. Inspectors are typically not allowed to provide comments beyond their level of training; therefore, many would not be permitted to inspect the package. Consequently, the data required for an accident damage database would not be recorded unless a supplemental report was initiated. On the other hand, basic police reports may indicate that a cargo tank was involved and, if so, would include carrier information. Thus, police report data could be used to identify those carriers who have had incidents and are required to submit Form DOT F 5800.1.

RSI-AAR TCAD Feedback

Since 1970, the RSI-AAR TCAD has been periodically evaluated for its effectiveness in aiding the industry in achieving various improvements in the safety of hazardous materials transportation by rail. The rail industry associations that sponsor that database indicate a savings of at least 11 times the cost of the implementation since inception. Periodic cost-benefit analyses have consistently indicated positive returns on investment in terms of improved safety and business operations. Furthermore, this industry-managed database has contributed to a greater degree of trust in the industry and contributed to consensus in regulatory proposal development. Regulators have been provided with analyses using data recorded in the TCAD to assess the need for and nature of new regulations. This has resulted in more pragmatic, effective, and fact-based regulatory proposals.

Approaches to Data Collection

The following three dichotomies were considered to facilitate decisions regarding the different approaches for development of an accident database:

- Voluntary versus mandatory data reporting.
- An extension of Form DOT F 5800.1 versus a new program.
- Government-sponsored versus industry-sponsored program.

Voluntary versus Mandatory Data Reporting

Voluntary Data Reporting

In a voluntary data-reporting approach, companies transporting hazardous material(s) would decide whether or not to participate in the data-reporting process. There could be guidelines or incentives, but the decision to participate would be strictly voluntary. By its nature, voluntary reporting results in self-selection, which might introduce some biases into the resulting data set that could be difficult to account for during data analysis. Voluntary reporting may be successful if incident information cannot be traced back to the individual or company because concerns about possible repercussions regarding the accident would be minimized. Individuals or companies submitting voluntary reports would need to recognize sufficient value from participation in the program. If the program was augmented by incentives such as an improved federal safety rating, the perceived value of participation might be enhanced. A successful voluntary program—in which there was substantial stakeholder participation, with a large number of high-quality reports—could offset the uncertainty related to the self-selection bias. Furthermore, a successful program might result in greater accuracy in the submitted data because of the vested interest of the contributors.

Mandatory Data Reporting

Mandatory data reporting would involve a statutory or regulatory mandate requiring that certain information be reported to an organization that would compile and manage the database. Since the approach is mandatory, the vested interest of individual contributors may be lower; therefore, efforts to ensure compliance would be required. Providing incentives would encourage contributors to increase data accuracy and improve compliance. A successful mandatory program would have near 100% reporting with high accuracy, resulting in a bias-free analysis.

Extended Form DOT F 5800.1 versus New Program

An Extension of Form DOT F 5800.1

Form DOT F 5800.1 records approximately 70% of the information identified as necessary to evaluate bulk package accident performance and estimate component-specific conditional probability of release. In order to increase the amount of information necessary to calculate bulk package performance that is available from Form DOT F 5800.1, the following additional data fields would need to be added:

- Bottom accident damage protection.
- Rollover accident damage protection.
- Presence of jacket.
- Jacket material.
- Jacket thickness.
- Insulation type.
- Type of damage (replaces "Type of Failure" in Form DOT F 5800.1).
- Whether the type of damage sustained resulted in failure.
- Damage location (on the bulk package).
- Damaged components (replaces "What Failed" in Form DOT F 5800.1).
- Whether the damage sustained by the component resulted in failure.

In order to calculate various conditional probabilities, these new data fields would also need to be linked to crash reports in PHMSA's HMIRS database. An extension of Form DOT F 5800.1 may be desirable as it would minimize the additional burden on individuals and companies required to file reports. However, this option does not address carrier and shipper concerns about data confidentiality and the improper use of data and analyses in ways that could harm contributors. These concerns might influence the degree of candor in reporting. One possibility that may enable the collection of additional data while maintaining the current level of reporting is the development of a possible "no-fault" appendix form, specific to the highway mode. This form could be used to collect additional data to describe the results of a root cause analysis and the tank damage observed as a result of crashes. Using the "no-fault" form would protect against improper use of data and analyses that could harm contributors.

New Program

In contrast to an extension of Form DOT F 5800.1, a new program could be set up to independently collect all the information necessary to compute the conditional probability of release. The anonymity of reporting could be preserved if the new program is not linked to PHMSA's HMIRS database and only collects information related to accident damage and not accident identification information such as date, time, location (of accident), and carrier/shipper information. Furthermore, a new program may have more flexibility in terms of adding or removing information fields in the future.

Government versus Industry Sponsored

Government Sponsored

In a government-sponsored program, either agency staff or a contractor would develop and manage the database. Such a program could be subjected to Freedom of Information Act requirements and may be less flexible and thus harder to make changes to, but it would have the stability and resources of a government program.

Industry Sponsored

In an industry-sponsored approach, data would be collected and housed by an industry association, a consortium of industry associations, or by a contracted private firm, research organization, or university. Industry would decide how to respond to requests for data analyses, including requests from government agencies. An industry group or consortium could hire a contractor to collect, compile, and analyze additional information from different sources such as police accident reports. Since this approach relies on industry funding, the value of such a database would need to be accepted by the majority of potential industry participants. Such an approach may result in greater potential anonymity because procedures and policies can be implemented to protect the information against the improper use of data and analyses in ways that harm contributors.

Industry Opinion

In addition to the surveys conducted to determine what information different stakeholders believe would be most useful in an accident damage database, stakeholder preferences regarding database development, structure, and functionality were surveyed. Due to the potential differences in the use of bulk package accident performance data, five surveys—targeting package manufacturers, carriers, shippers, repair facilities, and researchers/government organizations—were developed. Questions were tailored to each survey group to maximize collection of industry-sector-specific information. Copies of the surveys and an explanation of their development can be found in Appendix A.

Database Structure Preferences

The survey respondents were asked to identify whether the proposed accident database should be mandatory or voluntary,

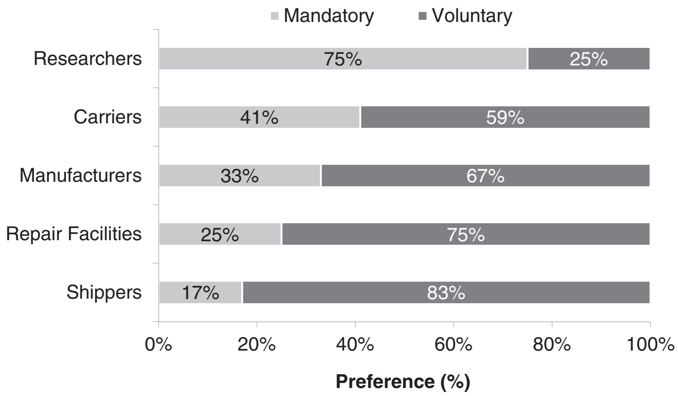


Figure 17. Survey respondent preferences for mandatory versus voluntary bulk package accident performance data collection program.

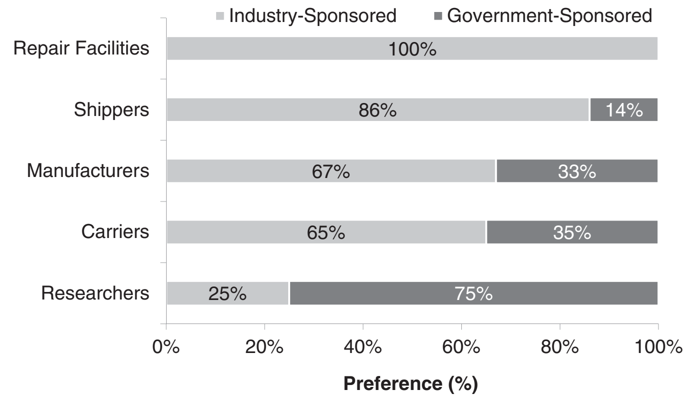


Figure 18. Survey respondent preferences for industry- versus government-sponsored bulk package accident performance data collection program.

sponsored by industry or government, and whether a new process/database should be built on existing programs (i.e., adding fields to Form DOT F 5800.1 and increasing reporting compliance). Opinions varied within industry groups concerning the preferred database approaches; however, the reasons for choosing one approach over another tended to be similar across stakeholder groups, regardless of the preferred approach.

In general, the respondents who may be responsible for providing accident and bulk package information tend to prefer a voluntary, industry-sponsored reporting approach while individuals using the reports for analyses tend to prefer a mandatory, government-sponsored approach (see Figures 17 and 18 and Tables 37 and 38). When comparing the possibility of building off of an existing database and designing a new database approach, most respondents favored the former option (see Figure 19 and Table 39).

Anticipated Voluntary Program Participation

Overall, the survey respondents believe that there would be little participation in a voluntary database if one were to be adopted. This contrasted with respondents' replies regarding whether they would participate in such an effort.

Manufacturers

The manufacturers who replied to the survey indicated that liability considerations and, to a lesser extent, confidentiality and paperwork are of greatest concern when considering participation in a voluntary program. As a result, while two manufacturers indicated they would be willing to participate in such a voluntary effort, one indicated that it probably would not.

Repair Facilities

Six of the repair facilities indicated that they would, or most likely would, be willing to provide data to populate a voluntary program while only one indicated that it probably would not participate in a voluntary program. The concerns identified by repair facilities are primarily the amount of paperwork accompanying such an effort followed by confidentiality, liability considerations, and cost.

Carriers

Of the 29 carriers who responded to the survey, 26 (90%) indicated that they would, or most likely would, be willing to

Table 37. Main concerns expressed by survey respondents regarding mandatory and voluntary bulk package accident performance data collection program.

Main Concerns	
Mandatory Approach	**Voluntary Approach**
• Increased workload justification/fairness • Fear of legal liability leads to unreported incidents if not mandatory • Small sample sizes from which to draw conclusions if reporting is not mandatory	• Increased workload with little perceived benefit • Fear of legal liability leads to underreporting • Small sample size for particular cargo tank type • Time lag between crash and report submittal

Table 38. Main concerns expressed by survey respondents regarding industry- and government-sponsored bulk package accident performance data collection program.

Main Concerns	
Industry-Sponsored Approach	**Government-Sponsored Approach**
• Industry has the expertise (knowledge/experience) to correctly interpret the data • Industry will be better able to keep the program on track • The industry is overregulated as it is, but has good self-regulation • Increased ability to change what is being reported • Industry-sponsored approaches lead to more homogeneous samples	• Government is better equipped to keep the program on track and deal with enforcement issues (if mandatory approach is also adopted) • Government is better able to absorb costs of maintaining such a database • Government has the expertise (knowledge/ experience) to correctly interpret the data • Data will be available for researchers to analyze

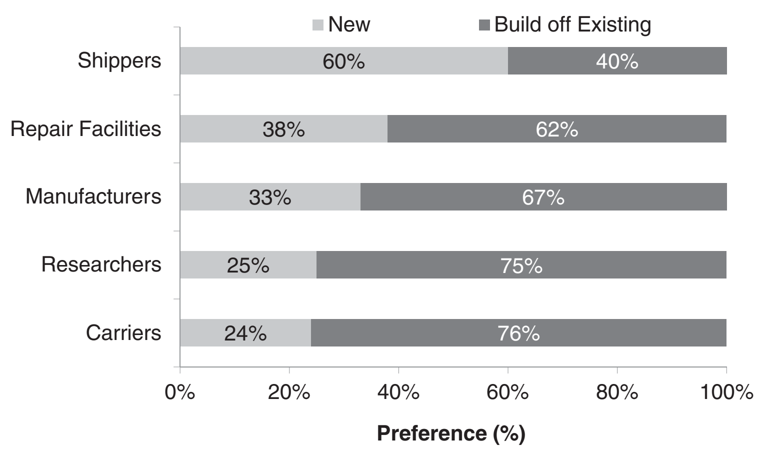


Figure 19. Survey respondent preferences for new bulk package accident performance data collection program versus accident performance data collection built off of existing program.

Table 39. Main concerns expressed by survey respondents regarding new bulk package accident performance data collection program and accident performance data collection built off of existing program.

Main Concerns	
New Bulk Package Data Collection Program	**Built Off Existing Program**
• Maintain familiarity with reporting • Reduce amount of information reported • Newer reporting technology leads to a better understanding of events and better quality data	• Quicker enactment • Ability to improve efficiency and simplify reporting • Reduce redundant reporting

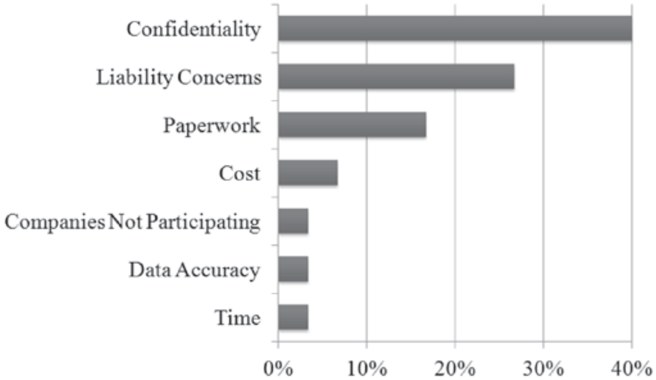


Figure 20. Carrier concerns with participating in a voluntary program.

provide data to populate a voluntary program. However, this positive response is from carriers who chose to participate in the survey. Consequently, the responses to this question may be skewed in favor of participation in another voluntary effort. Figure 20 shows the carriers' greatest concerns with participation in a voluntary program.

Shippers

Of the seven shippers who responded to the survey, six (85%) indicated that they would, or most likely would, be willing to provide data to populate a voluntary program. However, this positive response is from individuals who chose to participate in the survey. Consequently, the responses to this question may be skewed in favor of participation in another voluntary effort. The primary concerns identified by shippers are confidentiality, paperwork, and liability.

Data Collection Process Options

Combining the three dichotomous choices and the possible option to improve compliance with the existing Form DOT F 5800.1 results in the following nine options:

- Option A: Improved compliance with existing Form DOT F 5800.1 with damage reporting modifications.
- Option B: Government-sponsored extension of Form DOT F 5800.1 with mandatory participation.
- Option C: Government-sponsored extension of Form DOT F 5800.1 with voluntary participation.
- Option D: Government-sponsored new database with mandatory participation.
- Option E: Government-sponsored new database with voluntary participation.
- Option F: Industry-sponsored extension of Form DOT F 5800.1 with mandatory participation.
- Option G: Industry-sponsored extension of Form DOT F 5800.1 with voluntary participation.
- Option H: Industry-sponsored new database with mandatory participation.
- Option I: Industry-sponsored new database with voluntary participation.

Based on the survey results, Option G, an industry-sponsored extension of Form DOT F 5800.1 with voluntary participation, was considered the most desirable by respondents. However, Option B, a government-sponsored extension of Form DOT F 5800.1 requiring mandatory participation, is regarded as the best option to develop useful statistics within a suitable timeline. Both of these options are discussed further in the following section, together with the option to improve compliance with existing Form DOT F 5800.1 (Option A). Since these three options are based on extending Form DOT F 5800.1, a fourth option, Option D, a government-sponsored new database requiring mandatory participation, is also discussed. These four options were critically examined to identify the approach that was used in a pilot study.

A preliminary prioritization of the approaches was developed based on each approach's pros and cons, taking into consideration the following five procedural issues:

- Who would collect data.
- How data would be collected.
- Where it would be housed.
- How privileged data would be protected.
- Ease of implementation.

Option A: Improved Compliance with Existing Form DOT F 5800.1 with Damage Reporting Modifications

During the stakeholder interview process, Form DOT F 5800.1 was often identified by individuals and organizations as suitable for developing conditional probability of release and other useful statistical estimates. This would require the following:

- Failure descriptions would be modified to include damage descriptions regardless of whether or not a release occurred.
- Compliance would be increased in two areas: reporting that an accident had occurred and accurately reporting package design and accident characteristics.

As mentioned in Section 2, Form DOT F 5800.1 collects approximately 70% of the information identified as essential for estimating conditional probability of release. The modification of fields to record the damage type and identify the components damaged, regardless of whether or not a release occurred, would enable a general estimate of the conditional probability of release. However, the HMIRS (the database of accident reports submitted through Form DOT F 5800.1) is currently incomplete due to underreporting and the poor quality of reported information.

In terms of the five procedural issues listed above, Option A can be described as follows:

- **Who Would Collect Data.** PHMSA would continue to collect the accident data.
- **How Data Would Be Collected.** The data would continue to be collected using Form DOT F 5800.1.
- **Where Data Would Be Housed.** The data would be housed in PHMSA's HMIRS database.
- **How Privileged Data Would Be Protected.** The data fields in Form DOT F 5800.1 are non-privileged; therefore, protection is not currently provided.
- **Ease of Implementation.** PHMSA is currently working on updating the data-reporting process to improve data quality (e.g., the responses would be selected from a drop-down list as opposed to a free-form data entry field). Additionally, PHMSA is working with other DOT organizations to facilitate incident identification, thereby ensuring greater compliance (reduce underreporting). Additionally, compliance officers may be employed to ensure greater reporting compliance.

Modifying the form to ask for damage type and identification of damaged components may be more difficult and time consuming to implement. It may require a formal notice, review, and comment process as described in the Administrative Procedure Act. The previous change to Form DOT F 5800.1 took over 2 years to complete.

Option B: Government-Sponsored Extension of Form DOT F 5800.1 with Mandatory Participation

In addition to the information already collected using Form DOT F 5800.1 and the damage reporting modifications discussed as part of Option A, the following variables, at a minimum, are identified as essential to estimating cargo tank performance:

- Bottom accident damage protection.
- Rollover accident damage protection.
- Presence of jacket.
- Jacket material.
- Jacket thickness.
- Insulation type.
- Type of damage (replaces "Type of Failure" in Form DOT F 5800.1).
- Whether the type of damage sustained resulted in failure.
- Damage location (on the tank).
- Damaged components (replaces "What Failed" in Form DOT F 5800.1).
- Whether the damage sustained by the component resulted in failure.

Extending Form DOT F 5800.1 to include these additional variables would result in the ability to determine a reasonable estimate of the component-specific conditional probability of release combined with strategies to increase package performance in the event of an accident.

In terms of the five procedural issues listed above, Option B can be described as follows:

- **Who Would Collect Data.** Since most of the necessary information is collected in Form DOT F 5800.1, the most logical entity to collect the additional data is PHMSA; however, any government agency capable of making the reporting of accident data mandatory could also collect the additional accident data as long as the PHMSA report number was referenced in the extension database.
- **How Data Would Be Collected.** The data would be submitted to the government agency through an extended version of Form DOT F 5800.1 or a supplementary form.
- **Where Data Would Be Housed.** The data would be housed in an updated version of the HMIRS database or a database that references the corresponding HMIRS report number.
- **How Privileged Data Would Be Protected.** Since the option is an extension of Form DOT F 5800.1, the additional data collected, similar to the data now stored in the HMIRS, would be subject to current Freedom of Information laws and would therefore not be protected, unless a "no-fault" provision is being used.
- **Ease of Implementation.** Modifying the current Form DOT F 5800.1 to include the proposed fields would require an amendment to the current laws governing compliance. Therefore, this option may be difficult to implement because the process to change or establish new regulations must follow the procedures outlined in the Administrative Procedure Act.

Option D: Government-Sponsored New Database That Is Independent of Form DOT F 5800.1 with Mandatory Participation

This option focuses on methods to reduce the risk that data from a government-sponsored program would be used in a manner detrimental to database contributors. Reducing this risk could be achieved by using a "no-fault" system to report information regarding incidents and associated bulk container damage. In this system, access would be restricted, and individual or company names and other details of the accident that would enable identification of the parties involved would not be recorded. With this method, compliance with report submission would need to be addressed to ensure participation. Furthermore, the quality of data provided would need to be checked to encourage complete and consistent reporting.

In terms of the five procedural issues listed above, Option D can be described as follows:

- **Who Would Collect Data.** This option calls for mandatory data reporting by industry. A government agency would be required to carry out the compliance checks to ensure that reports are being submitted for all crashes in which the lading retention system is damaged.
- **How Data Would Be Collected.** To ensure confidential, mandatory reporting, an electronic form could be created that would provide the necessary quality checks for complete and consistent reporting. This could be achieved by providing options from which a respondent selects the most appropriate response and limiting the number of free-form answers. Furthermore, the new program would include a method for conducting compliance checks to ensure the reporting of all highway incidents involving the bulk transportation of hazardous material and resulting in damage to the lading retention system.
- **Where Data Would Be Housed.** There are multiple options for how the data could be stored. In a confidential reporting system, the data would be vetted for completeness and consistency prior to submittal of the incident report. Furthermore, there may be no possibility of correcting submitted reports. Therefore, the "no-fault" factual data could be added to the database and made available to the public upon receipt of the report.
- **How Privileged Data Would Be Protected.** Many details of an accident that enable the identification of the parties involved (e.g., individual or company name and date and location of the accident) are not required for estimating cargo tank performance and developing component-specific conditional probability of release. With a new database, focused solely on data fields that enable the development of cargo tank performance estimates, an anonymous reporting system could be developed. The data collected would be available to the public per the current Freedom of Information laws; however, anonymity could be maintained due to the large number of bulk hazardous material incidents that occur per month (approximately 132 per month).
- **Ease of Implementation.** Since this option requires establishing new regulations, according to the procedures outlined in the Administrative Procedure Act, the implementation might require a lead-time of 2 or more years. The database would also be less flexible for subsequent modifications.

Option G: Industry-Sponsored Extension of Form DOT F 5800.1 with Voluntary Participation

This option involves referencing records collected by PHMSA's HMIRS and requesting data not included in Form DOT F 5800.1 that are required for determining cargo tank performance and estimating the component-specific conditional probability of release. This database would be developed and maintained by a private sector organization or consortium of organizations on behalf of the carriers, shippers, and/or manufacturers of bulk packages transporting hazardous materials. There are two variations on this database that could be considered. In the first variation, the entire database would be consolidated. Carriers and/or shippers transporting hazardous materials would provide both accident damage information and package design information for all reportable incidents. Package design information would be limited to name plate and specification plate information as well as external visual information. The second variation would involve development of a separate database that contains package design parameters for all bulk packages. The advantage of this approach would be that the collection of more detailed information would be feasible. Accident data would be recorded using the extended Form DOT F 5800.1 as described above, but physical parameter data for the bulk packages involved would come from a second database. The ISO tank container information may be available from the UMLER provided they are all registered in that database. In this approach, the success of the accident damage database would depend upon widespread participation in the package design parameter database.

- **Who Would Collect Data and How It Would Be Collected.** In the first approach, a private sector organization would collect the accident damage information through an online or paper form. The process would require tracking and follow-up that would take multiple months to complete, as different data sources became available. The data collection process would need to be standardized by employing consistent definitions and criteria. Using an online form would enhance data quality and result in more reliable statistical development in a shorter timeframe. In the second approach, package design information for all major models of cargo tanks would be collected initially and then kept up-to-date on an ongoing basis. Accident damage information would be collected from the carriers using the extended Form DOT F 5800.1 along with the vehicle identification number (VIN) of the tank involved. This VIN would be used to identify the appropriate package design record from the tank characteristics database during data analyses.

- **Where Data Would Be Housed.** The accident damage data in both approaches would be housed with a private sector organization. The first approach would store basic package design information along with the accident damage database, while the second approach calls for a separate database.
- **How Privileged Data Would Be Protected.** Potential measures to protect any sensitive or proprietary information include using a flexible submittal deadline, limiting access to the database, controlling use of the information, approving all analysis of the information, and controlling the analysis distribution. A flexible submittal deadline involves allowing for information to be updated or submitted after potential litigation has been completed. The system would need to allow for updates to the initially submitted report. Time-based reminders may be beneficial as they encourage contributors to complete the initial report once litigation has finished. Access to information in the database could be limited to information provided by the requestor. For example, an individual company would only be able to view its own submitted accident reports. Only individuals employed by or authorized by the organization would have access to the entire database and only under strictly controlled terms of confidentiality. An oversight panel selected by the sponsoring organization would strictly control use of the database and the specifications for any analyses to be commissioned. When using this database users would be required to
  - Redact information superfluous to determining bulk package performance when combining information in the HMIRS and the extension information.
  - Only present information in aggregate.
  - Submit to oversight panel review and approval of all proposed analyses.

  Finally, completed analyses would be reviewed and approved by the panel who would also decide on distribution of results of each study.
- **Ease of Implementation.** Option G depends upon the willingness of industry organizations to host such a database, encourage their members to participate in such an effort, issue appropriate access to companies and consultants, and bear the associated costs. One benefit of such a system is that alterations to the data collected (such as adding or subtracting data fields) may be implemented within a short timeframe.

PHMSA staff members are currently updating their data-reporting system to incorporate more multiple choice options and pull-down menus, rather than free-form individual answers. This will improve consistency and probably the reliability and completeness of reporting as well. Such capability is best supported by an online program that can be easily adjusted to add, subtract, or modify fields as the need arises. However, not all respondents will have reliable, convenient Internet access, so a paper-based system will also be needed. For these cases, a printable version of the data entry form should be made available.

Selected Data Collection Process for Further Implementation

The four approaches to data collection—Option A: Improved compliance with existing Form DOT F 5800.1 with damage reporting modifications, Option B: Government-sponsored extension of Form DOT F 5800.1 requiring mandatory participation, Option D: Government-sponsored new database that is independent of Form DOT F 5800.1 with mandatory participation, and Option G: Industry-sponsored extension of Form DOT F 5800.1 with voluntary participation—were presented to the HM 07 project panel. The panel members were asked to evaluate the four options based on the following criteria (see Appendix D):

- Primary evaluation tools for HM 07:
  - Ease of implementation.
  - Program utility.
- Criteria required for success:
  - Participant acceptance.
  - Preservation of anonymity/confidentiality.
  - Participation in program/compliance.
  - Accuracy and completeness of the reports.
  - Container type representation.
- Cost/benefit criteria:
  - Value of program realized by sponsors.
  - Cost of program.
- Long-term capability criteria:
  - Stability/longevity of program.
  - Ability to expand program to evaluate other factors affecting hazardous materials release.

Using the evaluation criteria above, the panel suggested undertaking a more detailed consideration of the feasibility and efficiency of Option B: Government-sponsored extension of Form DOT F 5800.1 with mandatory participation. This represents a logical option that would incorporate some means to compel participation. It is possible and preferable that participation be compelled through an industry-based agreement.

The details of the possible implementation of Option B with a Level 4 degree of data refinement (as defined in Appendix D), plus fields describing the extent of damage and package breach, as discussed in Section 2, are examined here in further detail. The information to be collected for the database is identified and grouped according to logical associations. A review is also conducted of the following:

- Implementation considerations, such as offering logical response options based on previous responses;
- A possible prototype database management system including an appropriate schema for storing recorded accident and incident data; and
- Security access control considerations.

Collection of Data

A new addendum to Form DOT F 5800.1, for the purposes of evaluating highway bulk package performance, would be used to collect information in the following categories:

- Administrative variables.
- General package design characteristics.
- Compartment-specific design characteristics.
- Commodity information.
- Damage information.
- Accident information.

The specific data for these categories are discussed in subsequent sections. PHMSA's HMIRS includes much of the package design, commodity, and accident information needed for evaluating package performance. Additionally, for those incidents that have resulted in a release, the database also includes identification of components that failed. These variables could be imported into the bulk package performance database for incidents in which the bulk package consists of a single container. However, the underreporting and data quality issues in PHMSA's HMIRS need to be addressed prior to use in the addendum.

The bulk package performance database would be focused solely on highway bulk package performance. Therefore, it would not contain information for other modes. Furthermore, in the data set created by information gathered through the addendum, a single report might contain information corresponding to more than one commodity if an incident involves a multi-compartment bulk package. This differs from the current HMIRS which contains a report for each commodity transported by the bulk package at the time of the accident. Finally, the database created by information gathered through the addendum would include bulk tank capacity and commodity quantity by compartment instead of commodity type.

Administrative Variables

As with the existing databases, administrative variables would be necessary to properly track information in the bulk package performance database (see Table 40). At a minimum, the bulk package performance database should include a link to the Form DOT F 5800.1 report, a report submittal timestamp to track participation, and a variable to record whether the information submitted was verified.

Table 40. Administrative variables.

Variable	Possible Responses
PHMSA Incident ID	Numerical Value
Report Time-stamp	Date and Time
Quality Check	Verified Not Verified

General Package Design Characteristics

Several general highway bulk package design characteristics are already available in the existing Form DOT F 5800.1 records (see Table 41). These include the following:

- The response to Question 24 identifies the type of bulk package.
- The response to Question 26a identifies the specification of the bulk package.
- The response to Question 27 identifies the number of compartments in the package.
- The response to Question 28 identifies the package's general material type.

These general bulk package design characteristics could be imported from PHMSA's HMIRS into the highway bulk package performance database.

Additionally, the bulk package performance database should indicate whether a cargo tank is mounted on a trailer or on a chassis (see Table 42) and whether or not the bulk package is jacketed.

Compartment-Specific Design Characteristics

Individuals reporting a bulk package accident using Form DOT F 5800.1 are instructed to identify the capacity of the package in Question 27 and working pressure, shell thickness, head thickness, and type of valve or device (if it failed) in Question 28. However, for packages with multiple compartments, not all of the compartments would be damaged or compromised in an accident. Therefore, the specific design characteristics for each compartment in the package should be collected (see Table 43). This information can be found on the specification plate associated with each compartment.

Table 41. General package design characteristics available from existing Form DOT F 5800.1 fields.

Variable	Possible Responses	
Packaging Type	Cargo Tank Portable Tank	
General Material Type	Aluminum Stainless Steel Carbon Steel Composite Materials Combination	
Cargo Tank Specification	**Cargo Tank**	**Portable Tank**
	DOT 406	T1
	MC 306	T2
	DOT 407	T3
	MC 407	T4
	DOT 412	T5
	MC 312	T6
	MC 331	T7
	MC 338	T8
	Asphalt Cargo Tank	T9
	Compressed Gas Tube Trailer	T10
	Other	T11
		T12
		T13
		T14
		T15
		T16
		T17
		T18
		T19
		T20
		T21
		T22
		T50
		T75
		DOT Specification 51
		DOT Specification 56
		DOT Specification 57
		DOT Specification 60
		IM 101 – IMO Type 1
		IM 102 – IMO Type 2
		IMO Type 5
		Cryogenic Tank Container – IMO Type 7
		Tube Module
		Other
Number of Compartments	**Cargo Tank**	**Portable Tank**
	1 2 3 4 5 6	N/A

Table 42. Other general package design characteristics.

Variable	Possible Responses	
Mounting	Trailer Mounted Truck Mounted	
Jacketed	Yes No	
	Cargo Tank	**Portable Tank**
Other Spec CT	Text-entered	N/A
Other Spec PT	N/A	Text-entered

To ensure data quality, the available responses for material thickness (see Table 44) could be provided for various general material types.

Additionally, the available responses for working pressure (see Table 45) could be provided for some specifications.

Commodity Information

Commodity information from Form DOT F 5800.1 can be imported from PHMSA's HMIRS (see Table 46) if there is only one compartment. In Question 16, the individual reporting the accident identifies the hazard class and division. In Question 17, the material's identification number is reported. The material's packing group is reported as part of Question 18. Finally, the amount of hazardous material in the package is reported as part of Question 27. It is important to note that the accident data collection system presented here calls for commodity information to be provided for each compartment. Thus, a package that contains more than one type of commodity will have only one record in the general accident data set. Furthermore, providing logical responses from which the reporter must choose will improve the quality of the record.

Damage Information

The accurate recording of damage information is necessary to develop bulk package statistical performance metrics, regardless of whether the damage resulted in the release of lading. When responding to Question 25 in Form DOT F 5800.1, the individual currently identifies which component failed, how it failed, and the cause of the failure. However, damage information for incidents that did not result in a release and information concerning the location of the failure are not recorded in the current Form DOT F 5800.1. Thus, the bulk package performance database should record the general location of the damage (see Table 48). To assist with the selection of the appropriate damage location, illustrations could be provided—such as those shown in Figures 21, 22, and 23. For each location where damage was sustained, the damaged components should be recorded (see Table 49). For the purposes of increasing the quality of the information collected, the possible responses should be tailored so that only a logical list of components is available for selection. For each damaged component, the type, dimensions, and whether the damage resulted in a release of lading should be indicated (see Table 50). Finally, if the damage resulted in a release of lading, the amount of lading

Table 43. Compartment-specific package design characteristics.

Variable	Possible Responses
Tank Capacity	Text-entered numerical value
Tank Capacity Units of Measure	GCF (Gas—Cubic Foot) LGA (Liquid—Gallon)
Head Material (as listed on spec. plate)	Text-entered
Shell Material (as listed on spec. plate)	Text-entered
Front Head Thickness	See Table 44
Rear Head Thickness	See Table 44
Top Shell Thickness	See Table 44
Side Shell Thickness	See Table 44
Bottom Shell Thickness	See Table 44
Working Pressure	See Table 45

Table 44. Material thickness response options.

Material	Thickness Range (Inches)	Corresponding Gauges
Aluminum	0.100 inches to 0.500 inches	10 gauge (0.102 inches) 9 gauge (0.114 inches) 8 gauge (0.129 inches) 7 gauge (0.144 inches) 6 gauge (0.162 inches) 5 gauge (0.182 inches) 4 gauge (0.204 inches) 3 gauge (0.229 inches) 2 gauge (0.258 inches) 1 gauge (0.289 inches) 0 gauge (0.325 inches) 00 gauge (0.365 inches) 000 gauge (0.410 inches) 0000 gauge (0.460 inches)
Stainless Steel	0.100 inches to 0.500 inches	12 gauge (0.109 inches) 11 gauge (0.125 inches) 10 gauge (0.141 inches) 9 gauge (0.156 inches) 8 gauge (0.172 inches) 7 gauge (0.187 inches) 6 gauge (0.203 inches) 5 gauge (0.219 inches) 4 gauge (0.234 inches) 3 gauge (0.250 inches) 2 gauge (0.266 inches) 1 gauge (0.281 inches) 0 gauge (0.312 inches) 00 gauge (0.344 inches) 000 gauge (0.375 inches) 0000 gauge (0.406 inches) 00000 gauge (0.437 inches) 000000 gauge (0.469 inches)
Carbon Steel	0.100 inches to 0.240 inches	12 gauge (0.105 inches) 11 gauge (0.120 inches) 10 gauge (0.134 inches) 9 gauge (0.149 inches) 8 gauge (0.164 inches) 7 gauge (0.179 inches) 6 gauge (0.194 inches) 5 gauge (0.209 inches) 4 gauge (0.224 inches) 3 gauge (0.239 inches)
Composite Materials	0.100 inches to 0.500 inches	N/A
Combination	0.100 inches to 0.500 inches	N/A

and the dimensions of the breach should be recorded (see Table 51). However, if multiple components release lading, the quantity lost from each of the leaking components may be difficult to ascertain.

Accident Information

Basic accident information is currently recorded on Form DOT F 5800.1. Question 37 requests the estimated speed of the bulk package prior to impact and whether the vehicle overturned. A bulk package performance database should also record whether an object struck the bulk package or the bulk package struck an object, the type of object, and the object's speed (if appropriate) (see Table 52).

Technical Implementation Considerations

A modern data collection system could take advantage of the capabilities offered by information technologies and systems to improve the quality of reported data and the

Table 45. Working pressure response options.

Specification	Pressure Range
DOT 406 or MC 306	2.65–2.99 psig 3.00–3.49 psig 3.50–4.00 psig
DOT 407 or MC 307	25–29 psig 30–34 psig 35–40 psig
DOT 412 or MC 312	5–9 psig 10–14 psig 15–19 psig 20–25 psig
MC 331	100–199 psig 200–299 psig 300–399 psig 400–500 psig
MC 338	23.5–99 psig 100–199 psig 200–299 psig 300–399 psig 400–500 psig
All Others	Text-entered numerical value (in psig)

ease of reporting. For the bulk package performance database proposed here, appropriate technical capabilities may include dynamically adjusting the availability of questions and responses based on logic and previous responses, providing a text-based area for special cases, and performing automatic quality checks as much as possible.

Logical Presentation of Questions and Responses

The reporting form can be designed to offer logical choices by dynamically adjusting which fields are displayed based on responses to earlier questions. This would improve responders' efficiency and reduce errors. The following fields are candidates for such a dynamic form:

- Any field collecting text-entered information corresponding to "Other" responses could be hidden if "Other" is not selected.
- A question asking whether the package is truck or trailer mounted can be hidden if "Portable Tank" is selected as the bulk package type.
- Compartment-specific bulk package design questions can be hidden for all compartments greater than that selected.
- Questions regarding a commodity's hazardous division could be hidden until the hazardous class has been selected.
- Diagrams and questions corresponding to the damaged area could dynamically reflect the type of bulk package involved in the accident. At a minimum, damaged areas are recommended to be based on selections of "Portable Tank," "Cargo Tank," and "Truck Mounted," or "Cargo Tank" and "Trailer Mounted." A fuller implementation of this concept may designate damaged areas based on the bulk package specification and number of compartments, in addition to how the bulk package was mounted (if appropriate).

Table 46. Commodity information.

Variable	Possible Responses
Hazardous Class	Class 1—Explosives Class 2—Gases Class 3—Flammable Liquids (and Combustible Liquids) Class 4—Flammable Solids, Spontaneously Combustible Materials, etc. Class 5—Oxidizing Substances and Organic Peroxides Class 6—Toxic Substances and Infectious Substances Class 7—Radioactive Materials Class 8—Corrosive Substances Class 9—Miscellaneous Hazardous Materials/Products, Substances or Organisms Non-Hazardous
Hazardous Division	See Table 47
Packaging Group	I II III
Hazardous Material Identification Number	NA or UN plus a text-entered numerical value consisting of four digits
Packaged Amount	Text-entered numerical value
Packaged Amount Unit of Measure	GCF LGA

Table 47. Possible responses for hazardous division.

Hazardous Class	Possible Responses
Class 1—Explosives	Division 1.1—Explosives with a Mass Explosion Hazard Division 1.2—Explosives with a Projection Hazard Division 1.3—Explosives with Predominantly a Fire Hazard Division 1.4—Explosives with No Significant Blast Hazard Division 1.5—Very Insensitive Explosives with a Mass Explosion Hazard Division 1.6—Extremely Insensitive Articles
Class 2—Gases	Division 2.1—Flammable Gases Division 2.2—Non-Flammable, Non-Toxic Gases Division 2.3—Toxic Gases
Class 4—Flammable Solids, Spontaneously Combustible Materials, etc.	Division 4.1—Flammable Solids Division 4.2—Spontaneously Combustible Materials Division 4.3—Water-Reactive Substances/Dangerous When Wet Materials
Class 5—Oxidizing Substances and Organic Peroxides	Division 5.1—Oxidizing Substances Division 5.2—Organic Peroxides
Class 6—Toxic Substances and Infectious Substances	Division 6.1—Toxic Substances Division 6.2—Infectious Substances

Table 48. Damage locations.

Possible Responses	
Cargo Tank (see Figures 21 and 22)	**Portable Tank (see Figure 23)**
1 - Front Head Damage Below Centerline	1 - Head Damage Below Centerline
2 - Front Head Damage on Centerline	2 - Head Damage on Centerline
3 - Front Head Damage Above Centerline	3 - Head Damage Above Centerline
4 - Front Head Destroyed	4 - Head Destroyed
5 - Rear Head Damage Below Centerline	5 - Shell Destroyed
6 - Rear Head Damage on Centerline	6 - Damage at Either End on Bottom Half of Tank
7 - Rear Head Damage Above Centerline	7 - Damage at Center on Bottom Half of Tank
8 - Rear Head Destroyed	8 - Damage at Either End on Top Half of Tank
9 - Bottom Front Driver-Side Damage	9 - Damage at Center on Top Half of Tank
10 - Bottom Middle Driver-Side Damage	10 - Damage in Vicinity of Sump
11 - Bottom Rear Driver-Side Damage	
12 - Top Front Driver-Side Damage	
13 - Top Middle Driver-Side Damage	
14 - Top Rear Driver-Side Damage	
15 - Bottom Front Passenger-Side Damage	
16 - Bottom Middle Passenger-Side Damage	
17 - Bottom Rear Passenger-Side Damage	
18 - Top Front Passenger-Side Damage	
19 - Top Middle Passenger-Side Damage	
20 - Top Rear Passenger-Side Damage	
21 - Damage to Piping and/or Undercarriage Below the Tank	

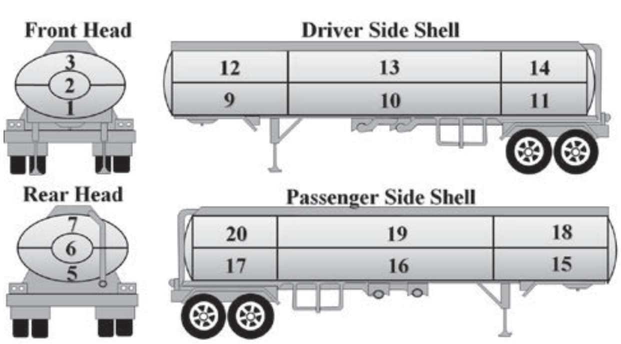


Figure 21. Example illustration of damage locations for a trailer-mounted cargo tank.

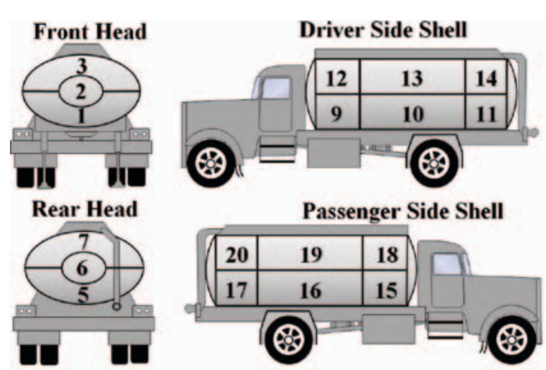


Figure 22. Example illustration of damage locations for a truck-mounted cargo tank.

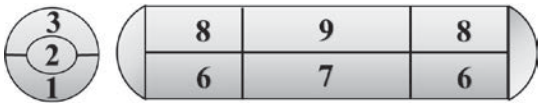


Figure 23. Example illustration of damage locations for a portable tank.

- Identification of components damaged within a damaged area could be hidden until that part of the bulk package is selected.
- Questions concerning the damage type, its dimensions, and whether or not a release occurred could be hidden until a particular component is selected.
- Questions concerning the amount released and the dimensions of the breach could be hidden until a release had been verified.
- Questions concerning the speed of the object impacting the bulk package could be hidden until a type of object with the ability to move has been selected.

Table 49. Component damaged.

Possible Responses	
Cargo Tank	**Portable Tank**
Tank Head	Tank Head
Tank Shell	Tank Shell
Air Inlet	Bolts and Nuts
Bolts and Nuts	Bottom Outlet Valve
Bottom Outlet Valve	Check Valve
Check Valve	Chime
Cover	Closure (e.g., Cap, Top, or Plug)
Discharge Valve or Coupling	Cover
Excess Flow Valve	Frangible Disc
Fill Hole	Fusible Pressure Relief Device or Element
Flange	Gasket
Frangible Disc	Gauging Device
Fusible Pressure Relief Device or Element	Hose
Gasket	Inlet (Loading) Valve
Gauging Device	Lifting Lug
Heater Coil	Liner
High Level Sensor	Loading or Unloading Lines
Hose	Manway or Dome Cover
Hose Adaptor or Coupling	Outer Frame
Inlet (Loading) Valve	Piping or Fittings
Lifting Lug	Pressure Relief Valve or Device—Reclosing
Liner	Threaded Connection
Liquid Line	Vacuum Relief Valve
Liquid Valve	Weld or Seam
Loading or Unloading Lines	Other
Locking Bar	
Manway or Dome Cover	
Mounting Studs	
O-Ring or Seals	
Piping or Fittings	
Shear Section	
Pressure Relief Valve or Device—Non-Reclosing	
Pressure Relief Valve or Device—Reclosing	
Remote Control Device	
Sample Line	
Sump	
Thermometer Well	
Threaded Connection	
Vacuum Relief Valve	
Valve Body	
Valve Seat	
Valve Spring	
Valve Stem	
Vapor Valve	
Vent	
Washout	
Weld or Seam	
Other	

Table 50. Damage information collected for each component damaged.

Variable	Possible Responses
Damage Type	Abraded Bent Burst or Ruptured Cracked Crushed Failed to Operate Gouged or Cut Leaked Punctured Ripped or Torn Structural Torn Off or Damaged Vented Unknown Other
Damage Width	Text-entered Numerical Value
Damage Width Units of Measure	Inches Feet
Damage Height	Text-entered Numerical Value
Damage Height Units of Measure	Inches Feet
Damage Depth	Text-entered Numerical Value
Damage Depth Units of Measure	Inches Feet
Whether Damage Resulted in a Release	Yes No

Logical Responses and Quality Checks

Presenting logical responses based on previous responses reduces the time and effort it takes to fill out a report and improves data quality. This can be achieved by making the selection of responses accessible using drop-down menus and/or check box or radio button graphical user interfaces. However, where it is possible that not all of the responses have been provided, an "Other" field should be available and followed by a field in which text can be entered.

Additionally, whether or not responses are adjusted dynamically, a series of quality checks should be conducted upon submission of the report to ensure that the responses are congruent.

Table 51. Information collected for each component resulting in release.

Variable	Possible Responses
Amount Released	Text-entered Numerical Value
Amount Released Units of Measure	GCF (Gas—Cubic Foot) LGA (Liquid—Gallon)
Breach Width	Text-entered Numerical Value
Breach Width Units of Measure	Inches Feet
Breach Height	Text-entered Numerical Value
Breach Height Units of Measure	Inches Feet

Variables influencing responses include the following:

- Packaging type (cargo tank or portable tank) influences which specifications will populate the responses for the variable "Tank Specification" and whether the number of compartments within the bulk package can be greater than one.
- General material type—whether aluminum, stainless steel, carbon steel, composite materials, combination, or other—causes the responses for head and shell materials and their associated thicknesses to be populated.
- Tank specification, itself a subsidiary of "packaging type," should adjust the available ranges of working pressure from which the reporter can choose. Furthermore, the commodity information for each tank type should be reflected in the available responses for the commodity-related variables.
- Hazard class and division, packaging group, and hazardous material identification number influence each other. The ideal form would allow the reporter to respond to the variable of their choice and adjust the available responses for the remaining variables accordingly.
- Tank capacity bounds the packaged amount.
- Packaged amount bounds the amount released.
- The damaged component selected limits the damage type and dimensions (including damage width, height, and depth).
- The damage dimensions restrict the dimensions of the breach.
- If the bulk package was struck by an object, that object must not be stationary.

Prototype Database Management System

A prototype database management system was developed using Microsoft Access to provide a framework in which to record accident data. This basic framework illustrates a methodology for storing information collected as part of the pilot study; however, it requires further enhancement to enable data collection by the online form to be mapped directly to the database management system.

Schema for Storing Recorded Data

The envisioned schema for storing recorded data consists of six tables (see Figure 24):

- Administrative variables.
- General design characteristics.
- Compartment-specific package design characteristics.
- Compartment-specific commodity information.
- Basic accident information.
- Damage information.

Table 52. Accident information.

Variable	Possible Responses	
Vehicle Speed Prior to Crash	• 0–4 mph • 5–9 mph • 10–14 mph • 15–19 mph • 20–24 mph • 25–29 mph • 30–34 mph • 35–39 mph • 40–44 mph • 45–49 mph • 50–54 mph • 55–59 mph • 60–64 mph • 65–69 mph • 70–74 mph • 75–79 mph • 80 mph or greater	
How Vehicle Speed Was Established	• Obtained from Vehicle Data Recorders • Estimated Based on Speed Limit • Driver Estimated • Other	
Overturned	• Yes • No	
Whether the Bulk Package Was Struck by or Struck an Object	• An Object Struck the Bulk Package • The Bulk Package Struck an Object	
Impacting Object	Object Struck the Bulk Package	Bulk Package Struck an Object
	• Passenger Vehicle • Heavy Vehicle • Other	• Passenger Vehicle • Heavy Vehicle • Roadway • Ground • Concrete Barrier • Guard Rail • Lighting Pole • Other
Speed of Impacting Object Prior to Crash	Passenger Vehicle or Heavy Vehicle	Other Objects
	• 0–4 mph • 5–9 mph • 10–14 mph • 15–19 mph • 20–24 mph • 25–29 mph • 30–34 mph • 35–39 mph • 40–44 mph • 45–49 mph • 50–54 mph • 55–59 mph • 60–64 mph • 65–69 mph • 70–74 mph • 75–79 mph • 80 mph or greater	N/A
How the Impacting Object Speed Was Established	• Obtained from Vehicle Data Recorders • Estimated Based on Speed Limit • Driver Estimated • Other	N/A

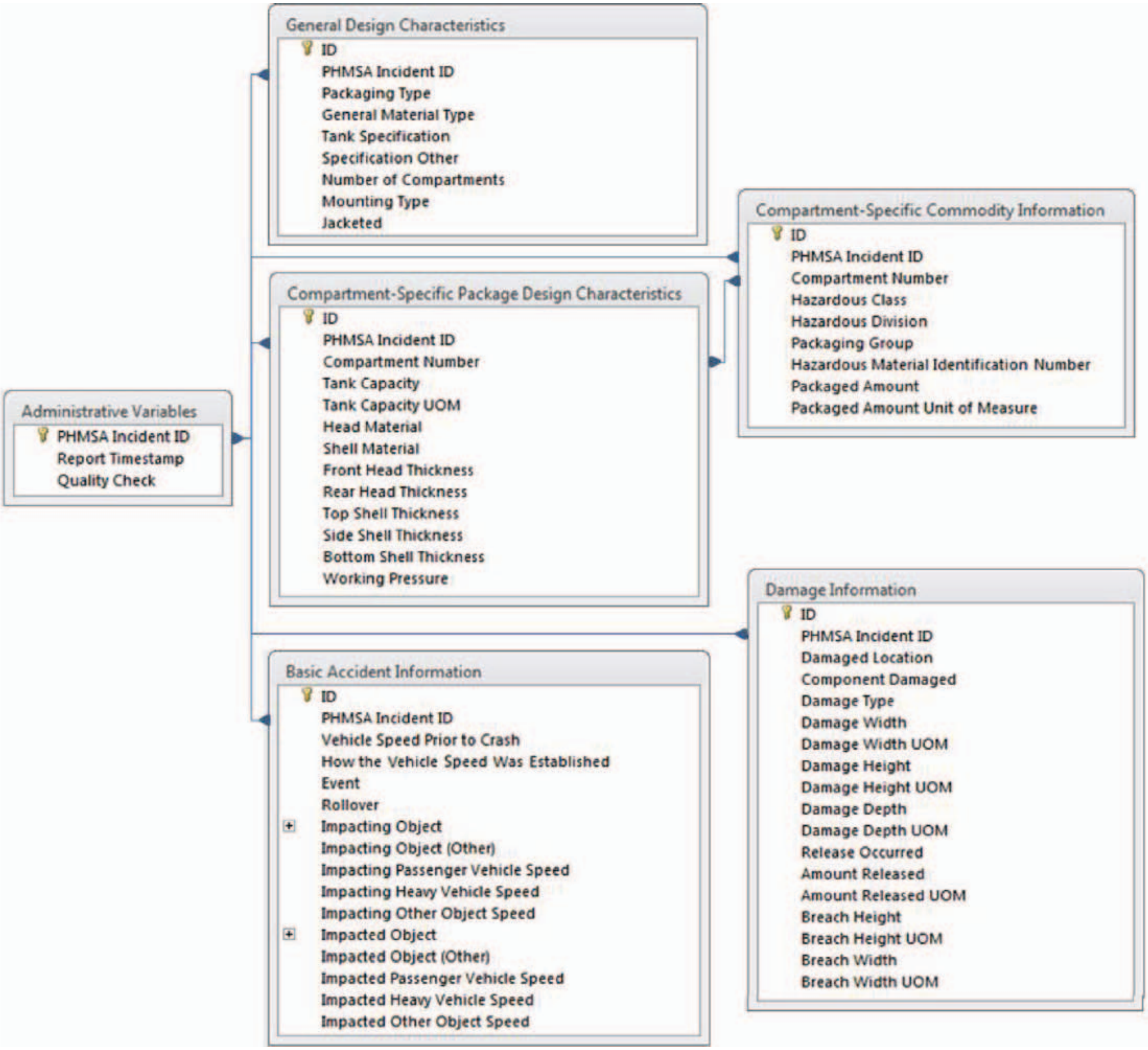


Figure 24. Prototype database management system.

In this database schema, each cargo tank involved in an accident is assigned a separate incident identification number. Due to the nature of the data collected in the Administrative Variables, General Design Characteristics, and Basic Accident Information tables, one record corresponding to each reported accident is expected. Should this methodology be incorporated into the Form DOT F 5800.1 reporting system, these data sets could be combined directly with the existing HMIRS.

The number of records in the Compartment-Specific Package Design Characteristics and Compartment-Specific Commodity Information tables corresponds to the number of compartments for each recorded incident. For error checking and analysis purposes, these two data sets should also be linked using the compartment number.

It is proposed that damage information be stored in such a way that there may be multiple listings of a particular damage location because multiple components within that area may be damaged. The number of records in this data set will be the product of the number of reported accidents (represented by the number of unique PHMSA Incident IDs), the number of areas damaged on the cargo tank, and the number of components damaged. Caution should be exercised in the interpretation of the responses stored in this data set as an incident resulting in a release will also contain records of non-release damage.

Security Access Controls

The implementation of this prototype database management system may require, at a minimum, three levels of access: administrator access, reporter access, and public access. Administrator access would enable database owners to provide access to other users, create back-ups of the data sets, implement data quality checks, correct errors, track the number of views the data set generates, and link to data sets generated by other organizations. By necessity, this level of access should have the greatest amount of security. Reporter access is granted to those individuals or companies who will be required to submit a report. Access can be granted on a per-accident basis or to all bulk package transporters. Distinguishing between reporters and the general public ensures that data validity will be maintained. Finally, public access is the most general type of access. Currently, PHMSA allows free access to its data via an online form.

An alternate approach is to provide access through a third party, similar to the approach employed by FMCSA. Prior to the implementation of such a database, there should be careful consideration of the level of public accessibility. The decision about whether to share raw or processed data with the public should be weighted with possible confidentiality concerns. Additionally, if automatic data checks are not implemented, it may be desirable to institute a manual quality check prior to making the data publicly available.

To ensure that individuals (1) are allowed to access the system, (2) access the system from an appropriate connection, (3) have permission to utilize the data/system in a particular manner, and (4) generate an activity log should data security become a concern, security access controls should be incorporated. Access to the system is typically ensured using a login identification coupled with a password. This is particularly important for administrator access to prevent actions such as deleting or maliciously altering collected data. Administrative access may also be restricted to within a company firewall to maintain data integrity. The same requirement is not anticipated to be necessary for reporter or public access; however, limiting access to within the United States may be considered. Granting permissions to utilize the data/system in a particular manner is necessary to ensure that the database is used appropriately. Therefore, the general public should be restricted to reading database contents and viewing a directory of the database contents. Reporters should have limited authorization to create new reports or update existing reports that they have previously submitted. Another method to ensure that the database is used appropriately is to generate an activity log. The activity log should include the time and date of changes to the data set as well as who initiated the changes and what was changed. Thus, should accidental changes occur, they can be undone and progress tracking can be accomplished. Activity logs can also be used to count the number of views or downloads of the accident damage data and gather information concerning the individuals accessing the public documents, thus enabling administrators to determine how best to present the data.

Pilot Study

The potential collection of this bulk package accident damage data was explored using a pilot study. The purpose of the pilot study was to evaluate the quality of data expected from such a data collection system, to identify improvements to the data collection system itself, to demonstrate the types of analyses that could be facilitated by the database, and to estimate the period of time required to collect incident data sufficient to support reasonable statistical analyses.

To achieve these goals, an online pilot data collection tool was developed (see Appendix E). Invitations to participate in the pilot study were sent to NTTC members, Dow Chemical Company carriers, and individuals who had submitted Form DOT F 5800.1 corresponding to highway bulk package accident. Each pilot study participant was asked to provide one or two reports concerning accidents that may or may not have resulted in the release of hazardous materials. They were informed that recording non-release incidents was as important as recording incidents in which there was a hazardous materials release. Non-release accident information enables identification of accident scenarios during which certain materials and components do not fail. On the other hand, the recording of accident information for an incident that resulted in a release enables identification of accident scenarios during which tank components fail.

Due to a low level of participation in the pilot study, an alternative method for gathering bulk package accident performance information was employed to supplement the number of accident reports gathered by the data collection tool. This alternative method consisted of a manual review of NTSB reports and information gathered from multiple sources including PHMSA HMIRS reports, FMCSA MCMIS reports, and news articles.

Pilot Data Collection Tool

The online data collection tool was developed using a combination of Hypertext Markup Language (HTML), Cascading Style Sheets (CSS), PHP, and JavaScript. The data collection tool incorporated several dynamic features but was not designed to automatically perform quality checks. Instead, quality checks were conducted manually. Participants were encouraged to provide contact information (with the stipulation that all contact information would remain confidential) so that they could be contacted if manual quality checks revealed a need for additional information. Additionally, participants were assured that the contact information provided would only be used to verify responses to the pilot study and not for any purpose beyond the pilot study.

The pilot data collection tool was designed to enable bulk package accident damage information to be collected accurately and with minimal difficulty for pilot study participants. However, the project team envisions the incorporation of several additional features in a fully implemented system. To identify useful features, participants were also asked to share their ideas on how to improve the collection process through a series of comment boxes.

Pilot Data Collection Tool Launch Site

All invitations to participate in the pilot study directed the participant to a website that introduced the project and provided information about the types of information to be requested as part of the pilot study. (Screenshots of the sections of the pilot study data collection tool that are discussed here and below can be seen in Appendix E.) From the website's home page, participants could access the pilot data collection tool to submit a report.

Pilot Data Collection Tool Instructions

Upon accessing the pilot data collection tool, participants were instructed to forgo using their browser's "back," "forward," or "refresh" commands prior to submitting the report. This was necessary because the data collection tool was not sophisticated enough to prevent a resetting of the form when the browser refreshed a page, thereby causing their responses to be erased (see Appendix E).

The participant was then directed to the instruction page for the data collection tool (see Appendix E). The participant was again reminded not to leave the page or refresh their browser prior to submitting their information because doing so would cause the information entered to be lost. They were informed that the submit button could be found on the "Accident Information" tab, once the type of bulk package was identified. To start, the participant was asked to identify the type of bulk package. Once the type of bulk package was identified, additional fields appeared that were specific to the type of package selected. After completing the fields specific to the package type, the participant was asked to proceed to the "Bulk Package Information" tab.

The instructions also informed participants that if they were unsure what information was being requested or would like clarification concerning the available responses, they should refer to the tab marked "Pilot Test Supplemental Information." If the information was not there, they were requested to leave a comment so that this information could be provided in the future.

Finally, participants were informed that because this was a pilot study, quality checks had not been built into the data collection tool. Therefore, participants were asked to take measures to ensure that they had responded correctly. Participants were also asked to provide their contact information so that clarification could be obtained should an unexpected result be received. They were once again informed that all contact information provided would remain confidential and be removed from the data set containing the results of the pilot study after the information had been corroborated.

Data Collection Pages

The pilot data collection tool consisted of the following four sections (see Appendix E):

- **Bulk package design information.** For cargo tanks, this section recorded information that was visually detected or listed on the cargo tank name plate. To clarify what information was requested, an example name plate was included. For portable tanks, this section recorded information that was found either visually, stamped on the tank's head or a separate placard, or provided as part of the container specifications.
- **Basic commodity information.** This section recorded information found in shipping papers associated with the commodity transported at the time of the accident.
- **Bulk container damage information.** This section recorded information on the damaged area(s) and components, as well as the type of damage incurred in the accident and the amount of lading lost. Several dynamic form features were used, including the following:
  - Displaying the appropriate damage location image for a portable tank, a trailer-mounted cargo tank, or a truck-mounted cargo tank, depending on the package type selected.
  - Not displaying questions associated with undamaged components.
  - Not displaying questions associated with damage type and subsequent fields until the damage location had been selected.
  - Not displaying damage dimensions and questions concerning a release until the damage type had been selected.
  - Not displaying bulk package breach dimension questions until a release had been verified.

- **Basic accident information.** This section recorded information concerning the object impacting the bulk package, speeds of the vehicle(s) involved in the accident (when applicable), and whether the bulk package rolled over.

Note that the pilot data collection tool did not display location-specific components.

Supplemental Information

To further clarify what information was being requested, a supplemental information page was included in the pilot data collection tool. The intention was to provide responses to questions or comments that previous participants had included in the comments fields. Initially, however, the only supplemental information provided was the example specification plates for a cargo tank or portable tank, corresponding to the type of bulk package initially identified (see Appendix E).

Pilot Study Report Generation

The pilot study was designed to collect accident damage information that was volunteered by bulk package owners; however, despite extensive efforts to reach out to multiple individuals, the level of participation was unsatisfactory. Therefore, the project team employed alternative methodologies to generate pilot study data and populate the database. Accident reports from the NTSB along with information gathered from sources including PHMSA HMIRS reports, FMCSA MCMIS reports, and news articles were used.

Pilot Study Reports Using Information from NTSB Accident Investigations

Reports from several accidents investigated by NTSB contain some information concerning the bulk packages involved—specifically, commodity information and basic accident information. The reports do not contain release quantity or design information. Detailed damage information, if not included in the report text, was described based on a manual review of photographs included in the reports.

The reports included in the pilot study are the following:

- Highway Accident Report, Largo, Maryland—September 6, 1985.
- Hazardous Materials Accident Brief for Accident No. DCA-09-FZ-001 (2009).
- NTSB Report—Collision of Tractor/Cargo Tank Semitrailer and Passenger Vehicle and Subsequent Fire, Yonkers, New York—October 9, 1997.
- Overturn of a Tractor-Semitrailer (Cargo Tank) with the Release of Automotive Gasoline and Fire, Carmichael, California—Feb 13, 1991.
- Rollover of a Truck-Tractor and Cargo Tank Semitrailer Carrying Liquefied Petroleum Gas and Subsequent Fire, Indianapolis, Indiana—October 22, 2009.
- Propane Truck Collision with Bridge Column and Fire, White Plains, New York—July 27, 1994.

Pilot Study Reports Using Information from Multiple Sources

Information from multiple sources was used to develop reports of sample accidents occurring between March and October 2011. Selected accidents were reported to PHMSA, and photographs of the extent of damage to the bulk packages were collected through news articles. Additionally, FMCSA reports were used to supplement basic accident information.

Between March and October 2011, a total of 68 accidents reported to PHMSA were also found in news articles (links to the news articles are included in Appendix F). Photos and other footage of the bulk package involved in the accident vary with respect to how well they illustrate damage to the bulk package. Therefore, not all damage to the bulk package could be determined using the photos and descriptions gathered. In general, only the most severe damage type was identified in descriptions of the accident. Additionally, in several instances, the approximate location of the damage or breach was estimated based on the final position of the bulk package. Some accident reports provided insufficient information from which to generate a pilot study report. In all, 44 reports were generated from a combination of PHMSA HMIRS, news articles, and FMCSA MCMIS information. However, these reports typically do not contain compartment-specific information with the exception of bulk packages that consisted of only one compartment. Therefore, compartment-specific design and release information was not included in the pilot study report.

Improvements to the Pilot Data Collection Tool

Through the collection of accident reports, the following improvements to the pilot data collection tool were identified:

- Enable use of browser navigational tools so that data entered by a user is "saved" if the user accidently uses the browser's "back," "forward," or "refresh" buttons.
- Include "Quenched and Tempered Steel" as an option in the general material type.
- Adjust thickness ranges to include up to 0.5 inches for all material types.

- Include a mechanism that automatically fills in responses if the design parameters are the same for all compartments within the cargo tank.
- Enable the commodity fields to be automatically filled in once sufficient information is gathered in one field (i.e., if the commodity's hazardous material identification number is filled in, the hazardous class and division number and packaging group should automatically populate the appropriate fields).
- Dynamically list relevant bulk package components within the area impacted. This will simplify reporting and increase the accuracy of the reports.
- Enable more than one type of damage to be selected for each component.
- Include fire as a damage type. Vehicles involved in accidents can also be exposed to fire, which may cause the temperature in the immediate vicinity of the bulk package to increase beyond the melting point of bulk package components. Should a vehicle fire be sufficiently hot, bulk packaging may melt and result in a release although the bulk package may have escaped damage in the initial accident.
- Utilize FMCSA's accident event descriptions together with an event order. This would eliminate the need for indicating whether the bulk package struck or was struck by an object and replace the identification of the object impacting/impacted by the bulk package. Include the angle of collision if involved in a collision with a moveable object. Event IDs provided in FMCSA correspond to the following types of events:
  - Non-collision, ran off road.
  - Non-collision, jackknife.
  - Non-collision, overturn (rollover).
  - Non-collision, downhill runaway.
  - Non-collision, cargo loss or shift.
  - Non-collision, explosion or fire.
  - Non-collision, separation of units.
  - Non-collision, cross median/centerline.
  - Non-collision, equipment failure (brake failure, blown tires, etc.).
  - Non-collision, other.
  - Non-collision, unknown.
  - Collision involving pedestrian.
  - Collision involving motor vehicle in transport.
  - Collision involving parked motor vehicle.
  - Collision involving train.
  - Collision involving pedalcycle.
  - Collision involving animal.
  - Collision involving fixed object.
  - Collision with work zone maintenance equipment.
  - Collision with other moveable object.
  - Collision with an unknown moveable object.
  - Other.

Conclusion

A number of potential data collection process options were evaluated, and a more detailed consideration of the feasibility and efficiency of Option B: Government-sponsored extension of Form DOT F 5800.1 with mandatory participation was explored through the development and implementation of a pilot study. The main purposes of the pilot study were to evaluate the quality of data expected from such a data collection process, and identify improvements to the data collection system itself.

SECTION 4

Identifying a Methodology for Data Analysis

The third objective of HMCRP Project 07, to identify methodologies for analyzing the collected data, was achieved through a literature review and the development of a model that incorporates measures of accident performance. The literature review focuses on studies and reports that evaluate crash risk and the risk of transporting hazardous materials. Methodologies for analysis of accident performance data are explored and a hazardous materials transportation risk model is developed to incorporate measures of accident performance. This transportation risk model is presented, and input values for most of the variables can be derived from existing studies and data sets, with the exception of the conditional probability of release and the estimated quantity of release. These two variables relate directly to bulk package accident performance. The conditional probability of release is a function of the damage incurred in an accident and the bulk package's ability to withstand that damage. Similarly, the expected quantity of release is a function of the size of the breach (related to the package's ability to withstand damage), the physical properties of the hazardous material, and the time elapsed before the breach can be plugged or the hazardous material can be off-loaded.

The methodologies for developing equations that estimate the conditional probability of release and the estimated quantity of release are discussed. Furthermore, variables that should be considered in these equations are identified and information pertaining to these variables, collected as part of the pilot study, is summarized to identify possible correlations. However, it must be stressed that the pilot study data are over-weighted in accidents that had a release and under-weighted in non-release accidents. For this reason, the analyses and evaluations of the pilot study data presented in this report are included here only to illustrate the process. The resultant statistics should not be considered valid estimates of the accident performance of highway bulk packages.

Literature Review

The purpose of the accident reporting system being investigated in this project is to enable the analysis of bulk package performance in the event of an accident. The database would be designed to accomplish the goal of determining container-design-specific risk factors for hazardous material cargo tanks and intermodal tanks. In addition, this project will identify possible methods to analyze such an accident database for transportation risk analysis. The sources listed below were reviewed for their approaches to support transportation risk analysis activities.

Comparative Risks of Hazardous Materials and Non-Hazardous Materials Truck Shipment Accidents/Incidents (Battelle 2001) presents a comparative risk assessment of hazardous material and non-hazardous material shipments. Battelle's (2001) analysis started by examining Class 3 (flammable and combustible liquid) accidents/incidents within a 1-year period using the HMIRS database. Subsequently, the analysis was expanded to include Division 2.1 (flammable gases) and Class 8 (corrosives) over a period of 3 years. In the final phase of the project, the analysis was expanded to all types of hazardous material cargo tank truck accidents. The HMIRS database was supplemented with non-spill accidents from the MCMIS database, and the degree of underreporting was estimated using factors developed by comparing HMIRS with other databases for eight states. The degree of underreporting determined for eight states was used to estimate the degree of underreporting for the nation. In the next step, Battelle (2001) developed event trees for each type of hazardous material and the probability of an event occurring was calculated using information, adjusted for underreporting, from the HMIRS and MCMIS databases. Where a hazardous material class/division did not have enough accidents to make a statistical evaluation, information from the HMIRS and MCMIS was supplemented with either probabilities from a similar class/division or theoretical accidents. Battelle (2001) then determined the likelihood that an en-route accident would occur in a year and developed an impact cost associated with each hazardous material class/division. Accident risk and cost per mile were calculated for each hazardous material class/division. Finally, accident risk and cost per mile were calculated for non-hazardous materials and compared to risk and cost per mile of hazardous materials.

A National Risk Assessment for Selected Hazardous Materials in Transportation (Brown et al. 2000) presents a quantitative risk assessment that considered in-transit releases for three types of hazardous materials: toxic inhalation hazards (TIHs), flammable materials, and explosives. The purpose was to assess and define the nature of the risk of transporting hazardous materials. The data used in this analysis were generated from PHMSA HMIRS reported accidents and, for non-gasoline accidents, national commodity flow surveys; a detailed consequence model; routing models; and National Weather Service meteorological observations. The Chemical Accident Stochastic Risk Assessment Model (CASRAM) used this data to generate samples of possible accidents. The model begins by using accident rates to determine whether an accident occurs in a particular run. The occurrence of a release is predicted based on conditional probabilities of release developed by Harwood and Russell (1990). Once a release occurs within a sample run, the size and shape of the affected zone is modeled based on PHMSA's HMIRS percentage of capacity released. With regard to highway bulk packages, release probabilities for MC 306 (using gasoline and fuel oil), MC 312 (using sulfuric acid), and MC 331 (using ammonia and liquid petroleum gas) cargo tanks were developed by dividing the number of HMIRS reported releases by the estimated number of accidents. All probabilities were adjusted by a factor of 1.5 to account for underreporting. The conditional probability of release was estimated to be 6.5% for MC 306 containers, 4.0% for MC 312 steel containers, 1.5% for MC 312 stainless steel containers, 2.5% for MC 331 steel containers with a 0.187-inch thick shell, and 1.05 for MC 331 containers used to transport chlorine and sulfur dioxide (where the lower probability is due primarily to the increased robustness of these containers). However, the release probabilities vary depending on the type of chemical transported in the container. The national risk assessment used percentage of capacity released because it offered the most robust statistic. Since the packaged amount was not recorded at the time of the analysis, there is an implicit assumption that all compartments within the bulk package are full. The analysis indicated that the amount of material released varies depending on the accident severity and the container specification. The 25th, 50th, and 75th discharge percentiles for MC 306, MC 307, and MC 312 cargo tanks are provided in Table 53.

In *The Dimensions of Motor Vehicle Crash Risk* (Wang, Knipling, and Blincoe 1999), General Estimates System (GES) data were analyzed in terms of both the specific role of a vehicle in a specific type of crash and the body type of the vehicle having a critical participating role in the accident. Cargo tank trucks were grouped with other combination or single unit trucks. The analysis developed several statistics by considering several metrics (numerators), including the number of crashes, the number of vehicles having a critical participating role, the number of vehicles involved, the number of people involved, the crash severity, economic cost, and comprehensive societal value costs. Of particular note, Wang, Knipling, and Blincoe (1999) addressed the injury severity level by assigning numerical values to injury severity categories defined by the National Safety Council (NSC 2007) and combining serious and fatal injuries because of the unacceptably large sampling errors associated with the small fatality estimates for specific crash/vehicle types. These metrics were standardized in a number of ways using denominator data such as the U.S. annual total number of reported crashes (by type), the total number of miles traveled per year in the United States, the annual number of U.S. registered vehicles, the expected operational life of a vehicle (by vehicle type), and the average number of crashes per driver over his/her driving career. After percentage estimates and derived statistics were calculated, the crash and injury statistics were rounded to the appropriate levels of significance. For example, crash and injury counts over 2,000 were rounded to the nearest 1,000, and counts less than 2,000 were rounded to the nearest 100. The paper also provides a discussion concerning the most relevant referents from which Wang, Knipling, and Blincoe (1999) assert that "identification of the most relevant dimensions of motor vehicle crash risk is even more fundamental to developing a framework for enlightened safety benefits assessment and decision-making."

Table 53. Discharge percentiles for cargo tanks.

	Percent of Capacity Released		
Cargo Tank Specification	**25th percentile**	**Median**	**75th percentile**
MC 306	2.6%	22%	60%
MC 307	0.16%	1.9%	18%
MC 312	1.3%	11%	50%

Large Truck Crash Causation Study (LTCCS) Analysis Series: Using LTCCS Data for Statistical Analysis of Crash Risk (Hedlund and Blower 2006) discusses the strengths and weaknesses of statistical analyses performed using the LTCCS database, a nationally representative sample of 963 injury and fatal crashes involving large trucks. Hedlund and Blower (2006) investigate crash causes in terms of risk-increasing factors because they do not wish to determine fault, crashes typically have more than one cause, and risk-increasing factors are based on facts (not inferences). Limitations of the LTCCS database, identified in this paper, include difficulties in the following:

- Applying statistics on a national scale because national referents (denominators) are not very accurate.
- Determining confidence errors of statistics due to the multistage sampling approach. Hedlund and Blower (2006) estimate that first order statistics will have an error of 3% while comparisons of two types of crashes will have an error of approximately 10%.
- Reducing bias due to incomplete data or second-hand data.

Uncertainty in the Estimation of Risks for the Transport of Hazardous Materials (Saccomanno, Stewart, and Shortreed 1993) discusses uncertainties associated with risks of hazardous material transportation. Saccomanno, Stewart, and Shortreed (1993) assert that hazardous material transportation risk analysis requires an estimation of several elements of the risk analysis process, including the probability of release given that an accident has occurred. The paper identifies the following three problems:

- **Control—**using average exposure (referent) or using exposure resulting from controlled conditions as opposed to actual exposure. Saccomanno, Stewart, and Shortreed (1993) emphasized the need to document several environmental factors in an accident record so that variations from mean values can be explained.
- **Omission—**excluding accidents because of specific parameters (i.e., excluding an accident because it occurred at an intersection).
- **Bias—**inputting values conservatively can result in an overestimation of risk, especially when analyses are later performed that incorporate biases cumulatively.

In terms of cargo tank motor vehicle releases, Saccomanno, Stewart, and Shortreed (1993) indicated that the size of the opening as well as the energy absorption characteristics should be recorded in addition to critical exposure values required to sustain damages.

Approaches to Analyzing Data

Background—How Bulk Package Performance Relates to Hazardous Materials Transportation Risk

Traditionally risk (R) is defined as the product of the probability of an event (P) and the consequences of that event (C):

$$R = P \times C \qquad \text{(Eq. 1)}$$

In the context of hazardous material transportation, risk refers to the probability and consequence of a release. Hazardous material releases can be classified as accident-caused or non-accident-caused, and the circumstances that lead to them are different. This section and this report in general focus on accident-caused release risk.

Early attempts to quantify the risk of transporting hazardous materials estimated the probability of a release based on the historical number of releases that occur per million miles, and the number of miles traveled. The consequences of these releases were estimated using the number of people residing within the hazardous materials' evacuation perimeter (Erkut and Verter 1998). Such methods may be sufficient for route selection models, but risk estimates may have large sources of variance depending on the commodity and the container in which it is shipped (Brown, Dunn, and Policastro 2000). Therefore, attempts to better estimate the risk of transporting hazardous materials have resulted in the use of conditional probabilities of release. Additionally, the accident itself affects risk in that, at a minimum, the risk associated with transporting hazardous materials is equivalent to the risk of transporting other goods (e.g., the risk of injury and/or property damage if the package becomes involved with a collision). Thus the risk of transporting hazardous materials (R) can be described by:

$$R = N \times P_A \times P_{R|A} \times C_R + N \times P_A \times C_A \qquad \text{(Eq. 2)}$$

where

N = exposure estimate. In this case it represents the number of miles traveled.
P_A = the probability of an accident.
$P_{R|A}$ = the probability of a release given that an accident has occurred or the conditional probability of release. Therefore, $1 - P_{R|A}$ corresponds to the events in which the vehicle is involved in an accident but does not result in a release.
C_R = the consequences of the release.
C_A = the consequences due to the physical aspects of the accident (e.g., the risk of injury and/or property damage if the package becomes involved in a collision).

The variables in the risk equation above can be estimated from existing databases (FMCSA's MCMIS, PHMSA's HMIRS, NASS GES, or the LTCCS). Exposure estimates can be determined based on the national commodity flow surveys, or, in a route-specific analysis, by the expected number of miles traveled by the bulk container(s). Probabilities of accidents can be determined using FMCSA's MCMIS and refined using the LTCCS. A basic conditional probability of release can be estimated by comparing the total number of releases (numerator) to the total number of accidents involving hazardous materials (denominator). Both variables are recorded in FMCSA's MCMIS. These estimates can be further refined by using variables available in PHMSA's HMIRS to consider specification- or component-specific conditional probability of release.

Underreporting in existing databases, especially if bulk packages did not release their contents when involved in an accident, introduce a considerable amount of uncertainty into the estimates of conditional probability of release. To address this, conditional probabilities of release can be further refined using the accident damage database presented in this report. The consequences of a release can be estimated using information from PHMSA's HMIRS, NHTSA's FARS, or using sophisticated hazardous materials dispersion models. In general, the consequences of a release are a function of the amount released, the potential adverse effects of the hazardous material, and the population density in the property potentially affected by the material. Finally, the consequences of the accident pertaining to the casualties and property damage sustained as a direct result of the accident, excluding any effects of the hazardous material, can be found in FMCSA's MCMIS for non-release accidents and PHMSA's HMIRS for release accidents.

Two variables in Equation 2 relate directly to bulk package performance: the conditional probability of release and the amount released. The conditional probability of release is a function of the damage incurred during an accident and the bulk package's ability to withstand that damage. Similarly, the amount released is a function of the size of the opening (related to the package's ability to withstand damage), the physical properties of the hazardous material, and the time elapsed before the opening can be plugged or the hazardous material can be off-loaded. In general, these two variables are independent of the probability of an accident occurring and the consequences of a particular release quantity. Therefore, independent regression equations can be developed using an accident damage database such as the options presented in Section 3. Indeed, a principal objective of developing such an accident damage database is to provide a robust source of empirical accident information on bulk package performance in a wide range of accident scenarios. As data are accumulated over time, the statistical power of these regression equations will increase, and more sophisticated analyses can be conducted. These include developing the conditional probabilities of release for various components, in different accident scenarios. Assuming the individual accident scenarios and the individual component-specific conditional probabilities of release are independent, the combined conditional probability of release can be determined using Equation 3:

$$P_{R|A} = 1 - \prod_{j=1}^{n}\left[1 - \left(1 - \prod_{k=1}^{m_j}\left[1 - P_{jk}\right]\right)\right] \qquad \text{(Eq. 3)}$$

where

$P_{R|A}$ = the probability of a release given that an accident has occurred, or the conditional probability of release.
P_{jk} = the conditional probability of a release from the kth source due to the jth accident scenario.
n = the number of accident scenarios.
m_j = the number of components considered for each accident scenario.

Logistic Regression Models

Previous experience involving analysis of railroad tank car safety performance using the RSI-AAR TCAD illustrates the use of statistical techniques to estimate package accident performance (Treichel et al. 2006). Several regression methods were employed to develop the conditional probabilities of release as part of the RSI-AAR Railroad Tank Car Safety Research and Test Project, including the following:

- Logistic regression in which a binary response variable such as release or no release is selected. Logistic regression makes an exponential transformation that allows probability estimate errors to conform to the required assumption of normality.
- Ordinal logistic regression in which response variables are binned. For example, binned data regarding the percentage lost would be an appropriate response variable for ordinal logistic regression.
- Multiple binary logistic regression in which there are several response variables representing, for example, release or no release of hazardous materials in several categories.

Wen and Simpson, in *Multivariate Regression Analysis of Tank Car Lading Loss* (Wen and Simpson, 2000), presented the following equations and some other details of the general logistic regression model (see Appendix G):

$$P_{jk}(Y_i = 1) = P_{jk}(\boldsymbol{X}_i) = \frac{e^{L(\boldsymbol{X}_i)}}{1 + e^{L(\boldsymbol{X}_i)}} \qquad \text{(Eq. 4)}$$

where

Y_i = a binary dependent variable associated with the ith record where 0 represents a non-release event and 1 represents a release event.

$\mathbf{X}_i$ = a vector denoting the values of l independent variables for the ith record:

$$\mathbf{X}_i = \begin{bmatrix} 1 \\ x_{i1} \\ x_{i2} \\ \vdots \\ x_{i1} \end{bmatrix} \qquad \text{(Eq. 5)}$$

L = the logarithmic odds ratio,
$= \mathbf{X}_i'\boldsymbol{\beta}$, and

$\boldsymbol{\beta}$ = the following vector denoting the values of l coefficients of the logarithmic odds ratio, L:

$$\boldsymbol{\beta} = \begin{bmatrix} \beta_0 \\ \beta_1 \\ \beta_2 \\ \vdots \\ \beta_l \end{bmatrix} \qquad \text{(Eq. 6)}$$

The incorporation of a linear equation is beneficial because it "allows consideration of a large number of independent variables and has well-established theoretical basis for further statistical inference" (Wen and Simpson, 2000), while the incorporation of a quadratic or higher-order equation allows interactions between variables (occurs when there is a covariance between two or more variables in the equation). Since the estimation of the conditional probability of release for bulk packages transported by highway is similar to the estimation of the conditional probability of release for tank cars, similar approaches for developing the response function may be used.

Accident scenarios that may initially be considered include accidents in which another vehicle is involved and incidents in which the vehicle and bulk package overturned. Similarly, the components that may be considered include the following:

- Valves.
- Loading/unloading lines, piping or fittings.
- Manway or dome covers.
- Tank head.
- Tank shell.
- Welds or seams.

The combination above results in the need to calculate 12 separate regression equations representing the conditional probability of release from the jth source given the kth accident scenario. These regression equations could consider the effects of the following factors:

- Material type.
- Damage location on bulk package.
- Thickness of the bulk package at the damage location.
- Bulk package operating pressure.
- Bulk package capacity.
- Packaged amount.
- Damage type.
- Speed.
- The speed of the other vehicle involved in the accident (if another vehicle was involved).
- The type of object striking or struck by the bulk package.

Not all of these factors may have a significant effect on a particular component's loss probability given a particular type of accident. Therefore, regression model building techniques comparing every subset of the full model should be conducted.

In Treichel et al. (2006), separate regression models for each of the four major components (head, shell, top fittings, and bottom fittings) were developed by removing factors that had no significant effect on a particular component's loss probability from that component's model. Similarly, a regression analysis of highway accident data may show that, for example, the capacity of the bulk package does not have a significant effect on the probability of a release from loading/unloading lines.

Similar to the methodology used in Treichel et al. (2006) to determine the coefficients for each significant factor, accident report selection criteria for the population to be analyzed should be constructed with the intention of eliminating the possibility of undesirable heterogeneities. Without these inclusion criteria, biased conclusions may be drawn, particularly if loading characteristics differ (bulk package is empty) or damage is sustained to the bulk package after the initial impact (such as prolonged exposure to fire). Thus, the inclusion criteria for accident records are particularly important when accident data include accidents involving cargo tanks whether or not they carried hazardous materials; were loaded at the time they were damaged; sustained sufficient damage to result in a lading loss; or were exposed to a fire for a prolonged period of time.

Population-Wide Accident and Release Rates

The amount of time necessary to yield accident performance measures is important when considering the implementation of such a system. The following analysis estimates the rate at which reports would be generated given current highway bulk package accident rates observed in the pilot study. This was achieved by compiling a data set consisting of PHMSA HMIRS reports, FMCSA MCMIS reports, and news articles over a 7-month period, estimating the total number of accidents per month, and calculating the average rate at which accidents occur.

Accident Rate Data Set

To estimate the rate at which reports would be generated given current highway bulk package accident rates, a data set consisting of PHMSA HMIRS reports, FMCSA MCMIS reports and news articles published between March and September in 2011 was compiled. The combined data set consisted of 924 accidents (see Figure 15) of which 236 resulted in a release of hazardous materials (see Figure 16). The majority of these accidents were reported by only one source and only five records were captured in all three data sets. News articles and FMCSA records shared a total of 11 records.

PHMSA HMIRS reports used in this analysis consisted of in-transit highway accidents involving cargo tank motor vehicles or portable tanks in which a crash occurred. These records correspond to the reportable incidents as defined by 49 CFR 171.15 and 49 CFR 171.16. For highway transportation, these include any incident in which one or more of the following apply:

- "As a direct result of a hazardous material: a person is killed, a person receives an injury requiring admittance to a hospital, the general public is evacuated for one hour or more, a major transportation artery or facility is closed or shut down for one hour or more" (49 CFR 171.15 7.b.1).
- "A situation exists of such a nature that, in the judgment of the person in possession of the hazardous material, it should be reported to the National Response Center (NRC) even though it does not meet other requirements" (49 CFR 171.15 7.b.5).
- "There is an unintentional release of a hazardous material or the discharge of any quantity of hazardous waste" (49 CFR 171.16 a.2).
- "A specification cargo tank with a capacity of 1,000 gallons or greater containing any hazardous material suffers structural damage to the lading retention system or damage that requires repair to a system intended to protect the lading retention systems, even if there is no release of hazardous material" (49 CFR 171.16 a.3).

In reality, accidents in which a bulk package is damaged but the damage does not result in a release are underrepresented in this database. Therefore, we can expect that the rate of accidents will be greater than the rate derived solely from considering this data set. Regardless, with these parameters, 123 accidents were reported to PHMSA HMIRS within the 7-month period. Of these 123 accidents, 98 resulted in a release.

FMCSA MCMIS reports consist of accidents involving a cargo tank or intermodal truck that has been placarded for hazardous materials transportation. These parameters yielded 754 accidents between March and September 2011. Some of the discrepancy in the number of accidents from PHMSA's HMIRS results from the inclusion of accidents in which the bulk package was not damaged (e.g., an accident in which a vehicle was rear-ended by the hazardous materials vehicle); however, the discrepancy cannot be entirely discounted because the MCMIS data set also contains 70 releases that are not included in the HMIRS (see Figure 16).

The third data set used in this analysis was derived from news articles found during the same period. These news articles described accidents that resulted in damage to the bulk package. During the 7-month period, 127 accidents were recorded, of which 103 resulted in the release of hazardous materials. Although the number of records in the news article data set was of a similar magnitude to the records in HMIRS, the two data sets only share approximately 30% (37 records were found in both data sets). Similarly, there are only six records in the news article data set that are also in FMCSA MCMIS. Like the PHMSA HMIRS data set, a data set composed of news articles tends to underestimate accidents in which the bulk package was damaged but no release occurred. Therefore, an accident rate derived solely from considering the number of accidents reported in news articles is expected to be lower than the actual accident rate.

Accident and Release Rates

The accidents in the combined data set were grouped by month to estimate the rate at which accidents occur (see Figure 25). If all the FMCSA MCMIS, PHMSA HMIRS, and news report accidents are considered, 132 ± 20 accidents can be expected per month (with 95% confidence). Furthermore, from these accidents, approximately 34 ± 7 releases will occur per month (with 95% confidence) (see Figure 26). Therefore, approximately 26% of accidents involving hazardous materials bulk packages result in a release. In contrast, Brown, Dunn, and Policastro (2000) show that the release rates from Harwood and Russell (1990) for highway bulk packages transporting gases and liquids are 8% and 19%, respectively.

As mentioned above, the pilot study data are over-weighted in accidents that had a release and under-weighted in non-release accidents. Furthermore, only a subset of data relating to MC 306 and DOT 406 cargo tanks has been used in the sample size analyses that follow. For these reasons, the analyses and evaluations of the pilot study data presented in

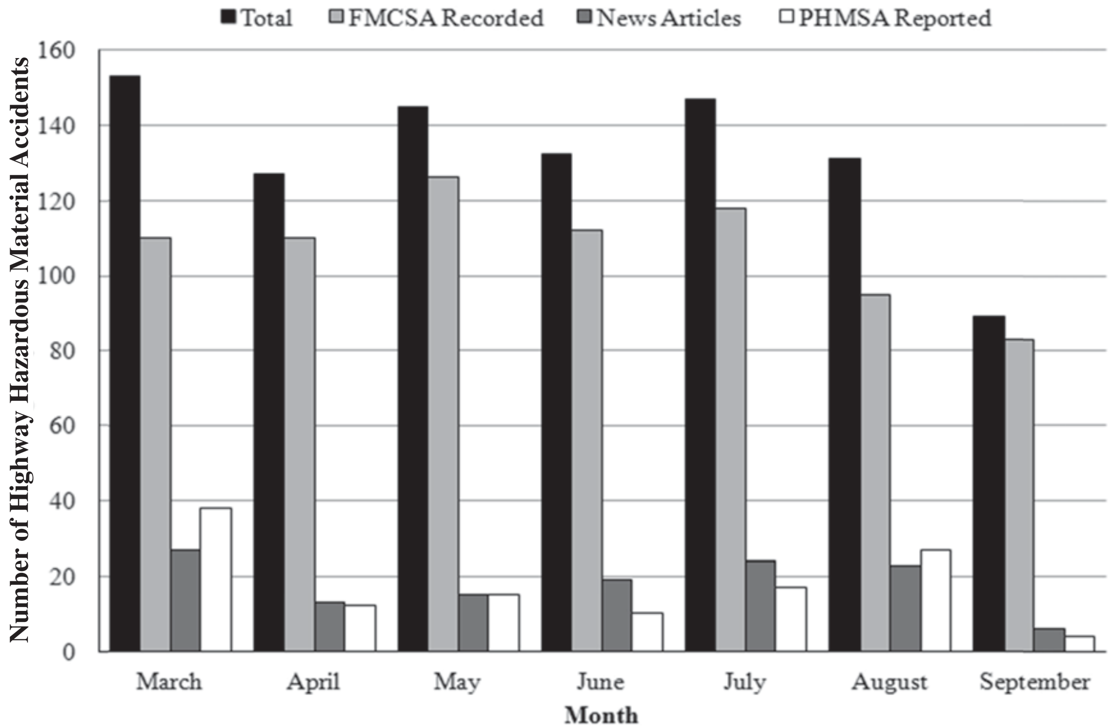


Figure 25. Highway hazardous materials accidents from March to September 2011.

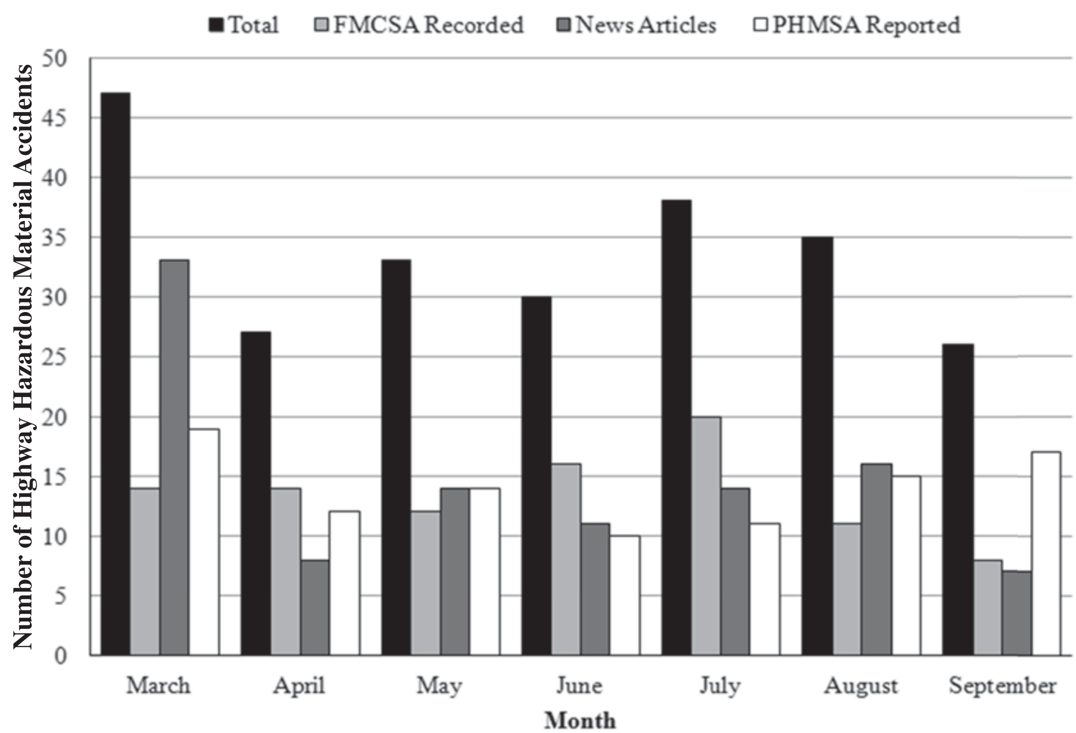


Figure 26. Hazardous materials releases resulting from highway accidents from March to September 2011.

this report are for illustrative purposes only and should not be considered reliable estimates of the performance of highway bulk packages. Such analyses will require a much more extensive data set, the development of which is the subject of this report.

Minimum Number of Records

The requisite sample sizes were estimated in order to determine when sufficient data would be available to conduct statistical analyses with acceptable confidence intervals. These sample sizes must satisfy two conditions:

1. There must be a sufficient number of accident records to minimize Type I errors (where insignificant variables appear to have a significant effect) and Type II errors (where significant variables appear not to have an effect on the probability of a release) when testing hypotheses with the model. While determining acceptable levels of Type I and Type II errors is not necessary for developing a model, sample size estimate approaches used in hypothesis testing may provide a rough estimate of the required sample size for developing a regression equation.
2. There must be at least 10 events per variable included in the model (Peduzzi et al. 1996). This is typically checked once the accident data have been collected. For each variable considered, there should be accident records pertaining to at least 10 release events and 10 non-release events.

Minimum Sample Size to Minimize Statistical Errors

To satisfy the first condition, the general multiple logistic regression form, given by Equation 4, with a single independent variable, was considered. The requisite sample size for each variable was determined by using a subset of data corresponding to hazardous materials typically shipped in MC 306 or DOT 406 containers. The probability of a damage case release was estimated using this subset of data and the percentage of accidents resulting in a release (26%). The parameters describing the distribution of each variable were calculated, and the odds ratio of each variable was determined. Using this information, the number of accident records needed to achieve specified significance and power levels was determined.

Sample Size Data Set

The pilot study data set was refined to contain records corresponding to hazardous materials typically shipped in MC 306 or DOT 406 containers. This subset consisted of 35 accident records that corresponded to 77 component-specific damage cases in which a component of the bulk package was damaged. On average, there were approximately 2.3 component-specific damage cases per accident. The data set was modified to contain the following variables:

- Thickness of the head or shell at the location where the bulk package was damaged.
- Total capacity of the bulk package.
- Packaged amount.
- Speed of the bulk package prior to impact.
- Speed of the other vehicle involved in the accident.
- Damage location.
- Component damaged within that location.
- Damage type.
- Whether a personal vehicle was involved.
- Whether a heavy vehicle was involved.
- Whether the bulk package crossed the centerline or median.
- Whether it ran off the road.
- Whether it rolled over.
- Whether it exploded or caught fire.
- Whether the units separated in the crash (if the tractor-trailer was also towing a pup trailer).
- Whether the bulk package struck the roadway.
- Whether it struck the ground.
- Whether it struck a concrete barrier.
- Whether it struck a guardrail.

Since the general logistic regression program used for the analysis did not allow categorical data, the damaged component, its location, and the type of damage were converted to a series of binomial variables.

Probability of a Release

Of the 77 component-specific damage cases included in the MC 306/DOT 406 data subset, 74 indicated whether a release occurred as the result of an accident. Of these, 48 damage cases contributed to a release of hazardous materials. Since the records generated during the pilot study correspond to accidents in which a release occurred, the conditional probability that damage to a particular component-location combination (damage case) contributed to a release, given that a release occurred, was 65 percent (48 of 74 records). Using the probability that an accident results in a release, the probability that a particular component-specific damage contributed to a release is found by:

$$P(\text{damaged component release}|\text{accident}) = P(\text{damaged component release}|\text{accident release}) \times P(\text{accident release}|\text{accident}) \quad \text{(Eq. 7)}$$

Assuming an accident rate of 26 percent (34 releases per 134 accidents per month, as developed in Section 3), the probability of release related to component-specific damage is 16.7 percent. This means that, in an accident, the bulk package components are able to withstand the incurred damage 83.3 percent of the time.

Odds Ratios

In order to estimate the required sample size for a logistic regression analysis, an initial estimate of the odds ratio is required (see Equation 4). As a measure of the ratio of probability of an event per unit change of a variable, the odds ratio depends upon an estimate of the mean and standard deviation of the variables used in the logistic regression equation. The following odds ratios estimates are based on data collected during the pilot study.

Scalar Variables. A normal distribution was assumed in order to estimate the mean and standard deviation of the scalar variables. This assumption yields favorable estimates of the minimum number of records required. It is likely that, given non-normal distributions, larger sample sizes will be required. Therefore, once sufficient data have been collected, the assumption of normality should be re-examined.

The following variables were standardized by dividing each value by its standard deviation (see Table 54):

- Thickness of the head or shell at the location where the bulk package was damaged.
- Total capacity of the bulk package.
- Packaged amount.
- Speed of the bulk package prior to impact.
- Speed of the other vehicle involved in the accident.

To get a reasonable value for the odds ratio, logistic regression analyses were performed using the standardized variables.

Binomial Variables. The distribution for binomial variables is described by the probability of a damage case release and the number of damage cases considered. The probability of a damage case release is determined by dividing the mean by the number of records considered in the initial odds ratio estimates (see Table 55). Logistic regression analyses were performed using the original variables to obtain the odds ratios used in the subsequent sample size analysis.

Analysis Parameters

In statistical analysis, there are generally two types of errors. In the case of estimating release probabilities, a Type I error, denoted by α, occurs when the variable is found to have a significant effect on the probability of release when it actually does not. Type I errors are controlled in experimental analysis by specifying the significance level, or the amount of Type I error allowed in the experiment. In most experiments where Type I errors are the primary concern, the significance level corresponds to $\alpha = 0.05$. On the other hand, a Type II error, denoted by θ, occurs when a variable is not found to have a significant effect when it actually does. Type II errors are controlled by designing experiments that have large values of power (and small values of θ). This is usually accomplished by increasing the number of samples considered in the experiment.

Since the minimum sample size required to determine whether a variable has a significant effect on the probability of release is to be identified, the Type I and Type II errors should be balanced. For example, more Type I error may be accepted in the experiment until sufficient sample sizes have been generated to control Type II error. For this reason, sample sizes were determined for two significance levels (0.05 and 0.1) and six levels of power (0.70, 0.75, 0.80, 0.85, 0.90, and 0.95).

Sample Size Estimates

The required number of accident records was estimated using the POWER procedure in SAS 9.2. Once the number of cases required to obtain a significant result with adequate probability had been determined, the number of accidents

Table 54. Distribution parameters of scalar variables and corresponding odds ratios.

Variable	Mean	Deviation	Adjusted Mean	Standard Deviation	Odds Ratio
Thickness	0.19	0.01	13.04	1	0.653
Capacity	4,160	4,525	0.92	1	1.389
Packaged Amount	6,506	2,621	2.48	1	1.166
Speed	44	20	2.20	1	0.682
Other Vehicle Speed	14	22	0.60	1	1.509

Table 55. Distribution parameters of binomial variables and corresponding odds ratios.

Variable	n	Mean	p	Odds Ratio
Damaged Valve	74	0.068	0.09%	2.273
Damaged Lines, Pipes, and/or Fittings	74	0.108	0.15%	4.266
Damaged Manway	74	0.108	0.15%	>999
Damaged Head	74	0.054	0.07%	0.163
Damaged Shell	74	0.622	0.84%	0.259
Damaged Weld and/or Seam	74	0.041	0.05%	>999
Abraded	74	0.027	0.04%	0
Bent	74	0.095	0.13%	0.183
Burst or Ruptured	74	0.041	0.05%	1.087
Crushed	74	0.392	0.53%	0.176
Cracked	74	0.068	0.09%	>999
Gouged or Cut	74	0.068	0.09%	2.273
Leaked	74	0.081	0.11%	>999
Punctured	74	0.054	0.07%	>999
Ripped or Torn	74	0.108	0.15%	>999
Torn Off or Damaged	74	0.068	0.09%	>999
Front Head Damage on Centerline	75	0.027	0.04%	1.000
Front Head Damage Above Centerline	75	0.053	0.07%	0.163
Rear Head Damage Below Centerline	75	0.040	0.05%	0.255
Rear Head Damage Above Centerline	75	0.013	0.02%	>999
Bottom Front Driver-Side Damage	75	0.053	0.07%	1.666
Bottom Middle Driver-Side Damage	75	0.040	0.05%	1.087
Bottom Rear Driver-Side Damage	75	0.067	0.09%	>999
Top Front Driver-Side Damage	75	0.053	0.07%	1.087
Top Middle Driver-Side Damage	75	0.027	0.04%	0.532
Top Rear Driver-Side Damage	75	0.080	0.11%	0.511
Bottom Front Passenger-Side Damage	75	0.040	0.05%	0.255
Bottom Middle Passenger-Side Damage	75	0.053	0.07%	0.163
Top Front Passenger-Side Damage	75	0.187	0.25%	0.969
Top Middle Driver-Side Damage	75	0.053	0.07%	1.666
Top Rear Passenger-Side Damage	75	0.080	0.11%	1.091
Damage to Piping and/or Undercarriage Below the Tank	75	0.133	0.18%	>999
Passenger Vehicle Involved	77	0.273	0.35%	1.729
Heavy Vehicle Involved	77	0.065	0.08%	2.273
Crossed Centerline	77	0.221	0.29%	0.384
Ran-Off-Road	77	0.675	0.88%	0.500
Rolled Over	77	0.818	1.06%	0.439
Units Separated	77	0.195	0.25%	0.384
Struck Roadway	77	0.468	0.61%	0.778
Struck Ground	77	0.688	0.89%	0.397
Struck Concrete Barrier	77	0.065	0.08%	0.334
Struck Guardrail	77	0.130	0.17%	0.891
Struck Tree	77	0.013	0.02%	1.000
Involved Explosion or Fire	77	0.182	0.24%	8.333

Table 56. Sample size required for the variable "Thickness."

Significance Level	Nominal Power	Number of Cases	Number of Accidents
0.05	0.70	274	120
0.05	0.75	308	134
0.05	0.80	348	152
0.05	0.85	398	174
0.05	0.90	466	203
0.05	0.95	576	251
0.10	0.70	209	91
0.10	0.75	239	104
0.10	0.80	275	120
0.10	0.85	319	139
0.10	0.90	380	166
0.10	0.95	480	209

was calculated. Table 56 shows the sample sizes needed to obtain the corresponding power for testing, at the specified significance level, the effect of the thickness of the head or shell at the location where the bulk package was damaged. For example, using a significance level of 0.1, in order to achieve 90% power, 166 accident records are needed.

For those variables containing sufficient information and variance, the number of accident records needed to determine their effect was calculated in a similar manner. These sample sizes indicated that there are three tiers of variables. Tier I variables required sample sizes of less than 800 accident records (see Figure 27 and Figure 28). Of these, damage to the shell or crushing damage required the smallest number of records.

The sample sizes required for Tier II variables at a significance level of 0.1 and 90% power ranged between 858 and 1,286 accident records (see Table 57). In comparison

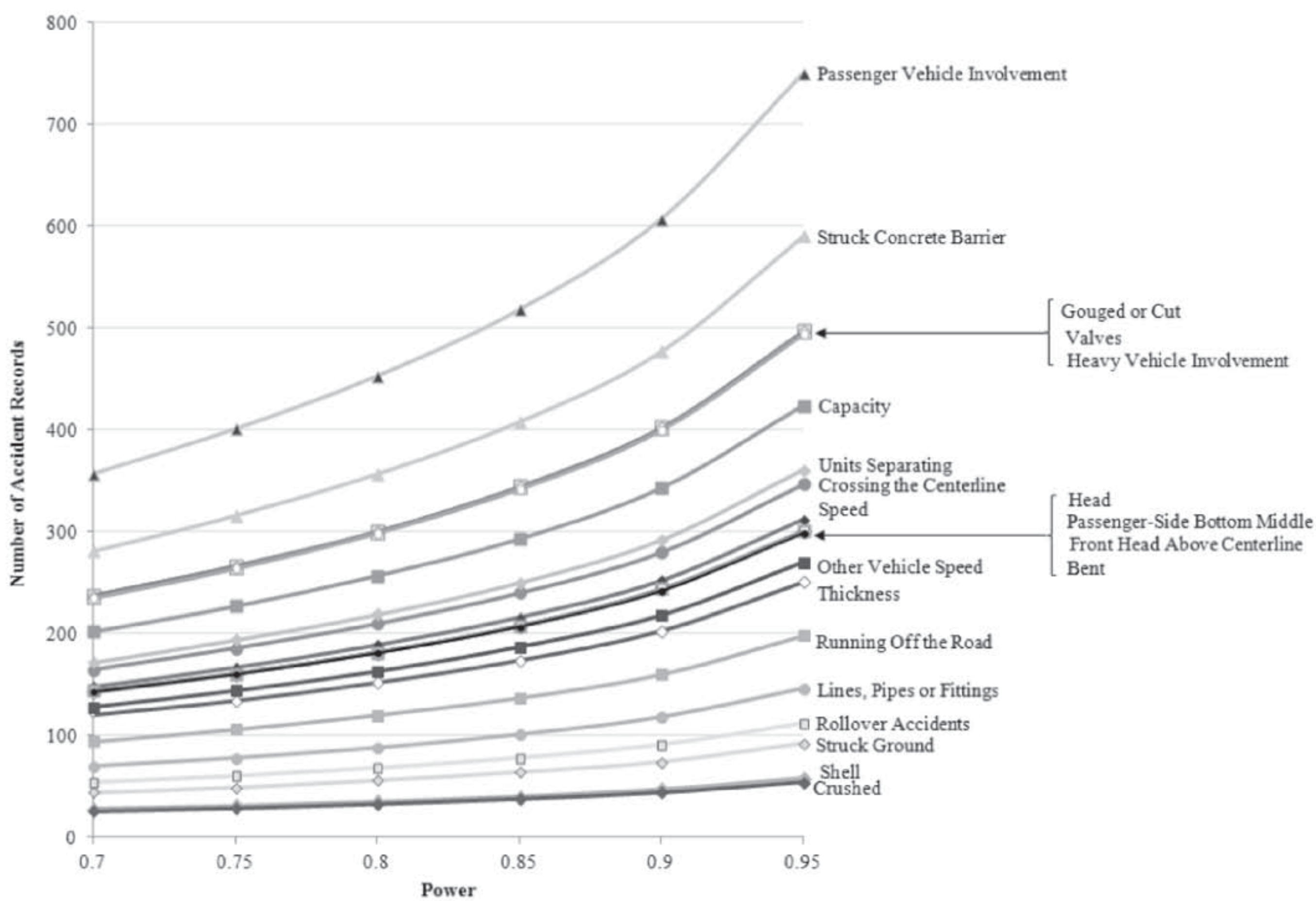


Figure 27. Sample size requirements given α = 0.05.

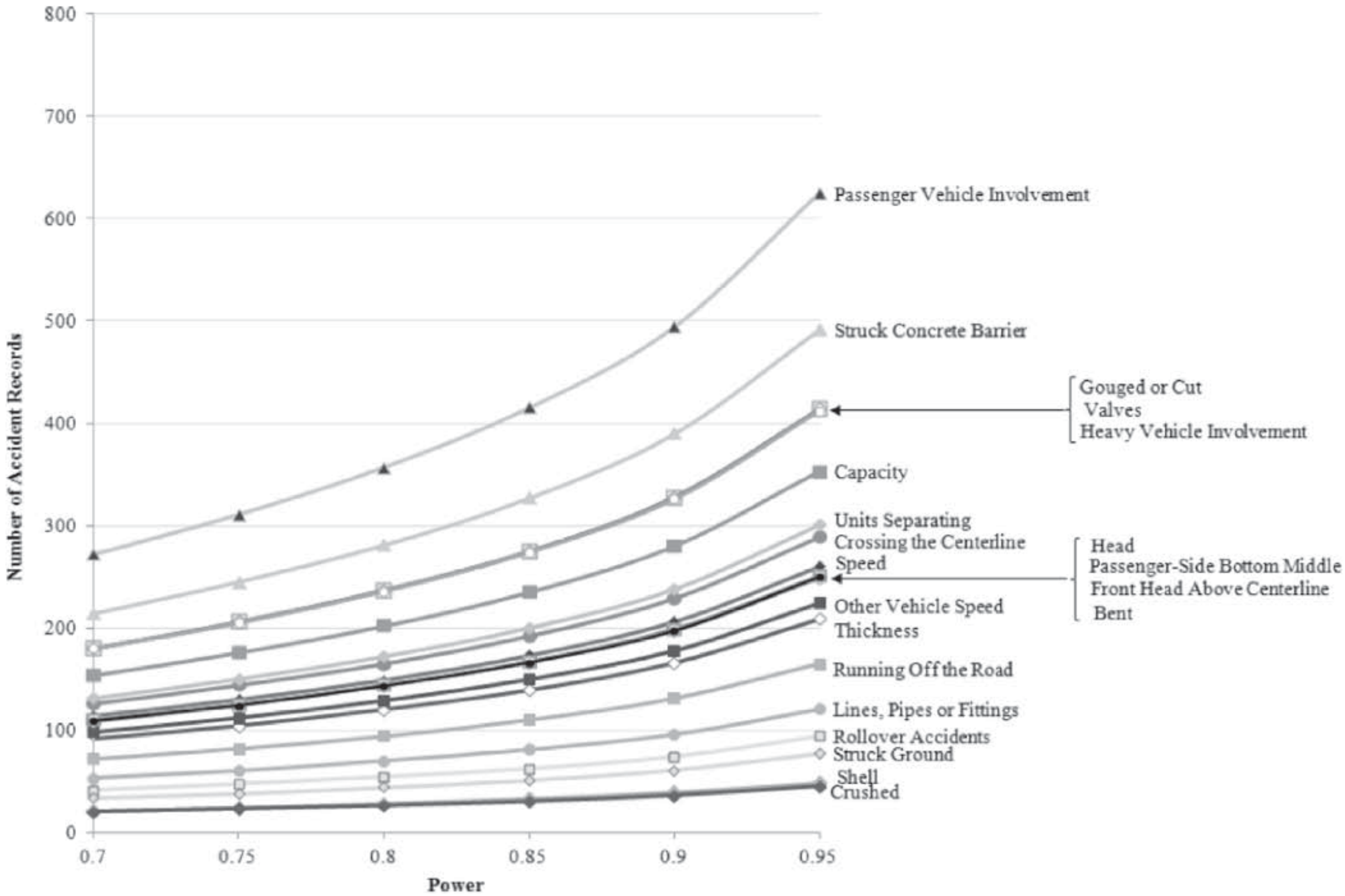


Figure 28. Sample size requirements given α = 0.10.

Table 57. Required number of accident records for variables.

Significance Level	Nominal Power	Packaged Amount	Driver-Side Bottom Front	Driver-Side Top Rear	Passenger-Side Top Middle	Struck Roadway
0.05	0.70	927	661	618	661	737
0.05	0.75	1,042	744	695	744	829
0.05	0.80	1,178	841	786	841	937
0.05	0.85	1,348	962	899	962	1,072
0.05	0.90	1,577	1,125	1,052	1,125	1,255
0.05	0.95	1,950	1,392	1,301	1,392	1,552
0.10	0.70	707	504	472	504	562
0.10	0.75	808	577	539	577	643
0.10	0.80	928	663	620	663	739
0.10	0.85	1,079	770	720	770	859
0.10	0.90	1,286	917	858	917	1,023
0.10	0.95	1,624	1,159	1,084	1,159	1,293

to Tier I variables, Tier II variables required twice as many accident records.

Those variables requiring sample sizes greater than 5,000 records are classified as Tier III variables:

- Bulk package design pressure.
- Burst or ruptured damage.
- Damage to the rear head below the centerline.
- Damage to the bottom middle driver-side.
- Damage to the top front driver-side.
- Damage to the top middle driver-side.
- Damage to the bottom front passenger-side.
- Damage to the top front passenger-side.
- Damage to the top rear passenger-side.
- Striking the guardrail.

These large sample size requirements may be attributed to a low correlation between these variables and the probability of a damage case release or limitations in the estimating procedure. Therefore, the required sample sizes should be re-evaluated after the collection of accident data has begun.

Multivariate Logistic Regression Sample Sizes

In multivariate logistic regression, the minimum sample size must also meet the conditions of a minimum number of records (Condition 1) and a minimum number of events per variable (Condition 2). To determine the minimum number of records, the interaction of the variables included in the logistic regression model must be considered. An example can be drawn from tank car performance analyses using the RSI-AAR TCAD (Treichel et al. 2005). In these analyses, the characteristics in the model were assumed to be independent of each other; therefore, for example, given a curve that represents the relationship between the probability of release and tank shell thickness (see Figure 29), the addition of a standard (non-varying) thickness jacket adjusts the curve towards lower probability of release values by the same amount. Note that in Figure 29 the slopes of the lines differentiating the presence of a jacket are equal.

The minimum sample sizes for models in which variables are not correlated is approximately equal to the largest sample size requirement of the variables included in the model. For example, using the MC 306/DOT 406 pilot study data subset, 277 accident records are needed for modeling the probability of a release as a function of thickness, capacity, and speed at a significance level of 0.1 with 90% power.

However, if the variables are correlated, as is typically the case for empirical data, the probability of a damage case release will be different from the sum of the probabilities of release from each variable. Referring to the RSI-AAR TCAD example, if the presence of a jacket and the thickness of the shell material were, in fact, correlated, the slopes of the lines would be different (see Figure 30). Here, given a curve that represents the relationship between the probability of release and tank shell thickness, the addition of a standard (non-varying) thickness jacket adjusts the curve towards lower probability of release values by increasingly greater amounts. In Figure 30, the hypothetical decrease in probability of a release due to the interaction effects of a jacket and shell thickness is represented by the grey area.

The required minimum sample size for models in which the variables are correlated will be larger than that required for models with uncorrelated variables. This is because additional records are needed to evaluate the interaction effects of the variables included in the model. The pilot study data set suggests correlations exist between the following variables:

- Damage to the shell, crushing type damage, rollover accidents, running off the road, "struck roadway," and "struck ground."
- Which component was damaged and the damage location (if not nested).

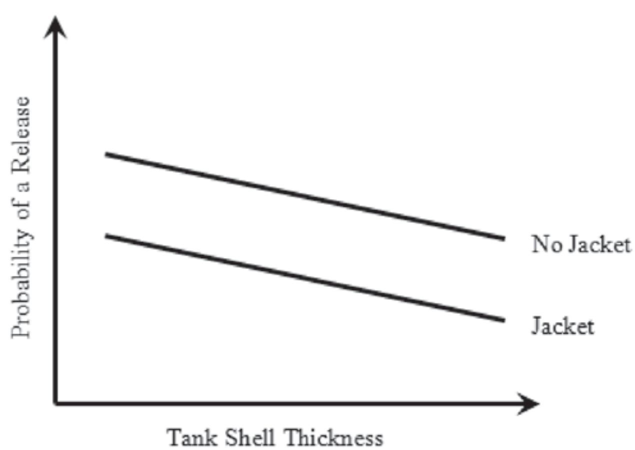


Figure 29. No correlation effects.

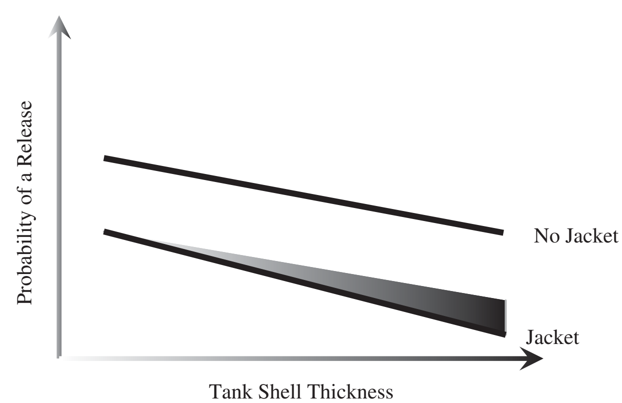


Figure 30. Effect of correlation between variables.

- Damage to fittings and accidents involving passenger vehicles (i.e., damage to Location 3: front head above centerline and damage to the head itself).
- Speed of the bulk package and speed of the other vehicle involved (this most likely resulted from the method employed to estimate the other vehicle's speed in the context of the pilot study, but correlation is nevertheless expected).
- Capacity and packaged amount.

Since the correlation between variables cannot be estimated due to the limited size of the pilot study data set, the increase in sample size cannot currently be determined.

Minimum Number of Events

Peduzzi et al. (1996) define the number of outcome events as "the smaller number of binary outcomes (e.g., alive versus dead)" and provide the example that "a particular study may have many subjects, but too few deaths for a valid analysis." In applying the results of Peduzzi et al. (1996) to the question of bulk package performance, each record represents a particular set of independent variables and an outcome (release or no release). Records in the data set are therefore equivalent to the subjects to which Peduzzi et al. (1996) refer. Similarly, since the percentage of accidents resulting in a release is less than the percentage of non-release accidents, release events are equivalent to Peduzzi et al.'s (1996) events.

It is also possible that, since the probability of an accident resulting in a release is approximately 26%, the accident data set may have many records but too few release events for a valid analysis. According to Peduzzi et al. (1996), at least 10 events per variable included in the model are desirable to maintain the validity of the model:

$$N = 10 \times \frac{l}{p} \qquad \text{(Eq. 8)}$$

where

l = the number of independent variables in the regression model.
p = the lesser of the percentage of release events or non-release events.

Given that 26% of accidents result in a release, if a model consisted of 10 variables, the minimum number of accident records required is 385 (see Table 58).

Table 58. Minimum number of records needed to satisfy Condition 2.

Number of Variables Included in the Model	Number of Records
1	39
2	77
3	116
4	154
5	193
6	231
7	270
8	308
9	347
10	385
11	424
12	462
13	500
14	539
15	577

Expected Implementation Time

Determining the amount of time required for the bulk package accident data collection system to yield statistically significant accident performance measures involved comparing the required sample sizes to the rate of data acquisition (see Table 59). If the implemented data set were able to obtain records for all accidents that occur (132 per month), the data set would yield significant results for some variables within 1 month of implementation. Within 1 year, there would be sufficient accident records to analyze each of the Tier I and Tier II variables.

Since reporting rates may be significantly lower than the expected accident rate, the number of months needed to generate sufficient sample sizes was determined for a range of reporting rates (recall that Battelle Memorial Institute [2009] estimated an HMIRS reporting rate of 26.9% and the underreporting analysis conducted in Section 3 estimated a reporting rate between 13% and 44%). This assumes that the ratio of non-release accidents to accidents in which a release occurs is maintained. As shown in Table 59, if complete records for only 20% of accidents are obtained, the data set would need 19 months of data accumulation before each of the Tier I variables could be tested. By the fourth year of data collection, the significance of each of the Tier II variables could be tested.

Statistical Summary of the Pilot Study

The pilot study resulted in a data set consisting of 50 records. A summary of data in Table 60 illustrates the range of responses obtained in the pilot test, grouped by hazardous material type. This data set has varying degrees of completeness, particularly regarding bulk package design, the extent of the damage, and the dimensions of the breach. As

Table 59. Number of months required to obtain sufficient sample sizes for testing significance at $\alpha = 0.10$ and power = 0.90.

Variables	Required Sample Size		Reporting Rate (%) 100	90	80	70	60	50	40	30	20	10
			Number of Months									
Tier I	Min	45	1	1	1	1	1	1	1	1	2	3
	Max	625	4	5	5	6	7	8	10	13	19	37
Tier II	Min	1,084	7	8	9	10	11	13	17	22	33	65
	Max	1,624	10	11	12	14	16	20	24	32	48	96
Tier III	Min	11,030	83	92	103	118	138	165	206	275	412	824

a result, while there are 50 records presented in Table 60, the completeness of the data set is not portrayed. For many variables, the actual number of records for which information was obtained sum to less than 50. Due to the limited data size and varying degrees of completeness, the statistical summary of this data is not representative of the entire population of accidents involving bulk packages. As mentioned above, the pilot study data are over-weighted in accidents that had a release and under-weighted in non-release accidents. For this reason, the analyses and evaluations of the pilot study data presented in this report are for illustrative purposes only and should not be considered reliable estimates of the performance of highway bulk packages. Nevertheless, the following discussion details variable response completeness, summarizes the collected data, and provides a basic interpretation.

In the pilot study, the design characteristics, commodity information, and accident information are stored so that one record pertains to one accident. Since one accident may result in damage to more than one part of the bulk package and more than one component, damage information is stored so that one record pertains to one location-component combination. For example, a rollover accident that resulted in damage to the shell along the entire length of the tank would result in a minimum of three location-component combinations: one for damage to the shell in each location (i.e., given

Table 60. Commodities and containers in the pilot study.

Number of Records	Description/Proper Shipping Name	Hazard Class	Identification Number	Packing Group	Container Specifications	Capacity [gallon]	Materials of Construction	Shell Thickness [inch]	Head Thickness [inch]	MAWP [psig]
3	Not Reported	3	Not Reported	Not Reported	MC 306	3,000 - 3,400	Aluminum (AL)	Not Reported	Not Reported	1
1	Ammonium Nitrate, Liquid	5.1	UN2426	N/A	MC 307	Not Reported	Mild Steel (MS) or High Strength Low Alloy Steel (HSLA)	0.129	0.129	3
1	Diesel fuel/Heating oil	3	UN1202	III	DOT 406	9,000	Not Reported	0.179	0.196	3.0 - 3.5
7	Diesel fuel/Fuel oil/cleaning compounds	3	NA1993	III	DOT 406	7,400 - 12,500	Aluminum (AL)	0.15 - 0.194	0.187 - 0.24	3.0 - 3.5
24	Gasoline/Gasohol	3	UN1203	II	MC 306 & DOT 406	5,500 - 9,500	Aluminum (AL)	0.179 - 0.204	0.175 - 0.250	3.0 - 5.0
2	Alcohols, n.o.s.	3	UN1987	I, II, or III	Not Reported	8,000	Aluminum (AL)	0.187	0.187	5
1	Petroleum Crude Oil	3	UN1267	II	DOT 407	9,500	Aluminum (AL)	0.25	0.25	25-29
1	Hydrochloric Acid	8	UN1789	II	DOT 412	5,400	Fiber Reinforced Plastic	0.25	0.75	35
1	Acrylic Acid, Stabilized	8	UN2218	II	Not Reported	7,000	Austenetic Stainless Steel (SS)	0.105	0.135	250
1	Propane	2.1	UN1978	N/A	MC 331	11,500	High Strength Low Alloy Steel (HSLA)	0.38	0.25	200 - 299
2	Liquefied Petroleum Gas (LPG)	2.1	UN1075	N/A	MC 331	11,600	High Strength Low Alloy Steel (HSLA)	0.378	0.25	200-299
3	Flammable Liquids, n.o.s.	3	UN1993	III	MC 331	Not Reported	Not Reported	Not Reported	Not Reported	Not Reported
1	Isopropenylbenzene	3	UN2303	III	ISO	6,300	Mild Steel (MS) or High Strength Low Alloy Steel (HSLA)	Not Reported	Not Reported	Not Reported
1	Hydrogen, Refrigerated Liquid	2.1	UN1966	N/A	MC 338					

a rollover onto the passenger side of the bulk package, Location 18—top front passenger-side, Location 19—top middle passenger-side, and Location 20—top rear passenger-side are likely to be the three locations incurring damage). For the purposes of the following discussion, the terms "case" or "damage case" refer to one of these location-component records. A total of 115 damage cases were identified from 46 accident records (4 of the 50 accidents did not have sufficient damage information).

Container Types

The pilot study considered a total of 50 records in which 49 (98% of the pilot study accident records) correspond to cargo tanks and 1 (2%) corresponds to an ISO tank. While specification information was unavailable for 13 of 16 truck-mounted cargo tanks and 8 of 33 trailer-mounted cargo tanks, container specifications are matched to all but two commodities in this pilot study (see Table 60).

Number of Compartments

In general, it was difficult to ascertain the number of compartments a bulk package contained from the information provided by PHMSA and/or photos of the bulk package. Where this information was not available, the bulk package was assumed to have at least one compartment with a capacity corresponding to "Cont1 Package Capacity" listed in PHMSA's HMIRS. Similarly, for those PHMSA-reported accidents in which two separate kinds of hazardous materials were involved, the bulk package was assumed to have at least two compartments. As a result, 40 accident records (80%) indicate a bulk package with one compartment and 4 records indicate a bulk package with two compartments. Five records correspond to bulk packages with four compartments and one record corresponds to a bulk package with five compartments.

Materials of Construction

The materials of construction were determined for 34 records (68%). Aluminum was the material of construction for 28 (56%) of the bulk packages. Two (4%) were constructed of stainless steel, three (6%) were constructed of carbon steel, and one (2%) was constructed of composite materials.

Capacity

Since PHMSA only records the total capacity of a bulk package (by type of hazardous material), capacity for individual compartments was incompletely recorded in the pilot study. Should this data collection system be implemented, it is anticipated that this information will be more readily available. To account for bulk package capacity in the analysis of pilot study data, the total capacity of the bulk package was recorded when available. Capacity information is available for 32 of the 50 records (64%). The total bulk package capacities range between 2,500 gallons and 12,500 gallons (see Figure 31).

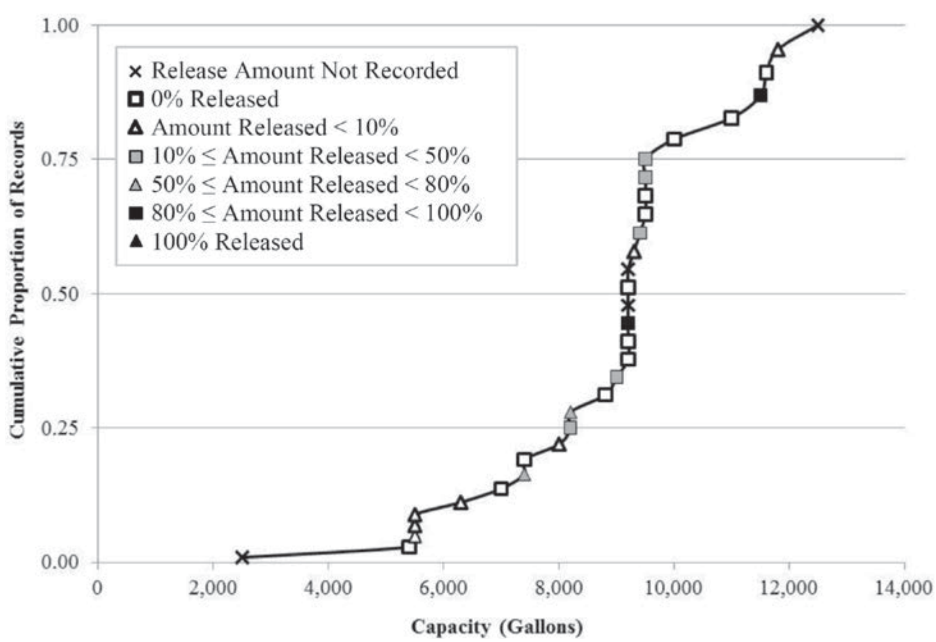


Figure 31. Cumulative proportion of pilot study bulk package capacities.

Head/Shell Thicknesses

Head and shell thickness were recorded for 22 records (44% of the pilot study accident records). These thicknesses were obtained for 11 DOT 406/MC 306 containers (22%), 2 DOT 407/MC 307 containers (4%), 1 DOT 412 container (2%), and 3 MC 331 containers (6%). Four records (8%) did not list a corresponding specification. Additionally, one record (2%) listed only shell thickness information. Examining the data for the largest homogeneous group, the DOT 406/MC 306 containers, the head thicknesses range from 0.175 inches to 0.25 inches while shell thicknesses range from 0.15 to 0.204 inches.

Working Pressure

Tank pressure ratings were recorded for 27 accidents (54%). The pressure ratings range from 1 psig to 5 psig for the DOT 406/MC 306. The majority (17 records or 34% of the pilot study accident records) indicate a pressure rating of 3 psig. Pressure ratings of up to 29 psig were recorded for the DOT 407/MC 307 containers. The DOT 412 container indicated a pressure rating of 35 psig, and the MC 331 containers indicated pressure ratings from 200 psig to 300 psig.

Hazard Class

The class of the hazardous material was determined for all 50 records included in the pilot study. Six of the records (12%) indicate Hazard Class 2, 41 (82%) indicate Hazard Class 3, 1 (2%) indicates Hazard Class 5, and 2 (4%) indicate Hazard Class 8.

Packing Group

The packing group of the hazardous material was reported for 36 records (72%). Of these records, 28 (56%) correspond to Packing Group II while 8 (16%) correspond to Packing Group III.

Hazardous Materials Identification Number

It was possible to determine the hazardous materials identification number for 46 (92%) of the 50 records (see Table 60). Gasoline/Gasohol (UN1203) was the commodity listed for most of the records in the pilot study data set (24 of 50 records). Other commodities included the following:

- Ammonium nitrate, liquid (UN2426).
- Diesel fuel/heating oil (UN1202).
- Diesel fuel/fuel oil/cleaning compounds (NA1993).
- Alcohols, n.o.s. (UN1987).
- Petroleum crude oil (UN1267).
- Hydrochloric acid (UN1789).
- Acrylic acid, stabilized (UN2218).
- Propane (UN1978).
- Liquefied petroleum gas (LPG) (UN1075).
- Flammable liquids, n.o.s. (UN1993).
- Isopropenylbenzene (UN2303).
- Hydrogen, refrigerated liquid (UN1966).

Hazardous Materials Packaged Amount

Similar to the capacity for individual compartments, the packaged amount for individual compartments was poorly recorded in the records found for the pilot study. Should this data collection system be implemented, it is anticipated that this information will be readily available. To account for the packaged amount in the pilot study analysis, the total packaged amount was recorded when available. Packaged amount information was recorded for 29 (58%) of the 50 records. These range from 500 gallons to 9,501 gallons (see Figure 32).

Vehicle Speed

The speed of the bulk package vehicle prior to incurring damage was estimated for 48 (96%) of the records. The pilot study grouped speeds in 5 mph bins. These speeds ranged from 0 to 65 miles per hour (see Figure 33).

Damage Location

The location of damage to the bulk package was determined from photographs accompanying newspaper articles and damage descriptions included in PHMSA's HMIRS "Description of Events." Since photographs of rollovers typically depict the bulk package's final resting position, damage to the side in contact with the ground could only be approximated. Damage was estimated for 47 records (94%). Based on this method of approximation, the locations most likely to be damaged are the top front passenger-side and the piping and/or undercarriage below the tank (see Table 61). These damage locations most likely correspond to different types of accidents: damage to the top front passenger-side results from rollover accidents while damage to the piping and/or undercarriage below the tank results from accidents involving other vehicles. Note that damage corresponding to the ISO container was converted to the location-naming scheme for cargo tanks for the purposes of this summary.

The following observations regarding damage location can be derived from the pilot study data (see Table 62):

- The passenger side of the bulk package is more likely to be damaged and result in a release if involved in an accident.

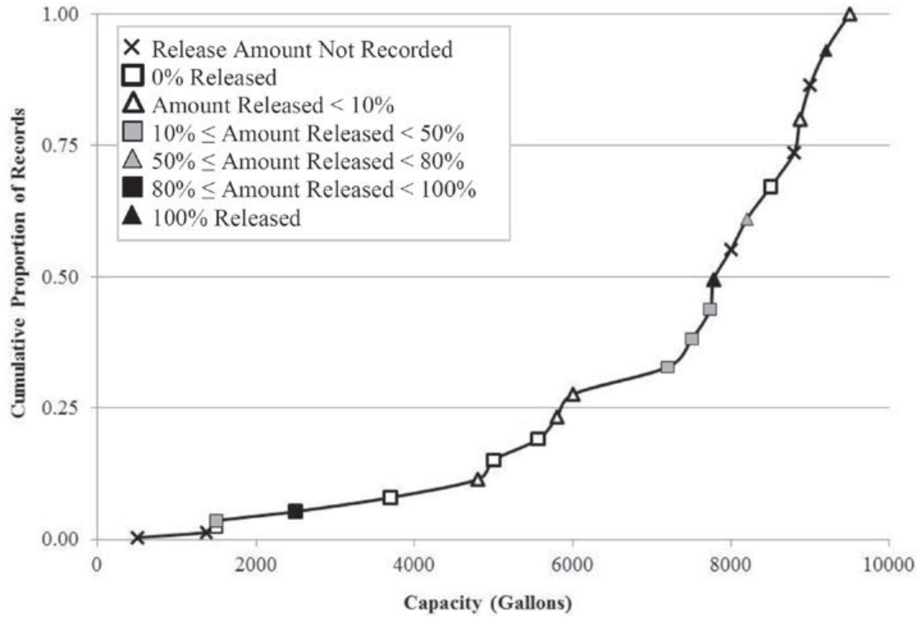


Figure 32. Cumulative proportion of pilot study bulk packaged amounts.

However, the driver's side of the bulk package may be more prone to release if it is damaged during an accident.

- The top of the bulk package is equally likely to incur damage and result in a release as the bottom of the bulk package; however, if piping and/or the bulk package's undercarriage are excluded, the top of the bulk package is twice as likely to be damaged in an accident.
- Although the top front passenger-side is most likely to be damaged, on average the front of the bulk package is equally likely to be damaged and involved in a release as is the rear. This is likely due to the additional protection afforded to the bottom of the bulk package by the tractor and the trailer wheel set.
- Both the front and rear of the bulk package are more likely to sustain damage that results in a release than the middle.

Damaged Components

Similar to the damage locations, the bulk package components damaged in an accident were identified using the photographs accompanying newspaper articles and damage descriptions included in PHMSA's HMIRS "Description of Events" and "What Failed Description." Detailed information regarding the identification of the type of valve damaged in the accident is limited; therefore, for the purposes of this analysis, the following valve components were grouped together:

- 106—Bottom Outlet Valve.
- 107—Check Valve.
- 115—Discharge Valve or Coupling.
- 116—Excess Flow Valve.

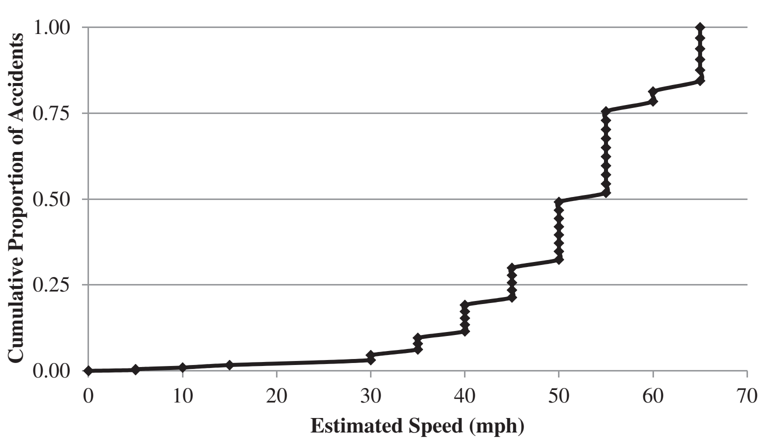


Figure 33. Estimated speed of bulk package prior to impact (mph).

Table 61. Number of accidents resulting in damage and releases by location.

			Proportion of Releases Per	
Location	Total Damaged	Releases	Number Damaged	Total Number of Releases
1 - Front Head Damage Below Centerline	1	1	1.00	0.02
2 - Front Head Damage on Centerline	3	1	0.33	0.02
3 - Front Head Damage Above Centerline	6	2	0.33	0.05
4 - Front Head Destroyed	0	0	0.00	0.00
5 - Rear Head Damage Below Centerline	3	3	1.00	0.07
6 - Rear Head Damage on Centerline	0	0	0.00	0.00
7 - Rear Head Damage Above Centerline	4	3	0.75	0.07
8 - Rear Head Destroyed	0	0	0.00	0.00
9 - Bottom Front Driver-Side Damage	3	3	1.00	0.07
10 - Bottom Middle Driver-Side Damage	3	2	0.67	0.05
11 - Bottom Rear Driver-Side Damage	5	4	0.80	0.10
12 - Top Front Driver-Side Damage	5	3	0.60	0.07
13 - Top Middle Driver-Side Damage	3	3	1.00	0.07
14 - Top Rear Driver-Side Damage	7	4	0.57	0.10
15 - Bottom Front Passenger-Side Damage	4	1	0.25	0.02
16 - Bottom Middle Passenger-Side Damage	3	1	0.33	0.02
17 - Bottom Rear Passenger-Side Damage	4	1	0.25	0.02
18 - Top Front Passenger-Side Damage	17	10	0.59	0.24
19 - Top Middle Passenger-Side Damage	7	4	0.57	0.10
20 - Top Rear Passenger-Side Damage	8	5	0.63	0.12
21 - Damage to Piping and/or Undercarriage Below the Tank	12	10	0.83	0.24

Note: These locations are identified in Figures 21 through 23.

- 127—Inlet (Loading) Valve.
- 134—Liquid Valve.
- 144—Pressure Relief Valve or Device.
- 154—Valve Body.
- 156—Valve Spring.
- 157—Valve Stem.
- 158—Vapor Valve.

Similarly, "Loading or Unloading Lines (135)" was grouped with "Piping or Fittings (141)."

Because damage to various components was identified using PHMSA's "What Failed Description," the pilot study estimates of component performance are expected to indicate a higher failure rate given that the component has sustained damage. A possible exception is the performance of the tank shell because the pilot study generally assumed shell damage on the ground-side of rolled bulk packages.

Damaged components were identified for 46 accident records (92%). The component most likely to be damaged

Table 62. Comparison of damage and release locations.

			Proportion of Releases Per	
Location	Total Damaged	Releases	Number Damaged	Total Number of Releases
Driver-Side	14	11	0.79	0.26
Passenger-Side	26	17	0.65	0.40
Top	30	22	0.73	0.52
Bottom (including piping)	26	21	0.81	0.50
Bottom (excluding piping)	16	11	0.69	0.26
Front	27	19	0.70	0.45
Middle	15	10	0.67	0.24
Rear	26	19	0.73	0.45

Table 63. Number of accidents resulting in damage and releases by component type.

Component Type	Total Damaged	Releases	Proportion of Releases Per Number Damaged	Proportion of Releases Per Total Number of Releases
Valves	7	7	1.00	0.17
Loading/Unloading Lines, Piping, or Fittings	12	9	0.75	0.21
Manway/Dome Cover	8	8	1.00	0.19
Tank Head	11	7	0.64	0.17
Tank Shell	28	17	0.61	0.40
Valve Seat	1	1	1.00	0.02
Weld or Seam	5	5	1.00	0.12

is the tank shell (see Table 63). This is not surprising as it is the largest component of the bulk package. Nevertheless, the pilot study also indicated that the tank shell was the least likely to result in a release if damaged.

The pilot study demonstrated the collection of damage information to determine whether component performance varied by damage location. Due to the number of damage locations (see Figures 21, 22, and 23), determining whether component performance varied by location requires a much greater number of records; therefore, only the tank shell is explored in further detail (see Table 64). This analysis indicates that tank shell damage probably does vary by location. Additionally, by considering damage cases, analysis of the pilot study data indicates that, in general, additional protection for the top front passenger-side (19% of all releases) and bottom rear driver's side of the tank (10% of all releases) might be a good idea.

Damage Type

Damage type was identified for all 115 damage cases (see Table 65). The pilot study data suggest that there are differences in the probabilities of release depending on the type of damage received. For example, the most prevalent type of damage resulting in a release is the ripping or tearing of the tank head, shell, or appurtenances. A total of 15 releases can be attributed to ripping or tearing although the frequency of this type of damage is low (only 16 cases). This differs from the most prevalent type of damage, crushing damage; there are 39 crushing damage cases of which 12 resulted in the release of hazardous materials.

Damage Dimensions

Damage dimensions were difficult to ascertain from many of the photographs and damage descriptions. Therefore, only 11 cases listed damage dimensions. However, with the

Table 64. Number of accidents resulting in tank shell damage and releases by location.

Location	Total Damaged	Releases	Proportion of Releases Per Number Damaged	Proportion of Releases Per Total Number of Releases
9 - Bottom Front Driver-Side Damage	3	3	1.00	0.07
10 - Bottom Middle Driver-Side Damage	3	2	0.67	0.05
11 - Bottom Rear Driver-Side Damage	4	4	1.00	0.10
12 - Top Front Driver-Side Damage	4	2	0.50	0.05
13 - Top Middle Driver-Side Damage	3	1	0.33	0.02
14 - Top Rear Driver-Side Damage	7	2	0.29	0.05
15 - Bottom Front Passenger-Side Damage	4	0	0.00	0.00
16 - Bottom Middle Passenger-Side Damage	3	1	0.33	0.02
17 - Bottom Rear Passenger-Side Damage	4	0	0.00	0.00
18 - Top Front Passenger-Side Damage	16	8	0.50	0.19
19 - Top Middle Passenger-Side Damage	5	2	0.40	0.05
20 - Top Rear Passenger-Side Damage	6	3	0.50	0.07

Table 65. Number of cases corresponding to each damage type by component category.

	Valves		Lines, Piping, or Fittings		Manways/ Dome Covers		Tank Head		Tank Shell		Valve Seat		Weld or Seam	
Damage Type	**D**	**R**	**D**	**R**	**D**	**R**	**D**	**R**	**D**	**R**	**D**	**R**	**D**	**R**
Abraded									5	0				
Bent	1	0	2	0	1	1	2	0	2	1				
Burst or Ruptured	1	1	1	1	1	1	2	1						
Cracked									2	2			5	4
Crushed			1	1			6	2	32	9				
Failed to Operate	1	1												
Gouged or Cut	1	1					1	1		4				
Leaked	2	2	1	1	5	5								
Punctured							1	1	9	6				
Ripped or Torn	1	1	7	6	3	3	2	2	1	1	1	1	1	1
Structural	1	1												
Torn Off or Damaged			1	1					6	4				
Vented														

Note: D represents the number of cases in which the component was damaged.
R represents the number of cases in which damage to the component resulted in a release.

full implementation of such a program, it is anticipated that sufficient data would be collected to evaluate the extent and severity of the damage.

Release Indicator

The pilot study data included an indication as to whether a release occurred due to damage to a particular component in the specified cargo tank location. This variable is used as the dependent variable when evaluating and modeling conditional probability of release. In the pilot study, this variable was coded "0" if no release occurred and "1" if a release occurred. Of the 46 tanks with damaged components in the pilot study, 42 (91%) tanks were damaged to the extent that a release occurred. Recall that the data are heavily weighted with accident records for which a release occurred and are under-weighted in records for non-release accidents. Each of the 46 cargo tanks with damaged components had at least one, and usually multiple, location-component combinations that sustained damage during the accident. In total, the data set included 115 location-component damage records for the 46 cargo tanks. While there were often multiple location-component combinations on a single tank that were damaged in a single accident, not all of the location-component combinations contributed to a release. Of the 115 location-component records, 67 (58%) resulted in a release of lading. This translates to a 58% probability of release per instance of damage.

Amount Released

The amount released was recorded for 40 (80%) of the 50 accidents and 62 (54%) of the 115 damage cases. This quantity reflects an estimate of the difference between the amount packaged and the amount recovered. Therefore, if the accident involved the combustion of hazardous material following its initial release, there was no distinction between hazardous materials spilled versus hazardous materials consumed in the fire/explosion. Additionally, since the amount released was obtained from PHMSA HMIRS, if leaks occurred from two different locations on the bulk package or as a result of the failure of two different components in the same location, the total amount released was assigned to both cases. The amount released ranged between a residual amount and 9,500 LGA (see Figure 34) with a mean of 2,470 gallons.

Breach Dimensions

The dimensions of the breach were very difficult to ascertain from the photos and were therefore recorded for only four cases. As with damage dimension information, with the full implementation of a data collection program, it is antici-

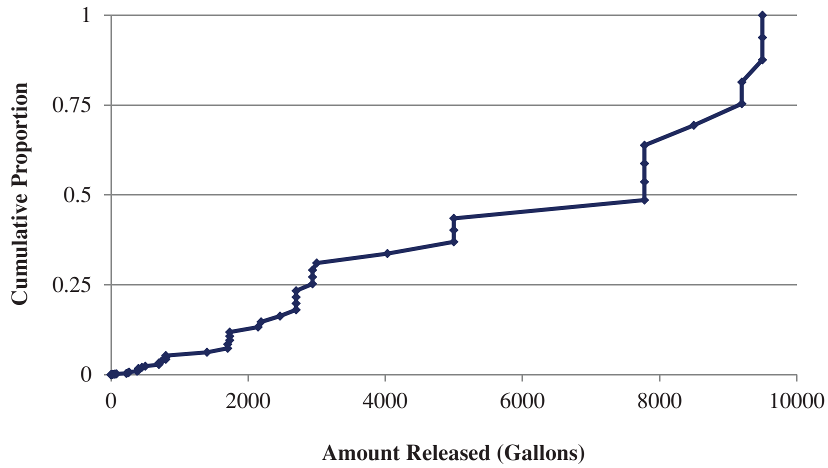


Figure 34. Cumulative proportion of pilot study release amounts.

pated that sufficient data would be collected. The breach dimensions along with the amount released can be used to estimate the rate of release and/or the amount of time until the release was mitigated. For example, large releases combined with small breach dimensions may indicate longer response times.

Roadway Collision Indicator

An incident involving the collision of the bulk package vehicle with another vehicle was coded as “1”; otherwise, it was coded as “0.” The data set generated by the pilot study contains 21 records (42% of the pilot study accident records) in which the bulk package was involved in a collision with another vehicle.

Passenger Vehicle Collision Indicator

There are two ways in which a passenger vehicle may be involved in a collision with a bulk package. The first, coded as “−1” in the pilot study data set, corresponds to a passenger vehicle striking the bulk package. There were 15 instances of a passenger vehicle colliding with the bulk package (30% of the pilot study accident records). The second, coded as “1,” corresponds to the bulk package vehicle striking a passenger vehicle. There were two instances of this type of collision (4% of the pilot study accident records).

Heavy Vehicle Collision Indicator

Collisions involving a second heavy vehicle were coded in a similar manner to the passenger vehicle collisions. The pilot study data set includes two records (4%) in which a heavy vehicle struck the bulk package and two records (4%) in which the bulk package struck another heavy vehicle.

Speed of Other Vehicle Involved in Collision

The speed of the other vehicle involved in a bulk package accident was recorded in 5-mph bins. Since vehicle speed was not provided in PHMSA’s HMIRS, it was estimated based upon the accident description and the speed of the bulk package vehicle. These speeds ranged from 0 to 65 mph (see Figure 35).

Jackknife Indicator

A jackknife occurring as part of the accident was recorded as a “1”; otherwise, a “0” was recorded. Of the 50 records in the pilot study, only one jackknife accident was recorded.

Cross Median/Centerline Indicator

Of the 50 records in the pilot study data set, 9 (18%) involve the bulk package traveling across the median or centerline of the roadway. These types of accidents correspond to an average release size of approximately 3,360 gallons of hazardous materials, while accidents in which the bulk package did not cross the median or centerline of the roadway resulted in an average release amount of approximately 1,550 gallons.

Ran-Off-Road Indicator

Of the 50 records in the pilot study data set, 32 (64%) involve the bulk package vehicle being driven out of the lane(s) of travel. Of these 32 records, 7 indicate collision with another vehicle. Of the 18 records where the bulk

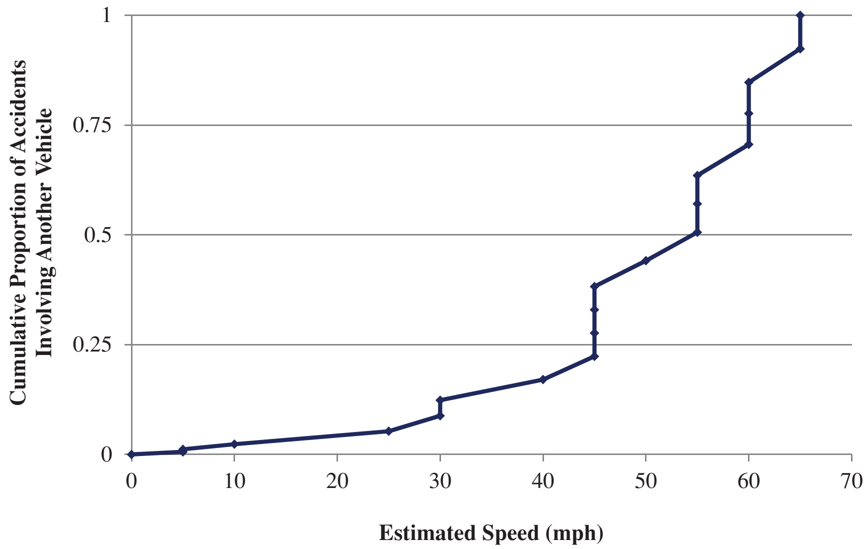


Figure 35. Estimated speed of other vehicle involved in the accident.

package vehicle was not driven out of the lane(s) of travel, 14 indicate collision with another vehicle. An average of 2,350 gallons was released for accidents in which the bulk package was driven off the road compared to approximately 1,140 gallons when the bulk package vehicle was kept on the roadway.

Rollover Indicator

Thirty-five accidents (70% of the pilot study accident records) involved the bulk package rolling over. Nine (18%) correspond to a roadway collision, eight (16%) correspond to accidents in which the bulk package was driven across the median or centerline of the roadway, and thirty (60%) correspond to "ran-off-road" accidents. Of the records that did not indicate a rollover, 12 (24%) correspond to a roadway collision, 1 (2%) involved crossing the median or centerline of the roadway and 2 (4%) involved running off the road. Rollovers resulted in an average release of 2,378 gallons compared to an average of 806 gallons when the package remained upright.

Explosion or Fire Indicator

A fire or explosion alters how much hazardous material is recovered. Material that is consumed in a fire or explosion is included in estimates of how much material was released in an accident. The accident data in the pilot study included a variable to indicate whether that record corresponded to a fire or explosion. Overall, 15 of the 50 records (30%) indicate that an explosion or fire accompanied the accident. These accidents resulted in an average release of 3,800 gallons compared to the mean release of 1,131 gallons for those accidents in which no fire or explosion occurred.

Listing of Objects Struck by the Bulk Package

In addition to indicating the type of accident a bulk package vehicle was involved in (collision, jackknife, cross median/centerline, ran-off-road, rollover, and fire/explosion), the pilot study indicated whether or not objects on or near the roadway were struck by the bulk package vehicle. The involvement of these objects was recorded with a "1"; otherwise, a "0" was recorded. Overall, the greatest number of releases involved the bulk package striking both the roadway and the ground (see Table 66). This is largely attributed to rollover accidents.

Conclusion

This section has summarized and interpreted the data collected in the pilot study. Additionally, minimum sample sizes required to test the effect of the variables on the probability of a release were generated using those pilot study records pertaining to hazardous materials typically transported in MC 306 and/or DOT 406 containers. These minimum sample sizes were compared to the expected number of accidents and releases involving hazardous materials to provide an estimate of when the bulk package data collection system, once implemented, could be expected to yield results. With a 20% reporting rate, the system can be expected to contain a sufficient number of records to test the significance of most variables within 4 years of its implementation.

Table 66. Objects struck by the bulk package and corresponding release sizes.

Roadway	Ground	Concrete Barrier	Guard Rail	Lighting/ Power Line Pole	Bride Column	Number	Average Release Volume (LGA)*
✓						2	32
	✓					9	1,444
✓	✓					12	2,730
✓		✓				2	1,240
✓			✓			3	700
	✓		✓			5	1,510
✓	✓		✓			1	452
✓	✓		✓		✓	2	9,200
				✓		1	736
Not identified	Not identified	Not identified	Not identified	Not identified	Not identified	13	1,637
Average Release Volume (LGA)*							
2,315	2,303	1,240	2,674	736	9,200		

Note: * denotes an average of the available release volumes.

SECTION 5

Institutional Barrier Identification

The fourth objective of HMCRP Project 07 was to identify potential institutional barriers to the development of a database and approaches to overcoming them. Since the database (created by an addendum to Form DOT F 5800.1) would be a government-managed activity, the associated institutional issues must be considered. These include the cost, the effect of public transparency on participation, data quality, and the regulatory hurdles of implementation. There are also institutional barriers associated with the parties that would report the accident data. These barriers stem from the perception that there is little benefit in reporting accident data and even some potentially negative consequences. The potentially negative consequences include the cost of completing reports and the risk that the information provided could be used in litigation against the provider. Additionally, it may be difficult for individuals reporting an accident to obtain damage information. This difficulty may be due to accident scene safety measures (i.e., evacuating the scene and clearing the roadway) and the disposition of the bulk package following an accident (i.e., being placed in an impound yard). These challenges will need to be overcome in order to achieve a successful data collection process.

Industry Opinion

A successful accident damage database will require collection of relevant information at minimal cost and with full cooperation or participation from key industry stakeholders. Industry concerns with gathering additional accident damage information need to be understood and overcome. To gauge the potential level of participation from the industry and understand its concerns, an extensive interview and survey process was conducted with the following industry associations:

- Truck Trailer Manufacturers Association (TTMA).
- International Tank Container Organization (ITCO).
- National Tank Truck Carriers Inc. (NTTC).
- American Chemistry Council (ACC).
- American Petroleum Institute (API).
- Compressed Gas Association (CGA).
- American Trucking Associations (ATA).
- American Transportation Research Institute (ATRI).

Concerns Raised by Industry Associations

Several stakeholder group representatives expressed little confidence that a voluntary database could be successfully established due to the 200 to 300 stakeholders involved in the trucking industry. By comparison, the rail industry tank car accident database involves only a dozen or so companies (See Appendix C for a discussion of this and other institutional differences affecting the development of a database). Moreover, several of the industry associations also expressed concerns about an accident damage database. The following subsections summarize the principal concerns.

Influence on Modal Competition

Some industry associations expressed concern that a shipper's use of the database and resulting analyses could lead them to shift traffic away from truck to rail. Ironically, the hazardous material shippers interviewed believed the opposite, stating that if there were adequate data to reliably assess highway transport safety and risk, motor carriers would obtain a larger share of business. Shippers believe that highway transport is less risky than it is currently perceived to be, but they must discount risk estimates because of the lack of the subject database needed to objectively assess risk. Shippers would prefer a level of quality in highway bulk package performance data that is equivalent to what they have for rail in the RSI-AAR TCAD. This view suggests that development of a highway bulk package database could lead to more favorable consideration of highway transport, rather than less.

Effect of Ranking One Type of Cargo Tank as Superior to Another

Some stakeholders are concerned that an accident damage database may show that some types of cargo tanks are better than others. The database probably will demonstrate differences among specifications; however, there is already qualitative understanding of this. An accident damage database would enable quantification of accident performance differences and better understanding of how specific design elements perform. Hazardous materials shippers and risk managers could use the resultant statistics to better inform their decision-making regarding cargo tank purchase and leasing decisions for products with different hazard levels. It might also be possible to use data to support a reduction in carriers' insurance premiums because their risks are better understood. An accident damage database would also provide a factual basis for discussions with regulators about whether proposed changes are justified and cost-effective. In general, an accident damage database could support a more accurate and refined approach to ongoing improvements in cargo tank design.

Litigation Concerns

Stakeholders have also expressed concern that the accident damage database may be used in litigation against them. This concern may be at the root of the substantial underreporting of accidents and incomplete reporting of accident information in PHMSA's HMIRS. Several stakeholder representatives suggested that certain information provided in Form DOT F 5800.1 or in an accident damage database should be protected against disclosure under Freedom of Information Act (FOIA) requests and/or be restricted from use in liability cases. In general, equipment manufacturers, shippers, and carriers comply with federal regulatory requirements. Under these circumstances, federal preemption can be used to defend challenges to cargo tank specifications and design. The 40-year experience of the RSI-AAR TCAD indicates that the accident data, analyses, and resulting actions taken based on industry consensus tend to provide reasonable means to effectively manage liability risks.

Survey Feedback

The industry organizations were asked to distribute a survey to their members regarding several aspects of a bulk package accident performance database. Survey respondents identified several concerns that would discourage participation, as well as challenges to collecting requested information.

Concerns Discouraging Participation

Manufacturers, repair facilities, carriers, and shippers were asked to identify concerns that might limit participation in an accident performance data collection process. The principal concerns for all industry groups are confidentiality, liability concerns, and increases in the amount of paperwork required (see Table 67). Since the number of responses is considered a small sample size (less than 30), generalization of responses may include biases that cannot be detected.

Measures Recommended to Increase Participation

Survey respondents also suggested approaches to increase the likelihood that crash and tank damage information would be reported. These include the following:

- Ensure the data are confidential or guarantee anonymity, at least from outside groups.
- Review, redefine, and simplify existing reporting requirements (this may include having law enforcement or

Table 67. Main concerns with providing bulk package accident performance data.

	Stakeholders			
Main Concerns	Manufacturers	Repair Facilities	Carriers	Shippers
Confidentiality	✓	✓	✓	✓
Liability Concerns	✓	✓	✓	✓
Paperwork	✓	✓	✓	✓
Cost		✓	✓	
Other Companies Not Participating			✓	
Data Accuracy			✓	
Time Requirements			✓	

emergency response officials communicate that the accident meets reporting criteria).
- Make reporting straightforward.
- Automate the reporting system to accommodate wireless transmission of data.
- Link multiple reporting systems to reduce redundant collection.
- Create an incentive program such as linking reporting of accidents to a company's safety rating, ensuring incident report records are up-to-date prior to issuing permits, or creating a tax incentive for compliance.
- Require participation and impose greater consequences for non-compliance (e.g., a $5,000 fine with no mediation).
- Have independent inspectors or assessors review/audit the data.
- Launch a campaign to highlight the benefits of equipment improvements that will reduce the damage caused by crashes.
- Provide useful feedback in a way that is easy for the drivers, mechanics, and others to understand (similar to the FMCSA cargo tank driver rollover prevention video).
- Train police officers to note damage on accident reports.
- Involve repair facilities in reporting.
- Identify responsibility for the crash more clearly.

Challenges of Data Collection

Manufacturers. One manufacturer indicated that it collects accident data on crashes involving its bulk packages; however, the collection of these data is dependent upon whether they are aware of the incident and the incident type. This manufacturer also indicated that there is no set amount of information they collect; rather, information was only collected if it was deemed relevant. The other two manufacturers that responded do not collect data regarding crashes involving their bulk packages.

Repair Facilities. Repair facilities were asked a series of questions concerning the amount of training needed to ensure the collection of accurate information, the degree of difficulty anticipated in collecting various kinds of bulk package design information and accident damage information, and a rough estimate of the amount of time needed to collect this information. Of the seven repair facilities that responded to the survey, six indicated that some certification was necessary to ensure data quality. Three respondents indicated that the highest level of certification (Authorized Inspectors) was required.

The damage information that was identified as most difficult to collect is whether the damage occurred near a previous repair and whether that repair influenced the structural integrity of the tank. Following the information concerning a previous repair, the information identified as moderately difficult to collect includes the following:

- Cause(s) of lading loss (i.e., shell puncture, bottom fitting damage, or rupture due to fire).
- Location of the crack, gouge, puncture, or rupture from which the most hazardous material spilled.
- Dimensions of the crack, gouge, puncture, or rupture from which the most hazardous material spilled.
- Location of damage resulting in the loss of hazardous materials.
- Shell or head thickness at damage locations resulting in the loss of hazardous materials.
- Dimensions of damage at non-spill locations.
- Shell or head thickness at non-spill locations.
- Whether the crack or tear occurred because of damage to the fitting or appurtenance.
- The type of wet line construction.

The majority of the bulk package repair facilities indicated that the following information would be easy to collect:

- Location of initial point of impact.
- Dimensions of dent, crack, gouge, puncture, or rupture at an initial point of impact.
- Shell or head thickness at an initial point of impact.
- Shell or head thickness at the location from which the most hazardous material was spilled.
- Dimensions of crack, gouge, puncture, or rupture from which the most hazardous material spilled.
- Location of damage that does not result in a spill.
- Location of damaged fitting.
- Type of fitting damage.
- Whether the cargo tank was repaired to specification, repaired to non-specification, or scrapped.
- Tank shape.
- Tank wall thickness.
- Baffle and bulkhead location.
- Type(s) of accident protection devices.
- Type(s) of roll stability devices.
- Presence of wet lines.

In addition to the above information, some repair facilities also gather the following damage information:

- Age of fittings.
- Tank dimensions (out of round).
- Frame, suspension, axle, and bumper damage.
- Attachment damage.
- Lighting damage.
- Records of previous repairs and testing.
- History of products hauled.

The repair facilities were asked to estimate how long it would take to gather the above information. Four of the repair facilities estimated that it would require between 1 and 5 hours, while one company estimated that it would take 2 to 3 days. Another company indicated that estimating damage repairs "varies from tank to tank depending on whether the tank is ASME coded or not." Estimates of the time required for collection of design information ranged from 15 minutes to 2 hours, with one repair facility estimating that 2 to 3 days would be required to collect the design data.

Carriers. In addition to variables recorded by various existing databases, as discussed in Section 2, several carriers also report collecting:

- Location information including GPS records and the number of miles from the home terminal.
- Driver information including driver age, length of employment, and years of experience.
- Bulk package data including vehicle maintenance records.
- Collision events data including electronic control module (ECM) or other on-board recorder information, photos of the accident scene and damage, root cause of crash, contributing factors, and accident reconstruction.
- Package damage information including damage location, type, size, depth, wall thickness of damaged cargo tank, repair orders, adjuster investigation, and additional damage caused by righting equipment (in the case of a rollover).

Since these data are being collected already, the additional burden of recording the data in a national database is minimal. However, the carriers also reported several challenges regarding the collection of crash and damage data. Working with local law enforcement at the accident scene and obtaining police reports in a timely manner was the challenge reported by the largest number of carriers. Other challenges to data collection include lack of software to collect specific data, lack of access to equipment due to impounding, increased response or remediation time due to inexperienced or insufficiently trained emergency response teams, driver inability to take photos of accident (due to safety or law enforcement guidance), difficulty in preservation of incident scene, and lag time in getting a trained accident investigation engineer to the site. Some obstacles that need to be overcome in order for carriers to populate an accident damage database include the inability to describe and/or determine the condition of the vehicle if it is severely damaged, ability to collect the data in a timely fashion, and the threat of legal liability.

Shippers. In general, shippers tend to collect information similar to that collected by carriers regarding hazardous material accidents. One shipper reported that when hazardous materials are shipped using carrier-owned vehicles, the shipper requires the carrier to submit a full incident investigation report including a root cause analysis. Therefore, in addition to variables recorded by various databases, as discussed in Section 3, several shippers also report collecting the following:

- On-board event recorder information (including speed and whether brakes were applied prior to the crash).
- On-board drive camera (recording front and back of the vehicle before and immediately after the crash, including view of driver behavior at the time of the incident).
- Pictures and witness information and interviews.
- Information to determine whether an incident report should be filed (leakage amount, citation information, closing of public roadways, injuries, and environmental impact).

Shippers also report several challenges in collecting accident information. These include the following:

- Difficulty in gathering information from a carrier or carrier's subcontractor.
- Conflicting opinions with the police report regarding what caused the accident.
- Inability of the driver to correctly recall events.
- Lack of information concerning the events in the accident because not all vehicles/trailers are equipped with event recording devices.

Identification of Institutional Barriers and Possible Solutions

The success of an accident damage data collection system depends upon overcoming several institutional challenges. Based on the industry feedback discussed above, several of these institutional challenges were identified and are further considered in the following discussion. Possible solutions are also suggested.

Institutional Barriers Associated with System Implementation and Operation

Cost Barriers

Barrier. During Fiscal Year 2011, the HMIRS cost approximately $2,255,000 ($1,945,000 annualized continuing resolution [P.L. 111-242 as amended] + $310,000 adjustments), and the research and analysis conducted by PHMSA cost approximately $435,000 ($423,000 annualized continuing resolution [P.L. 111-242 as amended] + $2,000 adjustments) (PHMSA 2011). These expenses would increase with the implementation of an addendum to Form DOT F 5800.1 and increased enforcement of participation. To justify this increase, the database must provide a return on investment. Since the addendum to Form DOT F 5800.1 to record highway bulk package accident damage is expected to accrue accident information at a relatively slow rate, this program may require several years of operation before the data can be used to assess accident performance and identify components or locations that would benefit from enhancements. Thus, a cost-effectiveness analysis should take this into account.

Possible Solution. A possible method for justifying the expense of the addendum is to communicate the positive net return on investment for the RSI-AAR TCAD project. Since 1970, that database has been used to provide sponsors with a scientific and statistical basis for evaluating the effectiveness and costs of new proposed rules and regulations. This approach has earned the respect of regulatory agencies and has resulted in more pragmatic, effective, and fact-based regulatory proposals. This database has been periodically evaluated for its effectiveness in aiding the industry to achieve various improvements in the safety of hazardous materials transportation by rail. Evaluations of the TCAD have consistently shown industry savings that were over 11 times the costs of implementing the database (T. T. Treichel to Phil Daum [principal investigator HMCRP Project 07], personal communication, 2/11/2011). The effort has led to safer, more secure, more competitive, and more profitable businesses.

Another possible method to justify the database is to conduct a pilot study with effective incentives for participation. The pilot study would enable realistic estimates of the additional cost of implementing an addendum to Form DOT F 5800.1. Additionally, the pilot study would provide further information regarding data accrual rates and lead to preliminary package performance estimates. These could be used to more accurately estimate the benefits of an accident database.

Regulatory Barriers

Barrier. Modifying the current Form DOT F 5800.1 to include the proposed fields would require a change to the current regulations governing compliance. Whatever changes are proposed must conform to the procedures outlined in the Administrative Procedure Act (APA). Therefore, this option would probably take several years and could involve opposition from the regulated community. The previous amendment to Form DOT F 5800.1 was revised many times over several years before being adopted.

Possible Solution. To streamline the process of modifying the current Form DOT F 5800.1 or adopting an addendum database into regulation, a coordinated effort could be undertaken. This effort would focus on developing consensus among stakeholders regarding how to modify the form. Engaging stakeholder participation in developing an addendum to the highway bulk package Form DOT F 5800.1 would help mitigate issues that might otherwise hinder its adoption. However, developing consensus among the industry may be difficult because the industry includes a diverse group of carriers and associations representing those carriers. A sufficient number of carriers must be convinced that such a database would be in their best interest. To achieve this critical mass, the individuals coordinating the revision effort should focus their initial effort on carriers already committed to risk-based approaches to safety.

Barriers to Reporting Accident Data

Several institutional barriers currently discourage individuals from reporting accidents to PHMSA. These include drivers having to fill out paperwork without compensation, the possibility that legal repercussions may arise from the information provided to PHMSA, and the possibility that the individual required to report the incident is for some reason incapacitated by the accident and thus unable fulfill this requirement. These challenges will need to be overcome if the accident reporting system discussed in this report is to succeed in gathering sufficient and accurate accident information on which to conduct useful analyses.

Reporting Responsibility Placed on Driver

Barrier. PHMSA estimates that completion of Form DOT F 5800.1 by the individual reporting the accident would take 1.6 hours. This time estimate includes the following actions: reviewing the instructions, searching existing data sources for information, gathering the required data, and then completing and reviewing the report. The individual reporting the accident is a representative of the company in possession of a hazardous material during transportation. In the case of in-transit accidents, the driver of the bulk package is involved in the reporting. Drivers are typically paid according to the number of hours or number of miles they have been driving, and paperwork is completed on personal time. Therefore, they may not be compensated for the time required to fill out a report. Any lack of compensation is a disincentive to the reporting individual and represents an institutional barrier to completing these reports.

Possible Solution. When the driver involved in an investigation is compensated for his/her time, this aspect of the institutional barrier is reduced or eliminated.

Reporting Responsibility of Carriers

Barrier. Not only do companies lack incentive to report the incident, there is a disincentive because of the possible legal repercussions resulting from the information provided in the accident report.

Possible Solution. Increased enforcement of existing requirements would motivate companies to ensure accidents are reported. An additional incentive may be provided by designing the system to rate a company's participation in the program according to how consistently and comprehensively it reports accidents and tying these participation ratings into FMCSA's safety rating system. However, if participation in the program is to be tied to the company's safety rating, the accident rate for the carrier should not be generated from PHMSA-reported accidents. Rather, the accident rate for carriers should be generated from an external source, such as FMCSA's database or a data set created from newspaper articles, and later matched to the carrier. For this incentive to be most meaningful and valuable, non-release accidents must also be reported.

Privacy of Information/Legal Repercussions

Barrier. Since the addendum would be an extension of Form DOT F 5800.1, similar to the information in the HMIRS, the additional data would be subjected to the current FOIA and, therefore, not protected. However, there is concern that the public availability of the stored data, under Option B, would have negative repercussions on the individuals and companies responsible for reporting. The availability of these data for public use may either discourage individuals from reporting an accident or affect the accuracy and completeness of data actually reported.

Possible Solution. A possible solution would be the implementation of a "no-fault" provision so that information reported using the Form DOT F 5800.1 addendum cannot be used in liability cases. One way to implement a "no-fault" provision is to store information collected via the Form DOT F 5800.1 addendum separately from the Form DOT F 5800.1 information so that the damage data cannot be traced to the carrier, shipper, or other involved entity. Individuals responsible for reporting would then be provided with a unique receipt number as proof of compliance during company inspections and audits. In this way, the general public would be unable to correlate a bulk container damage report with a particular accident or bulk carrier. It is important to note that access to accident damage data is already available as part of the litigation process; therefore, collecting factual data through an addendum to Form DOT F 5800.1 would do no additional harm.

Barriers to Obtaining Damage Information

There are also several barriers to obtaining accurate damage information. These include challenges in recording crash and damage information at the crash scene and restricted access to the vehicle(s) and bulk package following the accident.

Crash Scene Data Collection Barriers

Barrier. The need to collect accident damage information often conflicts with the primary goal of emergency responders at the scene, which is to contain or prevent a spill and ensure the safety of individuals at the site. The presence of individuals at the crash site increases the risk of someone being injured. Furthermore, a goal of local law enforcement, to regain the use of the transportation route, conflicts with data collection because the incident scene may often be cleared prior to the information being recorded.

Carriers reported several additional challenges that would result from trying to gather data while emergency responders and local law enforcement try to fulfill their responsibilities at the accident scene. Working with local law enforcement and obtaining police reports in a timely manner was the challenge most frequently reported by carriers. Other challenges to data collection include drivers' inability to take photos of an accident (due to safety or law enforcement guidance), difficulty in preservation of the scene, and lag time in getting a trained accident investigation engineer to the site.

Possible Solution. Prior to the removal of the bulk package and other vehicles from the accident scene, photos should be taken of the following:

- Bulk package specification plate(s).
- Hazard class placard.
- Object(s) that damaged the bulk package in the accident.
- Bulk package and any damage to the bulk package (these may be taken after the bulk package has been moved from its "resting" position).

These photos may be taken by law enforcement personnel if a representative of the company is not present or otherwise unable to perform these tasks. These photos would be used to ascertain accident damage and other parameters if the bulk package was later unavailable.

Additionally, an effort should be made to streamline the process of transferring photos and other information from local law enforcement to the carriers so that the information can be reported. This may be accomplished by creating an industry website that has instructions and links to law enforcement request forms.

Restricted Access to the Vehicle(s) and Bulk Package Involved in an Accident

Barrier. Carriers reported two challenges to collecting information after the truck and bulk package have been removed from the accident scene: (1) the lack of software to collect specific data and (2) the lack of access to equipment due to impounding. These two challenges are typically overcome by estimating damage and accident conditions (i.e., the location and extent of damage and how fast the bulk package was traveling, respectively) thereby reducing the quality of data initially reported as part of the addendum.

Possible Solution. The reporting system could allow for initial estimates to be revised once access to the vehicle(s) and bulk package has been granted.

Conclusion

The success of an accident damage data collection system depends upon overcoming several institutional challenges. These challenges and possible solutions to them include the following:

- **Cost barriers.** Possible methods for overcoming these barriers include communicating the positive net return on investment for similar projects (such as the RSI-AAR TCAD) or conducting a pilot study with effective incentives for participation.
- **Regulatory barriers.** Possible methods for overcoming these barriers include undertaking a coordinated effort that focuses on developing consensus among stakeholders regarding how to incorporate the accident damage data collection process. The initial attempt to gain support for such a regulatory revision could focus on carriers already committed to risk-based approaches to safety.
- **Reporting responsibility.** Possible methods for overcoming these barriers include ensuring that drivers are compensated for time spent filing accident reports and increasing enforcement to motivate companies to ensure that accidents are reported.
- **Privacy of information/legal repercussions.** Possible methods for overcoming these barriers include the implementation of a "no-fault" provision so that collected information could not be traced to information currently collected by Form DOT F 5800.1. In such a scenario, carriers would be required to provide proof of compliance during company inspections and audits.
- **Crash scene data collection challenges.** A possible method for overcoming this barrier is to ensure that photos of the damage and accident scene are taken prior to removal of the bulk package from the accident scene.
- **Restricted access to the vehicle(s) and bulk package involved in an accident.** A possible method for overcoming this barrier is to allow for initial estimates to be revised once access to the vehicles has been granted.

SECTION 6

Conclusion and Suggested Research

This report presents an analysis and possible methodology to develop and implement an accident reporting database system to collect information on the nature and extent of damage to U.S. DOT-specified hazardous materials bulk packages involved in accidents, whether or not the damage resulted in a leak of contents, as well as the characteristics of the accidents. This was achieved by (1) reviewing the nature and quality of the data currently being collected for accidents involving U.S. DOT-specified hazardous materials bulk packages (i.e., portable tanks, cargo tanks, and cargo tank motor vehicles), (2) determining what data were needed to develop a satisfactory database, (3) developing methodologies for systematic collection and analysis of the necessary performance data, and (4) identifying and evaluating the institutional barriers to establishing such a database and approaches to overcoming them.

A successful data collection system requires cooperation among bulk package manufacturers, carriers, shippers, multiple associations representing these groups, and multiple government agencies. Such a system will provide a powerful source of information for industry to pro-actively identify and assess improvements in package design, and to undertake quantitative, data-driven safety and risk analyses to inform private and public-sector package design and policy decisions.

If implementation of a mandatory extension of Form DOT F 5800.1 with a "no-fault" provision is considered, further research, prior to implementation, would:

1. Identify strategies to address underreporting in PHMSA HMIRS—this may include crosschecking with accidents reported to other databases (i.e., TIFA, MCMIS Crash File), getting data from repair shops, using comprehensive news alerts (similar to the Google news alert used in the pilot study), and collecting information from state or local police; development of outreach programs to increase awareness of the benefits to reporting accidents, even when there is no release; and increasing enforcement effort to improve compliance with existing reporting requirements.
2. Justify burdens to both industry and the government to execute this extension.
3. Further assess the feasibility of this endeavor by providing temporary incentives to encourage carrier participation until a sufficient number of responses can be obtained.
4. Determine the process and time required to comply with the Paperwork Reduction Act (PRA) in order to modify the form.
5. Conduct meetings or hearings to discuss the possibility of improving Form DOT F 5800.1 to collect important, additional information identified in this study.
6. Identify methodologies to develop and establish a database of detailed design information for the national fleet of individual bulk packages.
7. Establish best-practice procedures for accidents involving hazardous materials to obtain photographs of package damage and record key pieces of information prior to removing the bulk package from the scene.

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Acronyms

AADT	Annual average daily traffic
AAR	Association of American Railroads
ACC	American Chemistry Council
AI	Authorized inspector
AL	Aluminum
APA	Administrative Procedure Act
API	American Petroleum Institute
ATRI	American Transportation Research Institute
AVI	Automatic vehicle identification
CASRAM	Chemical Accident Stochastic Risk Assessment Model
CCPS	Center for Chemical Process Safety
CFR	Code of Federal Regulations
CGA	Compressed Gas Association
CI	Certified Individual
CSS	Cascading Style Sheets
ECM	Electronic control module
EDR	Electronic data recorder
ESC	Electronic stability control
FARS	Fatality Analysis Reporting System
FOIA	Freedom of Information Act
GCF	Gas cubic foot
GES	General Estimates System
GIS	Geographic information system
GPS	Global positioning system
GVWR	Gross vehicle weight rating
HIP	Hazardous Intelligence Portal
HMIRS	Hazardous Materials Incident Reporting System
HSLA	High strength low alloy
HTML	Hypertext Markup Language
ITCO	International Tank Container Organization
LGA	Liquid gallon
LPG	Liquefied petroleum gas
LTCCS	Large Truck Crash Causation Study
MCMIS	Motor Carrier Management Information System
MCS	Motor carrier safety
MISLE	Marine Information for Safety and Law Enforcement
MS	Mild steel

NASS	National Automotive Sampling System
NRC	National Response Center
NSC	National Safety Council
NTTC	National Tank Truck Carriers, Inc.
PRA	Paperwork Reduction Act
QA	Quality assurance
QI	Qualified inspector
RAIRS	Railroad Accident/Incident Reporting System
RFID	Radio frequency identification
RSC	Roll stability control
RSI	Railway Supply Institute
SCFH	Standard cubic feet per hour
SS	Stainless steel
STCC	Standard Transportation Commodity Code
TCAD	Tank Car Accident Database
TIFA	Trucks Involved in Fatal Accidents
TIH	Toxic inhalation hazard
TTMA	Truck Trailer Manufacturers Association
UMLER	Universal Machine Language Equipment Register
UMTRI	University of Michigan Transportation Research Institute
URS	Unified Registration System
VIN	Vehicle identification number
WMD	Weapon of mass destruction

APPENDICES A THROUGH G

Appendices A through G have been published on *CRP-CD-128*, which is bound into this report. Appendix titles are the following:

- Appendix A: Survey Development and Questions
- Appendix B: Conditional Probability of Release as a Function of Data Refinement
- Appendix C: Differences Between Highway and Rail Hazardous Material Transportation Affecting Development of a Bulk Package Accident Performance Database
- Appendix D: Option Evaluation Tool
- Appendix E: Pilot Study Data Collection Tool
- Appendix F: Links to Newspaper Articles
- Appendix G: An Example of Bulk Package Performance Analysis Using Multivariate Regression

Abbreviations and acronyms used without definitions in TRB publications:

AAAE	American Association of Airport Executives
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI–NA	Airports Council International–North America
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
HMCRP	Hazardous Materials Cooperative Research Program
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
PHMSA	Pipeline and Hazardous Materials Safety Administration
RITA	Research and Innovative Technology Administration
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S.DOT	United States Department of Transportation