Hazardous Materials Transportation Risk Assessment: State of the Practice

DETAILS

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HAZARDOUS MATERIALS COOPERATIVE RESEARCH PROGRAM

HMCRP REPORT 12

Hazardous Materials Transportation Risk Assessment: State of the Practice

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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 Stephan A. Parker
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HMCRP Report 12: Hazardous Materials Transportation Risk Assessment: State of the Practice documents the current practice for hazardous materials transportation risk assessment by government agencies and the private sector. The report will be of interest to shippers, carriers, government agencies, responders, risk managers/insurers, and researchers.

Hazardous materials transportation risk assessments are often designed for different purposes and used in different ways by government agencies and the private sector. There are a number of models/methodologies used in each sector, from simplified to extremely complex, that have varying data needs and make varying degrees of assumptions. Different assessment tools and approaches may be applicable to only specific transportation scenarios, activities, or purposes. In addition, many of the assessments address single modes of transportation, and there are few published methods to adequately compare risk across modes or in combinations of modes. There is a need for the government sector to better understand how the private sector performs and uses risk assessments and risk management and for the private sector to appreciate government needs in regulating hazardous materials in transport.

Under HMCRP Project 12, Visual Risk Technologies, Inc., was asked to prepare a report that (a) identifies existing tools, methodologies, approaches, and key sources of data for assessing hazardous materials transportation risks in the public and private sectors; (b) characterizes the capabilities and limitations of each; (c) identifies where there are significant gaps and needs in the available tools and approaches; and (d) recommends paths forward. The first phase of the project captured the status of the current practice of hazardous materials transportation risk assessment, including current uses, existing models, and available data sources. The second phase of the project focused on synthesizing the research compiled in Phase I and determining where gaps exist in available tools, techniques, and data. Phase II also included presenting a path forward for addressing these gaps and supporting better risk assessments in the future.

The project included a literature review and extensive interviews with hazardous materials transportation risk assessment stakeholders. In addition, an online survey was used to expand the collection of information to a wider group of stakeholders. The results of these information gathering steps were summarized, and the current uses of risk assessments for each stakeholder were reported according to the following categories: (1) current uses, users, modes, and decision making; (2) models, tools, methodologies, approaches; (3) key sources of data; (4) assumptions, limitations, biases, and availability; (5) updates; (6) risk communication; (7) desired improvements; and (8) implementation barriers.

The key risk assessment approaches involving models or methodologies with sufficient documentation or available information were further characterized in a set of decision matrices. The matrices are designed to facilitate selection of a model for application to a hazardous materials transportation stakeholder's particular needs.

A PowerPoint presentation that describes the entire project is available on the TRB website at http://www.trb.org/Main/Blurbs/169158.aspx.

CONTENTS

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

SUMMARY

Hazardous Materials Transportation Risk Assessment: State of the Practice

This final report presents the process and findings of a project documenting the current state-of-the-practice for hazardous materials transportation risk assessment. The first phase of the project captured the status of the current practice of hazardous materials transportation risk assessment, including current uses, existing models, and available data sources. The second phase of the project focused on synthesizing the research compiled in Phase I and determining where gaps exist in available tools, techniques, and data. Phase II also included presenting a path forward for addressing these gaps and supporting better risk assessments in the future.

The project included a literature review and extensive interviews with hazmat transportation risk assessment stakeholders. In addition, an online survey was used to expand the collection of information to a wider group of stakeholders. The results of these information gathering steps were summarized, and the current uses of risk assessments for each stakeholder were reported according to the following categories:

- Current uses, users, modes, and decision making
- Models, tools, methodologies, approaches
- Key sources of data
- Assumptions, limitations, biases, and availability
- Updates
- Risk communication
- Desired improvements
- Implementation barriers

The key risk assessment approaches involving concrete models or methodologies with sufficient documentation or available information were further characterized in a set of decision matrices. The matrices were designed to facilitate selection of a model for application to a hazmat transportation stakeholder's particular needs. The specific decisions included in the matrix are:

- Mode Choice
- Route Choice
- Facility Siting
- Packaging Selection
- Alternate Product Selection
- Emergency Management Resource Planning
- Operational Changes
- Security Measure Identification, Prioritization Evaluation
- Security Risk Situational Awareness

Each model listed in the decision matrix has been presented in greater detail in a separate matrix. The individual model matrices characterize each risk assessment approach in terms of its uses, model elements, data requirements, outputs, strengths and weaknesses, availability, and potential barriers to its use. The specific models and their developers included are shown in Table S1.

After characterizing each model, the project team then analyzed the information gathered. The general analysis included a discussion of the types of decisions different stakeholders make and the scope and timeframe for their analyses, how those decisions can be supported with different levels of quantification, and a more detailed discussion for each of the decision types listed earlier.

Table S1. Model risk assessments and developers.

Model	Sponsor/Developer
Boston Hazmat Route Evaluation	City of Boston
Center for Chemical Process Safety (CCPS) Guidelines: Qualitative Risk Assessment Process	CCPS
CCPS Guidelines: Quantitative Risk Assessment Process	CCPS
CCPS Guidelines: Risk Prioritization Process	CCPS
CCPS Guidelines: Security Risk Prioritization Process	CCPS
CCPS Guidelines: Security Vulnerability Assessment Process	CCPS
CCPS Guidelines: Semi-Quantitative Risk Assessment Process	CCPS
Chemical Manufacturer Risk Assessment Framework	Large Chemical/Plastics Manufacturer
Chemical Terrorism Risk Assessment (CTRA)	Department of Homeland Security (DHS) Science and Technology Directorate (S&T) Chemical Security Analysis Center (CSAC)
Fedtrak	The Kentucky Transportation Center (KTC) at the University of Kentucky (UK) for Transportation Security Administration (TSA)
GeoCTA	Oak Ridge National Laboratory (ORNL) Center for Transportation Analysis (CTA)
Institute of Makers of Explosives (IME) Safety Analysis for Risk (IMESAFR)	IME
Pipeline Risk Management Manual Risk Assessment Method	Pipeline and Hazardous Materials Safety Administration (PHMSA) Office of Pipeline Safety (OPS)
RADTRAN	Department of Energy (DOE)/Sandia
Rail Corridor Risk Management System (RCRMS)	Railroad Research Foundation (RRF)/ Association of American Railroads (AAR)
Readiness and Resiliency Assessment Framework	ORNL CTA
Risk-Based Preventative Radiological/Nuclear Detection Resource	National Center for Risk and Economic Analysis of Terrorism Events (CREATE)
TRACC	ORNL CTA/Miss. State Univ.
Transportation Routing Analysis Geographic Information System (TRAGIS)	DOE/Oak Ridge
Transportation Sector Security Risk Assessment (TSSRA)	DHS, TSA, Office of Security Capabilities (OSC)
Trucking and Hazmat Trucking Risk Assessment (THTRA)	DHS, TSA Highway Motor Carrier Branch (HMC)
University of Illinois at Urbana-Champaign (UIUC) Tank Car Risk Analysis	UIUC

The primary model components, frequency, probability, threat, vulnerability, and consequence, were also discussed separately, highlighting the approaches used by the different models and stakeholders along with any relevant issues, such as sources, availability, and level of detail. A discussion of the approaches used for interpreting and applying the results included a discussion on the types of output from risk assessments and the treatment of uncertainty.

The project team identified gaps in the models, model data, and in the availability of these models, data, and results to stakeholders. For models, the gaps included multi-modal/intermodal risk analyses, validation of prior assessments, comparability of model results, uncertainty, and route analysis tools. Data gaps included: inadequate highway exposure data and accident rates, conditional probability data, disparate data quality across modes, security assessment credibility and transparency, lack of public vulnerability and threat data, and validation of supporting data. Finally, for availability, the gaps included a formal risk management process; data building blocks for assessments; lack of awareness of available data, tools, and methods; and lack of public disclosure of datasets.

The project team offered several recommendations for improving the state of the practice in hazmat transportation risk assessment. These recommendations included:

- Recommendations for model development: development of a common risk assessment approach across all modes using a standard architecture. Highway and waterway hazmat route risk assessment tools were also recommended.
- Recommendations for data development: enhancement of the available hazmat commodity flow data to support improved accident rate information, enhancing the data to support conditional release probabilities for highway transportation, more research on commercial-scale explosives, data calibration across modes, developing a guidebook for hazmat transportation security-related elicitation from subject matter experts, and exploring options to increase safe sharing of security-sensitive threat and vulnerability data.
- Recommendations for communication and data/model sharing: integration of common methodologies used by private and public sector entities into a common framework with specific checklists, and development of a data repository or catalog of all relevant information that would be maintained over time.

SECTION 1

Introduction

This final report presents the process and findings of a project documenting the current state of the practice for hazardous materials transportation risk assessment. The first phase of the project (Tasks 1-4) involves capturing the status of the current practice of hazardous materials transportation risk assessment, including current uses, existing models, and available data sources. The second phase of the project (Tasks 5-6) focuses on synthesizing the research compiled in Phase I and determining where gaps exist in available tools, techniques, and data. Phase II also includes presenting a path forward for addressing these gaps and supporting better risk assessments in the future.

This report is organized into the following sections:

- **Section 2:** Describes the methodology employed for researching the current state of the practice of hazardous materials transportation risk assessment.
- **Section 3:** Presents the current state of the practice, including models, methodologies, approaches, and key sources of data used by public and private sectors.
  - Section 3.1: Identifies and describes relevant literature (Task 1). Further detail is provided for individual sources in Appendix A.
  - Sections 3.2 – 3.7: Identify and describe current approaches employed by shippers, carriers, government agencies, responders, risk managers, and academics (Tasks 2 and 3).
- **Section 4:** Characterizes distinct available models based on their uses, structure, inputs and outputs, strengths and weaknesses, and availability (Tasks 3 and 5).
- **Section 5:** Presents an analysis and synthesis of the Phase I information, including gaps and recommendations (Task 5).

Throughout this document, the term “model” is used to refer not only to distinct mathematical risk models, but also various tools, procedures, and tactics used for assessing hazardous material transportation risks. This more inclusive definition of a model allows for a wide range of techniques, such as committee- and process-based methods, to be included in the review of currently employed models described in detail in Section 3.

This report constitutes the deliverable for Task 5 of the project.

SECTION 2

Description of the Research Approach

2.1 Literature Review

The first task undertaken for the project was to understand the risk landscape for hazardous materials transportation through a review of relevant literature.

2.1.1 Identification

As this is a 'state of the practice' research project, the literature review initially focused on documents published since 2005 identified via online searches of transportation databases, including: the Transportation Research Information Service (TRIS),[1] the Transportation Research Board (TRB) Research in Progress (RIP) Database,[2] the Transportation Libraries Catalog (TLCat),[3] the National Technical Information Service (NTIS) Database,[4] and the International Transport Documentation Database (ITRD).[5] Open-source internet searches were also conducted using Google, Bing, and Google Scholar.

These databases and websites were then searched using the following terms:

- Hazardous Materials
- Dangerous Goods
- Risk and
  - Safety
  - Security
  - Assessment
  - Methodology
  - Analysis
- Vulnerability and
  - Assessment
  - Methodology
  - Analysis
- Threat and
  - Assessment
  - Methodology
  - Analysis
- Consequence and
  - Assessment
  - Methodology
  - Analysis

Bibliographic information, including title, sub-title, author(s), publisher, date, and abstract, was collected from the discovered documents and then compared to pare down documents that included the same subject and author and similar abstracts. It was found that data and information in guides and articles is often updated or used for further analysis in later papers. Thus, the literature was refined to focus on the most current and robust documents across subjects.

While relevant literature was identified through open-source searches, the literature search was not limited to freely accessible documents. Various documents were obtained through online purchases, already owned journals, and local brick-and-mortar research libraries.

To fill in potential gaps, the online search was augmented with documents identified by exploring the citations from other literature, subject-matter expert elicitation, suggestions by interviewees and project panelists, and research during interview preparation. As a result, the literature review was a continuous process designed to capture documents crucial to understanding how the transportation industry, especially the hazardous materials sector, assesses and uses risk to make decisions.

2.1.2 Compilation

Once a copy of the identified document was obtained, the document was read and reviewed, and information in the document was entered into a template with the following fields:

- Title,
- Author(s),

---

[1] Available via http://tris.trb.org/

[2] Available via http://rip.trb.org/

[3] Available via http://ntl.bts.gov/cgi-bin/fs.scr

[4] Available via http://www.ntis.gov/search/index.asp?

[5] Available via http://www.itrd.org/

- Publication year,
- Journal or source,
- Modes addressed,
- Categorization of risk theme (data improvement or identification, risk methodology, risk assessment, etc.),
- Geographic domain,
- Hazardous material area (substance or category), and
- Risk components addressed (probability, frequency, threat, vulnerability, and consequence).

Not all documents in the literature review contained data for all of these categories; however, the data gathered, along with brief summaries for each document, did allow the documents to be analyzed and categorized into four common themes:

1. New modeling techniques and approaches,
2. Data-driven risk assessment,
3. Use of risk analysis and route choice, and
4. Economic risk analysis.

Documents were categorized under the "New Modeling Techniques and Approaches" if they critiqued current risk models or practices, described new methods for calculating risk, or discussed the theory of risk assessments. The documents grouped under "data-driven risk assessment" focused on new data sets, improvements in collecting data, and new mathematical methods for calculating risk. The third category involved documents that went beyond risk methodology by specifically discussing route choice decision making. The final literature review category was for documents that centered on quantifying risk components, particularly consequence-related economic values.

Once categorized, the key documents were summarized to highlight their contributions to hazardous material transportation risk assessments. Additionally, other articles found in the literature review were added to the end of a section to provide interested parties with further references.

2.2 Interview and Online Survey Procedures

The project team identified the organizations listed in Appendix B as potentially conducting hazardous materials-related risk assessments or risk assessment research. This list was initiated from a similar list prepared for a related HMCRP Project HM-10, "Current Hazardous Materials Transportation Research and Future Needs." In many cases, the appropriate individuals for hazmat transportation research were also the most knowledgeable about their organization's involvement with the development or use of hazmat transportation risk assessments—making it efficient to connect the interview efforts of these two projects together. The list includes organizations identified by the HMCRP-Project 10 panel, in the HMCRP Project 12 solicitation, those added by the project team and enumerated in the project's working plan, and others suggested by the HMCRP Project 12 panel at the interim project meeting. Some additional organizations were identified through the interview process or by

- Conducting an Internet search for organizations conducting relevant risk assessments,
- Conducting an Internet search for completed risk-assessment research projects,
- Reviewing the HMCRP and other cooperative research program websites to identify organizations performing work that relates to risk assessment of hazardous materials transportation, and
- Reviewing the TRB Research Needs Database for organizations performing relevant work.

An additional step included a conference call with the HMCRP Project 10 panel, which generated some additional organizations and contacts.

One or more representatives of each organization were identified through research by the project team and consultation with the project panel.

After identifying relevant organizations and their representatives, an interview template was created to address specific questions of this project (Appendix D). Questions were meant to guide the discussion and while the project team captured direct responses to particular questions, it recorded general thoughts and ideas that the organizational representatives had about risk assessment and its use in hazmat transportation. Because the project team was also conducting hazmat transportation research related to HMCRP Project 10, the interview template was developed to serve both projects.

Several professional associations were interviewed and many suggested interviewing their membership directly. An online survey was designed to collect responses from these organizations. An invitation to participate in the survey (see Appendix E) was distributed to the Hazmat Transportation Research Committee of the TRB's distribution list and the specific associations that offered to distribute it. This survey can be found in Appendix F. Specific questions were geared towards the responding organization's practice of hazmat risk assessment. Contact information for these organizations was collected from the survey, and the project team followed-up with organizations, as appropriate.

Responses from the interviews and surveys were recorded in a standard template and analyzed by the project team. In cases where sufficient information was collected from the survey and subsequent follow-up discussions, the responses have been included in Sections 3 and 4.

SECTION 3

Current Uses

Current applications of risk assessments and the tools available for conducting them were explored through the literature review, organizational interview process, and an on-line survey. A summary of the results of these efforts is presented in the following section.

Section 3.1 presents a summary of relevant hazmat transportation risk analysis literature. Additional details of the hazmat transportation risk analysis activities and tools from individual articles are provided in Appendix A.

Sections 3.2 – 3.7 report information provided by interview subjects and survey respondents arranged into sections according to organization type (e.g., carriers, shippers, federal agencies, etc.) and are listed according to the responding organization (as opposed to the developer of the model or approach being used). Many of the contacted organizations (see Appendix B for a complete list) were involved in hazardous materials-related research activities, but had no direct involvement in developing, enhancing, or using hazmat transportation risk assessments. As such, only information from those organizations that provided substantive comments about hazmat transportation risk assessment is presented. Included is a summary of the risk assessment practices and capabilities of these organizations structured under the following headings:

- Current uses, users, modes, and decision making
- Models, tools, methodologies, approaches
- Key sources of data
- Assumptions, limitations, biases, and availability
- Updates
- Risk communication
- Desired improvements
- Implementation barriers

Risk assessment approaches discussed in this section involving concrete models or methodologies with sufficient documentation or available information are further characterized in Section 4 to facilitate selection of an approach for given decisions, data constraints, and desired output types.

3.1 General Literature Results

The literature review formed the basis of the project's Technical Memorandum and can be found in its entirety in Appendix A. Following the Literature Review Methodology, the documents were reviewed and sorted into four main categories according to theme or area of impact on hazardous materials transportation risk assessment: new modeling techniques and approaches, data-driven risk assessment, use of risk analysis and route choice, and economic risk analysis. Though some documents could have been included in multiple categories, they were listed in the most applicable section to avoid duplication.

3.1.1 New Modeling Techniques and Approaches

The first category, New Modeling Techniques and Approaches, contains a total of 15 sources, seven of which are reviewed in detail in Appendix A. Documents contained in this section deal with high-level approaches to risk assessment and modeling. The literature discusses a variety of initial or governing approaches to risk. In the case of Trépanier et al., the paper discusses data deficiencies through a comparison of accident databases that are collected and maintained by various agencies within Canada and found that only 41 true matches existed between two databases. Those matches accounted for 28.1% of the total reported accidents in one database and 2.9% in the other, which lead to the authors concluding that accidents are being under-reported. Another study, by Ghazel, builds a complex behavioral model to understand the causes of accidents between vehicular traffic and trains. The complex model was created using two simpler models that focused on trains' relationship to signals and signals' relationship with vehicular traffic. An article by Gheorghea investigates release-incident data and groups accidents into common themes based on the accident's cause. The authors conclude that identifying common themes allows for improved risk assessments and future planning. Additionally, the National Research Council's (NRC) report on Department of Homeland Security (DHS) risk assessments was reviewed. The report suggests that the DHS's assessments need to incorporate third-party peer reviews, extend to all hazards, and reduce the subjectivity of the assessments. Additionally, the NRC report found that DHS assessments heavily emphasized quantitative analysis, which may not be appropriate when dealing with adaptive adversaries—those that make adjustments in their strategies as security countermeasures are deployed—resulting in reduced effectiveness of those countermeasures over time.

3.1.2 Data-Driven Risk Assessment

Data-Driven Risk Assessment is the second category used to categorize documents, and contains five resources, three of which are summarized in depth in Appendix A. The article by Romano and Romano reviewed under this section focuses on quantifying risk elements in terms of the population affected based on the material being transported, the conditional release probability of all materials, and population data for surrounding areas. Akin to that article is Glickman's investigation of the conditional release and accident probabilities of the use of two different containers, both over two routes, and with the average case and worst case scenarios. The article by Clark and Beserfield-Sacre discusses a methodology that was developed to identify the cause of loading/unloading incidents and found the "causing object" variable (as opposed to failure mode, contributing actions, etc.) in such events to be the most important contributing factor. Additional source documents included information pertaining to techniques for gathering vehicle crash data.

3.1.3 The Use of Risk Analysis and Route Choice

The third section, The Use of Risk Analysis and Route Choice, is comprised of literature that specifically discusses the use of risk to inform route decision making. Unlike the first two categories, this section is focused on only one outcome of risk assessment. In most cases, the routing of hazardous materials is the key decision being made with regard to transporting those materials, so it was expected that a number of documents would deal with this issue. The seven articles summarized include information regarding transportation through tunnels, rural highways, routes with lower populations but fewer response resources, and the Boston metropolis; the four additional resources described offer more insight into regulations and risks surrounding transport through population centers and tunnels. The first article in the section deals with modeling population-based routing decisions using data on population, population density and accident/exposure-mitigation practices. The authors theorize that population-minimizing decisions are not always optimal as population centers are more likely to have the resources to mitigate accident consequences. Philippe Cassini authored a paper describing a model which used F/N curves to compare truck routing choices of going through an urban area or using a detour that involved tunnels. An article by Bubbioco et al. finds that compared to open-air routes, tunnels reduce the societal risk for rail hazmat transport but increase the risk involved with hazmat trucking. Additional articles describe how toll policy can be used to change the routing behavior of hazmat transportation or discuss the route-decision principles promoted by professional associations or municipalities.

3.1.4 Economic Risk Analysis

Finally, the Economic Risk Analysis category contains two summarized articles and two sources of additional information. The literature in this section focuses on calculating and financially quantifying the various components in a risk assessment, particularly with regard to consequence elements. Work by Wijnen et al. discusses the Value of a Statistical Life (VoSL) that is used to quantify human casualties in monetary terms. This conversion allows for human casualties to be added or included in the consequence calculations with economic costs. An article by Verma, meanwhile, discusses ways to measure the economic costs and benefits of decision making. By lowering the costs, or consequences, of transporting a hazardous material, industry stakeholders may also lower the overall risk. The articles and information in this section can assist industry stakeholders to quantify the consequence component to a common unit, which will allow decision makers a better understanding of risk between certain scenarios, including routing, packaging, modes, and mitigation strategies.

As a whole, the literature review established a baseline understanding of the key issues and assessment methodologies within the hazardous material transportation industry. This initial research helped to inform the remainder of the data gathering process for this project, including stakeholder interviews and surveys.

3.2 Carriers

3.2.1 Association of American Railroads (AAR)

Current uses, users, modes, and decision making. The Railway Supply Institute (RSI), the RRF, and the AAR all perform research and analyses that support hazmat transportation risk assessment. Their work is primarily intended to support the railroads that comprise their membership. Uses include supporting regulatory requirements for routing and determining the appropriate strategies to reduce the likelihood of a release when accidents occur (mostly related to rail car design and safety features). Their focus is on continuously improving the data and models that support their decisions.

Models, tools, methodologies, approaches. AAR, through the RRF, supports the development and operation of the RCRMS. This tool has grown nationwide to meet the federal regulatory requirements of 49 CFR 172.800–Additional Planning Requirements for Transportation by Rail.[6] RCRMS allows rail operators, as part of their route analysis (including assessment of route alternatives), to consider the 27 required criteria, including network infrastructure characteristics, railroad operating characteristics, human factors, and environmental and terrorist-related parameters. The regulatory requirements apply to high-hazard materials, which include toxic inhalation materials (TIH), explosives, and radioactive materials. Accident rates are incorporated for both mainline track and rail yard activity. Both safety and security risks are considered and consequences include potential human health, critical infrastructure, and environmental impacts. Safety and security risks are presented separately, but also combined into a single risk metric.

Key sources of data. The RSI/AAR Safety Research and Test Project utilizes 28 different data sources, as no one entity has reliable data on all aspects of design and features of specific tank cars, how those cars perform in accidents (e.g., did they leak, was there damage and, if so, where was it and how much damage was there?), and specifics of the accidents (e.g., speed, number of cars derailed—which is a proxy for severity, ambient temperature, and so on). Engineers interpret the data from these sources to integrate them into a complete picture. Where data are still not available, the RSI/AAR typically goes back to the engineers' interpretation and expert knowledge to fill the gaps.

Much of the data used in the RCRMS come from the individual railroads themselves. This includes commodity types and volumes, as well as some specific track characteristics (e.g., track class, grade, and defect detectors). Some data are more generic, such as Federal Railroad Administration (FRA) accident data. Other data, such as the inputs into the consequence estimates, are obtained from public sources, including the Federal Emergency Management Agency (FEMA).

Assumptions, limitations, biases, and availability. As with many data-driven approaches, the RCRMS methodology assumes that certain data derived at the national level are appropriate to use at a more localized level. Where there are significant deviations from those representative values at the local level, the analysis would not fully account for them. The methodology has been annually reviewed, as discussed below, to determine if new data or approaches can be adopted to improve the model.

Addressing uncertainty. A key concept is that the desired data are often missing, but users try to determine whether they have a representative sample that would support a meaningful analysis. It is often the case that a representative sample is available and users apply statistical analyses to quantify the biases or uncertainties for the decision makers. Of course, communicating the results to decision makers is often more difficult when the analyses are more engineering-focused.

For the RCRMS, uncertainty in the input data is addressed by grouping output route alternatives into broad categories of relative attractiveness, rather than having the user directly compare numerical output. This approach ensures that users do not make routing decisions based on seemingly high-precision output values when such confidence is not warranted by the quality of the input variables.

Updates. Currently, the railroads go through an annual review process for all of their high-hazard materials specifically listed in 49 CFR 172.800, which includes TIH, explosives, and radioactive materials. The regulation requires all movements of these materials that occurred in one year to be reevaluated for the following year.

Desired improvements. One area of current work that is progressing slowly relates to estimating the resulting impacts from specific changes in train and track operations or maintenance, such as changing track class or speed. RSI believes there is a need for cross-modal research to ascertain the potential consequences from spills, such as evacuations. A related desired improvement is understanding how dispersing clouds interact with the environment.

3.2.2 Class I Railroad

Current uses, users, modes, and decision making. A large Class I railroad conducts route risk assessments for its hazmat shipments as directed by federal regulations. Hazmat routing is largely dictated by the TSA and positive train control (PTC) requirements and TSA audits. As a result of these regulatory constraints, routing decisions have become more politically and economically driven than risk based. The railroad regards information about hazmat risk assessments as sensitive security information (SSI) and therefore cannot be disclosed.

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[6] Commonly referred to by the PHMSA rulemaking docket: HM-232E – Enhancing Rail Transportation Safety and Security of Hazardous Materials Shipments.

Risk communication. Risk analysis results are communicated externally only through federal audits.

Implementation barriers. Federal regulations constraining route choice and potential methods of hazmat route risk analysis are a barrier to alternative and more in-depth assessments, as well as to disclosing any information about further risk assessment activities.

3.3 Shippers

3.3.1 Large Chemical Manufacturer #1

Current uses, users, modes, and decision making. This company applies their risk assessment approach to mode and route choice, packaging selection, application of security measures, manufacturing locations, alternate product selection, operational changes, and emergency response resource planning. Their risk assessments might influence carrier selection if there were resulting requirements, such as tandem drivers, to implement risk reduction measures.

Models, tools, methodologies, approaches. This company follows an approach similar to that described in Guidelines for Chemical Transportation Safety, Security, and Risk Management.[7] Foundational safety and security risk management practices (such as compliance with regulations and strong company internal standards as well as root cause investigation and corrective/preventative actions to incidents) are built upon and enhanced with increasing levels of risk. Formal risk reviews are required for certain material/mode combinations based on a screening process that considers the hazards of the chemical shipped, the number of shipments, the container size, and the estimated consequence of a release. Chemicals of most concern include toxic inhalation hazard materials, flammable gases, and packing group I materials.

The risk review process is largely qualitative/semi-quantitative, and includes both safety and security elements. Full quantitative risk analyses are rarely performed due to data limitations, but may be conducted on very specific issues in order to assess the impact of certain risk mitigation options in more detail.

This company generally does not estimate fatalities in its assessments, but rather uses consequence analysis to understand the potential impact of different release sizes to an order of magnitude. Given the uncertainty as well as lack of specificity in certain critical data elements, they believe caution should be used to avoid evaluating one parameter to the most detailed outcome when there is significant uncertainty in the other parameters.

This company has examined some environmental, critical infrastructure/key resource, and economic consequences, but most of its formal distribution risk assessments have focused on human impact. For materials that may pose significant impact to the environment if spilled, but with less severe human health hazards, they may use the same risk review methodology to make decisions based on environmental consequences, exploring packaging and mode alternatives.

Key sources of data. For rail frequency data, this company currently uses data from the FRA website and current relevant publications.[8] For highway accident rates, they attempt to obtain these from their actual carriers since there can be considerable diversity in performance between trucking segments and individual companies. They separate accident frequency and conditional release probability into two elements to consider areas of influence within each. Rail probability data are derived from RSI/AAR work, and they support ongoing industry efforts to correlate conditional release probabilities to puncture resistance. For highway probabilities—and until the HM-07 project results are implemented—they may utilize data from a variety of sources, including data on pressurized gases and propane road tankers. However, they avoid use of data from studies where adequate delineation by tank design is lacking.

Where the level of the hazard is sufficiently high to warrant it, they may use proxies for some data. For example, as detailed road cargo tank and portable tank data are difficult to acquire, rail tank car data may be modified as appropriate where the thicknesses might be somewhat comparable but the forces applied to the tanks would be different.

Assumptions, limitations, biases, and availability. Many transportation risk assessments are constrained by a lack of reliable information, so conservative assumptions are used. However, overestimating risk can potentially lead to putting significant resources toward ineffective or unwarranted mitigation strategies.

Transportation risk assessments involve assumptions around essentially every factor (frequency and consequence). Prediction of when and where incidents will occur, and the conditions at the time of the incident (weather, speed, obstacles, population present, etc.) means that even selecting scenarios involves numerous assumptions. Fault tree assessments for transportation can become too large and unwieldy; developing a comprehensive tree and then assign-

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[7] Center for Chemical Process Safety (CCPS) of the American Institute of Chemical Engineers and John Wiley & Sons, Inc., Hoboken, New Jersey. 2008.

[8] Anderson, R. and C. P. L. Barkan 2004. Railroad Accident rates for use in rail transportation risk analysis. *Transportation Research Record: Journal of the Transportation Research Board, No. 1863:* 88-98.

ing an appropriate probability on each node in the tree can range from challenging to impossible. For fixed facilities, where assets generally do not move around, failure scenarios are more limited and failure data are generally more available.

This company uses an approach for security risk assessments that considers threat, vulnerability, and consequence, but recognizes that using threat and vulnerability as a proxy for frequency has limitations. As risk assessment is designed to be forward looking, current threat data may be not applicable in the future, and one needs to have effective mitigation strategies against current threats. This company accomplishes that by using a variety of information sources to assess current threats, and implementing a tiered program requiring added levels of security measures for certain materials as the threat level increases. The company also participates in programs such as C-TPAT, PIP, and AEO to institute strong security practices across its supply chain.

Some additional areas of concern mentioned by this company include the need for a holistic view of transportation risk. For example, transportation risk assessments may not always consider the loading and unloading operations, but this can be important in making mode selections and considering risk mitigation options within a given mode, whether in transportation or on site.

The selection of scenarios can also create bias. Not all scenarios that can occur are included in most risk assessments. Additionally, only some elements of a scenario can be quantified. Sometimes the elements that cannot be quantified can significantly impact the risk. It is important to understand the "big picture" (past just specific scenarios) to be aware of the important contributors to risk and mitigation, so that inappropriate conclusions are not drawn.

Addressing uncertainty. Consideration of uncertainty is extremely important. For example, if error bounds are not placed on F-N curves,[9] it may be difficult to discern that two options, while appearing different, are really statistically the same. One method used by this company is to evaluate results using high and low estimates for key variables to understand the range of results.

Even assuming good data, and whether using qualitative/semi-quantitative or full quantitative analyses, it can be difficult to answer the subsequent question about whether the risk (either before or after mitigation) is acceptable.

Updates. This company conducts risk reviews on a cycle that depends on the hazard and varies from every two to every five years. Additional reviews and special studies are performed as necessary, for example, with significant changes in the supply chain (new geographical market, new package, etc.).

Desired improvements The most pressing need is for improved data—more accurate and more detailed—for all aspects of the risk equation (accident frequency, conditional release probability, and consequence). Without better data, it is important to rely more on screening level analyses and not to attempt estimation of very detailed frequencies or consequences, such as fatalities.

Better data to support bulk truck risk assessment would be the most valuable. These data would be helpful not only in informing modal decisions, but in evaluation of design improvements for road tankers and portable tanks.

3.3.2 Large Chemical Manufacturer #2

Current uses, users, modes, and decision making. This company conducts committee-based hazmat transportation risk assessments in order to reduce the risk of transporting given chemicals by selecting shipment parameters. These assessments consider transport by barge, rail, and truck, and are used to review shipment variables such as methods of shipment, potential hazards and threats, chains of responsibility, and operational guidelines for carrier operators. Analysis results are used primarily to inform shipping decisions by senior managers.

Models, tools, methodologies, approaches. This company approaches hazmat transportation risk assessments through a committee review process adhering to internally developed standards and procedures. An assessment is carried out for each shipped chemical, with an assigned champion to oversee the assessment process. Each review committee is composed of a variety of company personnel, including representatives from operations, transportation, and internal emergency responder teams, as well as external shipment carriers. These committees review and recommend shipment parameters, such as timing, route path, container, employed technologies, etc. While shipment modes are generally predefined for existing chemicals, switching modes for a given commodity may be considered for increasing safety or security.

Assessments consider potential consequences to human populations and the environment. Considering potential economic impacts to the company is specifically excluded from the assessment process.

This company's method of analysis considers both safety and security. While safety analyses are primarily quantitative, security analysis is largely qualitative. Qualitative security

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[9] F-N curves are graphs in which the Y axis represents the cumulative frequency of fatalities (or other consequences) and the x axis represents the consequences. The X axis often uses a logarithmic scale.

analysis takes the form of reviewing management procedures for given scenarios. Some qualitative security aspects are incorporated as well, however, including developing trip profiles with strictly defined locations along a route at which a driver may stop.

Examples of data considered by review committees in risk assessments include internal toxicological profiles, container characteristics, previous incidents and lessons learned, emergency response capabilities, publicly available response guidelines, locations of population centers, and locations of water, among others.

Key sources of data. Data used in risk assessments are sourced primarily from internal company databases and, to a lesser extent, from carrier operators.

Assumptions, biases, limitations, and data availability. This company characterizes its risk assessments as being overly conservative. Common assumptions in the assessment process include the automatic selection of a company-owned trucking firm for extremely hazardous materials and that, in general, shipping by barge is safer than by train, which is, in turn, safer than by truck.

The company generally has access to the data necessary for performing risk assessments through its internally maintained databases. When it becomes necessary for them to collect data from outside sources, the lack of openness and information sharing throughout the chemical industry can present an obstacle.

Addressing uncertainty. Missing and insufficient data is noted in assessment committees' final reports to business managers. In some cases, noting the use of flawed or incomplete data is sufficient, while in other cases managers may call on assessment committees to collect or develop the data and incorporate them into an updated report.

Updates. Risk assessments for each chemical are scheduled for update every five years.

Risk communication. Risk assessment results are communicated to senior managers through formal reports and are shared with and agreed upon by carrier operators. Their risk analyses are not published for the general public.

Desired improvements. While hazmat containers have been well characterized with regard for failures and incidents, similar analysis is lacking for the hoses used to transfer chemicals to and from these containers. The development of hose failure and incident data for incorporation into the risk assessment process would help this company make better-informed decisions regarding the transfer of chemicals to and from carrier containers.

3.3.3 Institute of Makers of Explosives

Current uses, users, modes, and decision making. Representatives from the IME and constituent member organizations indicated that there is no industry-standard methodology for route risk assessment and that such assessments are left to each individual carrier. Carriers generally follow routes prescribed by the DOT, the DHS, and the DOE, making route risk assessment less of an operational and financial priority. As a result, hazmat transportation risk assessment for IME constituent members focuses primarily on explosives risks at transportation-related facilities, such as safe havens, ports, and industrial origins and destinations.

Users of the IME risk analysis model and software include senior managers of IME's constituent member organizations in all modes of transportation, as well as regulatory and enforcement officials, such as the U.S. Coast Guard, U.S. Bureau of Alcohol, Tobacco, Firearms, and Explosives (ATF), and several Canadian governmental authorities.

Models, tools, methodologies, approaches. IMESAFR is an industry standard tool used to assess explosives risks at facilities. The model was developed by the DOD for military use [Safety Assessment for Explosives Risk (SAFER)], and IME has translated it into a software tool for more general use. IMESAFR can be applied to hazmat transportation through its use in assessing current or potential "safe haven" locations, calculating allowable limits of materials at transportation facilities, and through its evaluation of loading and unloading activities at industrial facilities and ports. The model was developed with a focus on safety risks and, as such, employs the general risk equation: Risk = Frequency × Probability × Consequence. In order to account for security risks, the Frequency term in this equation can be multiplied by a predetermined factor according to the federally defined threat level (e.g., Red = ×10).

Data considered by the IMESAFR software include activity types (e.g., loading, unloading, repackaging, short-term storage, etc.), type and quantity of explosives, building construction information, exposed populations, and event frequencies. Consequences metrics include human fatalities, major and minor injuries, and a group-risk metric that describes the potential for complete fatalities to an entire given population.

Key Sources of Data. Frequency data are based on a DOD/IME database of historical events and nonevents. Consequence data are based on a controlled-testing database of explosion tests conducted by DOD/IME. All of the data necessary for performing model calculations are stored within the software and are accessible to users through a series of dropdown menus.

Assumptions, biases, limitations, and data availability. In order to overcome limitations in available frequency data for commercial activities, IMESAFR assumes that military event frequencies are a suitable proxy for commercial event frequencies. Of the 17 activities that IMESAFR considers, only three or four have enough associated frequency information from commercial applications to provide a suitable level of confidence in the data. Comparisons of these frequencies to military use data have shown that event frequencies for commercial and military applications tend to be similar. Consequently, frequencies associated with military activities are used in place of commercial data throughout the model.

A scarcity of explosion data has led to IMESAFR being designed as a strongly conservative model. The explosion database includes only a small number of tests (n × 30), and these tests generally represent the explosions of quantities of material much larger than most shippers would typically have on hand. To address the lack of data for small-quantity explosions, these explosions are assumed to behave similarly to large-quantity explosions.

Limits to the use of IMESAFR for hazmat transportation risk analysis include the lack of in-motion transport analysis and the lack of reliable frequency data for use beyond Canada and the United States.

Addressing uncertainty. Uncertainty in event probability data is handled by incorporating its upper and lower bounds into the model and returning results for the range of the input data. Additionally, IMESAFR addresses uncertainty by tending toward strongly conservative estimates of model parameters. One such example is the use of large quantity explosion data for modeling small quantity events. A similarly conservative tactic involves calculating fatalities at the intra-facility level to be 100%, despite historical evidence indicating fatalities at this level tend to be more along the lines of 10 to 20%.

Updates. Risk assessments are generally carried out on an as needed basis by IME member organizations and associated agencies.

Risk communication. Model results are typically used internally by IME constituent members and are rarely published for public review.

Desired improvements. The most meaningful improvements to the current IMESAFR approach involve generating or collecting better model input data. Data needs include additional testing of explosives, with a focus on smaller quantities of explosives, and improved event probability data, with consideration given to locations outside of the United States and Canada.

IMESAFR could be made a more useful tool for hazmat transportation analysis by incorporating in-motion risk assessment capabilities that include transport specific elements, such as the potential for highway accidents.

Implementation barriers. Barriers to the wider use of the IMESAFR model include the general lack of understanding of quantitative risk assessment by potential users, a lack of guidance on how to use model output values, potential political backlash from explicitly quantifying risks, a lack of focus and funding on the part of shippers, and the dearth of regulatory incentives.

3.3.4 Large Chemical/Plastics Manufacturer

Current uses, users, modes, and decision making. This organization responded to the online survey and evaluates the risk to human health and the environment from an accident or chemical release during loading and transporting their products.

Models, tools, methodologies, approaches. The risks posed by loading and unloading operations are evaluated within a materials-of-concern process involving operations; engineering; maintenance; and environmental, health, and safety. En-route transportation risk is considered by environmental, health, and safety professionals with experience in hazardous materials transportation. This evaluation is done globally, at a high level from headquarters, as well as at the plant level on a chemical- and route-specific basis.

Most of its evaluations are qualitative with a few semi-quantitative assessments for specific transportation activities.

The main risk assessment inputs are chemical toxicity and other properties of hazardous materials, route information, travel times and trip duration, probability, and consequence.

Risk communication. Risk assessment results are usually only communicated to immediate project stakeholders. Not much information is shared internally and is an area for improvement.

Desired improvements. For its purposes, an easy-to-access database of route-specific information would be very useful.

Implementation barriers. The biggest constraints to more accurate and repeatable results are awareness of and access to relevant data concerning route information. The availability of data overseas is particularly lacking. Another constraint is the availability of qualified risk assessment professionals.

3.4 Federal Agencies

3.4.1 Department of Energy

3.4.1.1 National Nuclear Security Administration

Current uses, users, modes, and decision making. The DOE's National Nuclear Security Administration (NNSA) serves a lead role in supporting the Federal Radiological Monitoring and Assessment Center (FRMAC), which is an inter-agency group charged with conducting the assessment of any radiological release in the United States. It is also called upon to assist in assessing radiological releases elsewhere, such as in Japan recently. The FRMAC assessment tool is, however, not a true 'risk assessment' tool but serves only to characterize the release. The outputs from FRMAC could be used to conduct elements of a quantitative risk assessment, but that is not the goal of the interagency group. The mission of the FRMAC is to coordinate and manage all federal radiological environmental monitoring and assessment activities during a nuclear or radiological incident, within the United States, in support of state, local, tribal governments, DHS, and the federal coordinating agency.

Models, tools, methodologies, approaches. The FRMAC assessment manual is a tool used by DOE to perform calculations centered on the assessment of radiological incidents and releases. The tool operates independently of the etiology of the event that produced the release or potential release, so it does not consider the specific events, whether natural or man-made, that might lead to a release. The assessment results are then presented to an inter-agency team which considers the exposure and other consequences of such release in light of their particular programs. The team's members are: Food and Drug Administration (FDA), Environmental Protection Agency (EPA), U.S. Department of Agriculture (USDA), Nuclear Regulatory Commission (NRC), DOE's National Nuclear Security Administration (NNSA), and the Centers for Disease Control (CDC). CDC convenes the inter-agency group as needed.

The assessment produces results in five areas: (1) Plume Phase Evaluations, (2) Population Protection, (3) Emergency Worker Protection, (4) Ingestion Pathway Analysis, and (5) Sample Management.

Key sources of data. For FRMAC, the tool uses health physics data along with embedded analytic assumptions about radiation exposure effects.

Implementation barriers. As the DOE is part of the federal government, the department's budget and division's share of the budget are the key constraints to any improvements or increased use of its tools.

3.4.1.2 Savannah River Site

Current uses, users, modes, and decision making. The DOE has developed and uses several complimentary risk-related tools that inform everything from packaging and securing radioactive materials for transportation, to selecting routing methods and itineraries focused on decisions to promote regulatory compliance when transporting hazardous materials between sites. The tools range from mode (road, rail, and water) and route selection to ensuring that the shipped materials are properly marked. The DOE 'risk' tools—RADCALC, TRAGIS, and RADTRAN—were mainly developed for internal use in transporting radioactive materials between points. *RADCALC is not a risk assessment tool.* RADCALC was designed as a pre-transport safety compliance/placarding tool, TRAGIS (Transportation Routing Analysis Geographic Information System) as a mode/route selection tool, and RADTRAN is fed by TRAGIS data and used to determine the risk of exposure of large campaigns (numerous shipments of the same material).

Models, tools, methodologies, approaches. RADCAT is the input file generator for the RADTRAN program and code. RADTRAN calculates risks of transporting radioactive materials for both routine/incident-free transport, as well as for the risks of transportation accidents. RADTRAN (versions I and II) was designed for the 1977 *EIS FOR THE TRANSPORTATION OF RADIOACTIVE MATERIALS (NUREG 0170)* and was thus initially supported by NRC. RADTRAN (currently Version 6) is now supported by DOE/EM. RADTRAN, bundled with its input file generator RADCAT, is available for download from https://radtran.sandia.gov/radcat.

RADCALC is an independent tool that helps packagers and shippers determine the classification of radioactive materials for shipping from the radionuclide shipment inventory.

DOE sites, such as Savannah River Site (SRS), use the RADCALC tool to comply with DOT placarding and safety regulations pertaining to transport of hazardous materials. TRAGIS minimizes travel time over preferred routes and minimizes distance over nonpreferred routes. RADTRAN runs risk analysis over a route (can be TRAGIS recommended routes) based on consequence/exposure data.

Key sources of data. The inputs to the RADCALC tool are: shipped hazardous material's radionuclide information, the amount of material being shipped, and information about the shipment container. SRS augments RADCALC with information about the frequency of shipments and the route's length and terrain.

In addition to the radioactive characteristics of the shipment, TRAGIS uses census data over the potential route (population density, day/night population) to calculate the preferred route. The preferred transportation mode can be determined before TRAGIS (as a constraint) or afterwards (as a result of the recommended route).

RADTRAN supplements TRAGIS data with historical/incident probability data and dispersal methodologies along with potential factors such as presence of fire or elevation of release. Furthermore, since RADTRAN is used for 'campaigns' which potentially increase the overall exposure along the selected route, the tool primarily looks at chronic and acute consequences of human exposure. Finally, RADTRAN allows for changes in route conditions like the addition of traffic delays, fuel stops, or construction.

Assumptions, limitations, and biases. All three of the DOE tools are limited by not including nonlethal human health effects, economic (such as business interruptions and indirect economic effects) or environmental consequences into the model. Furthermore, the tools calculate risk based on the maximum exposed individual, which leads to a higher estimated number of Latent Cancer Fatalities than are likely to occur. Also, RADTRAN relies heavily on user-input data, which can affect the results.

Addressing uncertainty. RADTRAN addresses uncertainty by allowing the user to change various parameters, including meteorological conditions, traffic patterns along the route, preferred mode of transportation, and exposed population. While this approach is essentially a method of sensitivity analysis and does not help in estimating absolute uncertainty, it does provide a better understanding of the importance of the parameters being applied to the decision that the user is making.

Availability and updates. Besides data updates that occur when data is re-released by third parties, the tools have not undergone major changes in the past five years. In 2006, DOE successfully attempted to adapt the tools for use by the international community.

Risk communication. As part of a large campaign where DOE uses RADTRAN, DOE describes the details of the campaign, including the potential risk, to emergency response/emergency management teams along the proposed route.

Desired improvements. A DOE representative stated the desire to have RADTRAN and TRAGIS validated, and possibly improved upon beyond solely updating data-sets, by security and safety experts.

Implementation barriers. As the DOE is part of the federal government, the department's budget and division's share of the budget are the key constraints to any improvements or increased use of its tools.

3.4.1.3 Oak Ridge National Laboratory Center for Transportation Analysis

Current uses, users, modes, and decision making. The Oak Ridge National Laboratory Center for Transportation Analysis (CTA) supports a wide range of hazmat transportation risk analyses in support of governmental and private-sector applications. CTA tools for hazmat transportation risk analysis address risks related to barge, rail, highway, pipeline, and transportation facilities. Output from these tools inform routing, security planning and countermeasure application, and emergency response and planning.

Models, tools, methodologies, approaches. TRACC is a web-based tool developed by CTA and Mississippi State University for tracking the location of barges carrying dangerous cargo and identifying high-risk transport situations. This system tracks hazmat barges using a Global Positioning System (GPS) to monitor their locations more consistently than the current, widely used methods, which include operators periodically reporting their locations by fax or phone. TRACC uses this GPS information to identify safety and security risks by detecting anomalous stops or movements and predicting hazardous conditions, such as multiple barges passing in a high-traffic area or the buildup of incompatible cargo at a given location.

GeoCTA is a geographic information system (GIS)-based analysis tool designed to facilitate planning for and responding to natural disasters and terrorist activity. GeoCTA specifically focuses on transportation and other critical infrastructure within high threat urban areas (HTUAs) and is described as a useful tool for preparing for and responding to hazmat shipment spills. For each HTUA, GeoCTA provides detailed, up-to-date digital maps; offers location data, information for mapped entities, and emergency contacts for critical infrastructure (including hazmat facilities); calculates potentially exposed populations and population risk indices; and provides 3-D visual navigation tools for reviewing geospatial data.

The Readiness and Resilience Assessment System (RRAS) is a tool developed for the Transportation Security Network Management office (TSNM) of the TSA. This system is used to gauge the ability of transportation facilities, systems (e.g., highway, rail, and pipeline networks), services, and security to withstand and recover from terrorist attacks, including those involving chemical, biological, and radiological hazmat.

Key sources of data. TRACC utilizes current and historical route and commodity data provided by carriers as well as spatial information gathered using GPS-enabled tracking devices. GeoCTA employs population statistics, HTUA, sensitive location, and critical infrastructure spatial data sourced from government-maintained databases. RRAS uses data describing security measures, technology, personnel, training, etc., gathered locally for each assessment.

Addressing uncertainty. The RRAS model addresses uncertainty quantitatively through the inclusion of confidence measurement values for its vulnerability, emergency response capabilities, and organizational awareness components.

Updates. TRACC analyses are performed continuously in real time. Standard update intervals for GeoCTA and RRAS analyses are not defined.

Risk communication. TRACC output is reported directly to carriers, government agencies, and responders as necessary.

3.4.2 Department of Transportation

3.4.2.1 Federal Aviation Administration (FAA)

Current uses, users, modes, and decision making. The FAA risk assessment focus is on ranking the potential consequences from the failure of some component of the transportation system or package. They are mostly concerned with high-consequence events and identifying appropriate risk mitigation strategies to reduce their probability of occurrence. The FAA would like to use the risk assessment process to manage overall hazardous materials transportation risk.

A critical issue for the FAA now is the overall scale of industry operations. A system that worked well in the past for 6 million packages might not be scalable to the current level of 12 million packages. With undeclared shipments being a significant concern, the FAA wants to understand the risk of these shipments and the appropriate requirements for carriers when they are given an undeclared package.

In exploring the potential for risk mitigation strategies, FAA focuses on opportunities to control potential events so that they become noncatastrophic. This includes fire suppression, emergency response, instructions to the pilot, etc.

The FAA does look at differences with the other modes in trying to understand risk. There are many differences and the key similarities are marking and labeling.

Models, tools, methodologies, approaches. As probability data are difficult to obtain, the FAA tries to find precursors and incidents/accidents with similar characteristics to the issue at hand. They are trying to develop ways to predict the probability and determine large-scale trends, such as whether the probability will change over the next decade. A good example relates to accident probabilities involving lithium batteries, which have quickly been getting more powerful, yet retaining the same package sizes. More heat can be generated with these more powerful batteries.

Consequence data focus on expected deaths and injuries. Critical infrastructure and the huge economic impacts arising from the loss of large air cargo sorting facilities (e.g., Memphis or Louisville) have not been considered to date.

The FAA is also moving toward using a risk ranking approach to assess shippers in the Hazmat Intelligence Portal (HIP) using thirty values and identifying those that might warrant some inspection or further investigation. Included factors are expected to include past inspection history, violations, serious incidents, and the materials they ship.

Key sources of data. The FAA has utilized a Volpe report on specific materials that could, under the right circumstances, cause an aircraft accident. The FAA Tech Center conducts engineering studies and experimental research to determine whether specific materials or items are too risky to allow onboard or to establish limits for them.

The FAA uses Hazardous Materials Information System (HMIS) and FAA data mining where possible. They utilize contracted work but also obtain useful data from the industry regarding specific regulations in their attempt to influence a regulatory change. The FAA reaches out to packaging experts for very specific issues and expertise, but these outreach effort are typically not systematic.

Assumptions, limitations, biases, and availability. One of the significant issues in hazmat aviation transportation is the lack of data on the amount of regulated hazmat that moves through the system on FedEx and other carriers.

Much of the prior research did not address very important issues, such as the differentiation between passenger and cargo aircraft or bulk vs. small overnight packages. The specific nature of the materials was also not known or reported in that research, for example, whether the material was paint or another, more hazardous, flammable liquid.

Overall, the FAA does not focus on a specific formula or equation for their risk-related assessments.

Addressing uncertainty. The FAA does not compute a risk number or score and does not address uncertainty in its analyses.

Updates. Updates to assessments or supporting analyses are done on an issue specific basis.

Risk communication. When initiating a new analysis, the FAA begins by investigating existing related research. Depending on the specifics analyses, the FAA Tech Center then reaches out to similar businesses to those involved. The FAA headquarters staff would contact other packaging experts for detailed needs. For more generic information, they would reach out to industry groups, such as the Dangerous Goods Panel.

Desired improvements and implementation barriers. Obtaining better numbers to use (including denominator data) were ranked high on the FAA list of desired improvements. They desire to include all of the risk components into their analyses. This also represents the largest barrier they face in being able to perform risk assessments.

3.4.2.2 Federal Motor Carrier Safety Administration (FMCSA)

Current uses, users, modes, and decision making. In recent years, FMCSA has primarily been an enforcement authority and has not been focused on hazmat transportation risk assessment, which has fallen mostly within the purview of the PHMSA which has the regulatory authority.

A significant number of the decision-making processes that consider risk assessments are driven by issues conveyed by external parties or through observations from field investigators. For example, a recent problem in the field with certain types of packaging triggered a detailed investigation to determine if the problem posed an imminent hazard along with the underlying root cause, so that the appropriate mitigation approach could be determined and applied.

Models, tools, methodologies, approaches. The implementation of the Compliance, Safety, Accountability (CSA) program and the Safety Measurement System (SMS) for measuring the safety of motor carriers and commercial motor vehicle drivers collectively take the place of a risk assessment tool. Items that are predictors of crashes get elevated emphasis, creating triggers for moving carriers to a higher level of scrutiny. While the CSA program covers all aspects of motor carrier operation, hazmat considerations are represented currently through the cargo-related Behavior Analysis and Safety Improvement Category (BASIC). Development of a separate, hazmat-specific BASIC would be a risk assessment activity itself. An important aspect of the methodology being developed for the HM BASIC is the determination of pertinent carriers (carriers transporting placarded loads).

Key sources of data. Field data from inspections and enforcement actions provide much of the information used by the FMCSA hazmat division. Where applicable, this information is combined with incident report data from the Federal Motor Carrier Safety Administration (FMCSA) and the PHMSA.

3.4.2.3 Federal Railroad Administration (FRA)

Current uses, users, modes, and decision making. FRA uses risk assessment to help identify potential risk reduction strategies, including those that consider route choice, packaging selection, application of security measures, operational changes, research prioritization, and inspection and enforcement prioritization. Its focus is on research prioritization.

Current FRA work focuses exclusively on rail; however, there is potential for exploring other modes in the future. The FRA would like to update a 10-year-old study that examined modal comparisons, to at least compare rail to highway transportation. Such a comparison would allow them to examine how modal shift affects the overall hazmat transportation risk.

Models, tools, methodologies, approaches. Often, FRA employs risk assessment models developed by the industry, such as the TIH work being conducted for FRA by ICF International. Current work is focusing on one material at a time, as opposed to a comprehensive approach.

For rail risk, the likelihood of an accident is not considered to be a hazmat-specific factor. FRA focuses on the factors that affect the probability that the package will be involved in a derailment or a major accident and the probability that it will be damaged or punctured and release the product. FRA is working to reduce the number of assumptions involved to pave the way for better risk assessments.

Consequence assessment is generally focused on acute human health and most often measured by potential exposure. The risk assessment considers environmental exposure to water and land but does not include potential economic consequences.

FRA relies on the industry use of the Rail Corridor Risk Assessment Model (RCRMS) for railroad selection of routes for security-sensitive materials. RCRMS is described in more detail in the AAR discussion in this document.

Key sources of data. Data are drawn from the FRA accident database of reportable accidents, from AAR/RSI data on damaged cars (irrespective of the cause), and the HMIS' 5800.1 incident report form, which is primarily used for non-accident releases. This information draws primarily from rail industry research to get conditional release probability data.

Assumptions, limitations, biases, and availability. The key limitations and assumptions pertain to missing data. There is a dearth of information on the types and number of intermodal hazmat shipments. The FRA's risk assessment assumes that intermodal hazmat shipments are small packages, ignoring larger intermodal bulk containers (IBCs). Additionally, the accident data is missing information on car or package type in many accident reports.

As its work is mostly focused on releases, the level of exposure for consequences is not being considered in a significant way. The probability of the release is the primary focus and consequences are determined by materials and impact range. They focus on accidents that may result in a large release, even if the probability for such incidents is low.

Addressing uncertainty. The FRA has a goal to compute uncertainty in their current risk assessment work on prioritizing its efforts. In the case of missing data on car or package type, FRA uses a waybill sample to apply assumptions to the accident data to determine information about the unknown cars.

Another approach considers the results of accidents involving a specific type of rail car to infer potential applicability to another material in another type of rail car.

Updates. Risk assessment components are currently not updated on a fixed schedule partly due to the ongoing nature of the work as well as dependency on the level of effort required for the updates.

Risk communication. A significant portion of the FRA's risk assessment-driven work is accessible in the public domain. There will be a publicly available report for their current project. The Tank Car Committee or the Advanced Tank Car Collaborative Research Program (ATCCRP) will provide updates on their activities and approaches. FRA obtains input and suggestions from those two sources.

Desired improvements. FRA would like to increase cooperation with AAR for obtaining more information. Other data sources with valuable information include tank car builders, owners, and the individual railroads. It wishes to obtain more data on hazmat flow in general and also data on rail cars, including availability and prevalence of each rail car type in the rail transportation system. For example, if movement and billing data were available suggesting that 60% of a certain type of rail car carried hazardous materials, it would provide good denominator data for risk calculations. Builders and owners could potentially provide information on the average trips and mileage for different types of cars, which would support estimation of car miles for different types of materials.

Implementation barriers. Key barriers that preclude greater use of risk assessments include the lack of accurate data; agreement on the types of metrics that should be used when computing and communicating risk; and agreement on an acceptable level of risk. Challenges also lie in determining the specific entities that can design and implement a methodology for defining the acceptable level of risk.

3.4.2.4 Pipeline and Hazardous Materials Safety Administration (PHMSA)/Office of Hazardous Materials Safety (OHMS)

Current uses, users, modes, and decision making. For PHMSA, risk assessment is the starting point for a wide variety of issues. It extends beyond application of the risk equation and includes gaining an appreciation for the quantitative and qualitative dimensions of risk. Some issues, such as affected entities and risk distribution, are important policy considerations that are not typically addressed in benefit-cost analyses because they do not alter the overall societal numbers. In other cases, PHMSA considers risk factors in the decision processes that focus on other factors, such as grant allocations.

PHMSA risk assessments are focused on very specific issues, such as the transportation of lithium batteries, particularly by air. Others are general or strategic, such as identifying the commodities that pose the greatest safety risk or understanding the outcomes that are being observed in industry. For regulatory evaluations, the focus is on benefit-cost analysis and the security benefits of their safety-based proposed regulations.

For special permits and approvals, PHMSA performs analyses, but would not characterize them as traditional risk assessments. It ensures that proposed approaches for transportation demonstrate an equivalent level of safety and their evaluations rely on information provided by the applicant.

Models, tools, methodologies, approaches. PHMSA focuses on the risk to the public from an unintentional release of hazardous materials. Typically, the focus is on a comparative risk assessment, with the current regulations establishing a baseline of acceptable risk. If a given design has limitations, for example, PHMSA would consider operational constraints that could adjust for those limitations. In other words, the combination of the package and the parameters of transporting it are considered together.

For most risk assessments performed by PHMSA, a separate analysis process is used, based on the specifics of the analysis and the available data. For regulatory evaluations, the Office of Management and Budget (OMB) guidelines are used. Their resource allocation is similar to FMCSA's Comprehensive Safety Analysis model.

In some cases, there are externally available risk assessments, such as those provided by industry in response to a proposed rulemaking, but they are rarely used unless there is transparency of the methodology and associated to avoid any additional bias.

Key sources of data. Data on prior incidents, inspections, violations, and complaints are used to assess the safety risks for specific companies. Other factors include the types of materials, quantities handled, and the size of the company. For targeting inspections, the HIP is the primary source of information and includes separate incident, inspection, and report data.

As for inspections and enforcement activity, shippers are the primary focus for PHMSA and carriers are most directly addressed by the modal administrations. Sometimes, industry data is obtained and is usually sanitized before being delivered to PHMSA. To improve data at the record level, National Response Center (NRC) data are used.

Assumptions, limitations, biases, and availability. While it is accepted that data are abundant, some of the key data elements are missing and the remaining are not particularly useful in the context of application. Analyses are limited by a lack of data. A risk evaluation to support a rulemaking is very different than an initial risk assessment to determine if a rulemaking should be even proposed. Sometimes a risk assessment is performed after the fact to support a rulemaking which constrains true applicability and induces unintended bias. Rarely are the assumptions used in a rulemaking revisited to determine whether they still apply.

Limitations of the hazmat transport incident data pertain to underreporting and missing data elements. Many of the elements of interest to PHMSA are subjective, such as the "cause" data field. Non-descriptive values (e.g., unknown, other, blank) are often reported. Additionally, the hazmat being transported and its quantity are sometimes unknown, which constrains the exposure analysis.

OHMS often makes assumptions due to the lack of data, but clearly states them in its work. It is implicitly assumed that in OHMS' inspection targeting models, the judgment of inspectors is useful in predicting future risk; this assumption has never been tested. The output from the targeting models is a ranked list of companies, but the inspectors have discretion in how they use that list.

As the hazmat program focuses on prevention, emergency response is largely ignored in its analyses. No assumptions are made in relation to response.

Often in its regulatory evaluations, it is assumed that the regulated entities will automatically come into compliance. In reality, different industry segments may be driven by benefit-cost ratios that do not necessarily translate into compliance.

A large number of biases can potentially impact risk assessments. Incident data reported by carriers may have an inherent bias. There is potential for institutional bias in the target inspection data as approaches are refined over time. There are potential psychological biases from operators that tend to affix blame to individuals rather than the system.

Addressing uncertainty. PHMSA addresses uncertainty in two ways. For risk assessments, instead of using a Monte Carlo approach, uncertainty is explored through sensitivity analysis, by varying key elements of the analysis and examining how the results change. This method does not quantify uncertainty within the model or consider the uncertainty inherent in the model's assumptions, but it provides a better understanding of the influence of the parameters on the user's decision.

The second area where uncertainty is addressed is in the reporting of its performance measures on deaths and major injuries. Since the numbers are small, there is a lot of fluctuation from year to year. Therefore, PHMSA started determining the longer-term trend and applying a one standard deviation above and below the trend line to see whether the risk fell outside that range.

It is interesting to note that PHMSA does not believe that better denominator data will help as much as is generally perceived. This is because incidents are stochastic events and they occur in relatively small numbers, so there is a lack of explanatory value.

Updates. PHMSA updates its assessments on an ad hoc basis. A few new analyses, such as for the most important commodities, will be regularly updated.

Risk communication. The results of regulatory evaluations get reported as part of the rulemaking process. Some of PHMSA's assessments and analyses are conducted for internal decision making and are not communicated externally. Other analyses are documented in reports and made publicly available.

Desired improvements. PHMSA's Office of Hazardous Materials Safety will identify its desired improvements after it has implemented its research plan.

In general, being able to explore insurance data to get a better understanding of hazmat incident underreporting would be highly desirable. There would be other useful applications of insurance data as well.

Performing analyses will allow PHMSA to address data quality and data gap issues. This effort could be part of an iterative process that improves the analyses while compiling pertinent but missing data.

Additionally, it would be useful to create metadata for the existing data so that analysts gain a clear understanding of possible code values and the order in which they were presented to the reporting entity. In addition, it is important to document who collects the data, who reports them, and what PHMSA does to capture them.

Implementation barriers. Data quality is a significant implementation barrier. Lack of analytical resources for processing the data can potentially restrict data use even if the data are available. Systematically evaluating the known and the unknown errors within the data, and in each step in the analysis, supported by creating processes for this evaluation, will improve the value of the analysis and further define its scope.

3.4.2.5 Pipeline and Hazardous Materials Safety Administration (PHMSA)/Office of Pipeline Safety (OPS)

Current uses, users, modes, and decision making. The PHMSA/OPS does not conduct risk assessments of pipelines itself, but rather oversees the individual pipeline operators who are required to ensure the safety, integrity, and reliability of their own pipelines. OPS is tasked with assuring pipeline safety, exclusively. Issues of security are of peripheral interest to the OPS mission, and are relevant only for managing third-party strikes, which may include terrorist events.

Models, tools, methodologies, approaches. Pipeline operators are required by Integrity Management and Distributed Integrity Management regulations to conduct risk assessments for high-consequence areas in accordance with approaches outlined by the American Society of Mechanical Engineers (ASME)/American National Standards Institute (ANSI). The Pipeline Risk Management Manual is the industry standard methodology for conducting pipeline risk assessments.

Key sources of data. A key data source is the PHMSA database of pipeline incidents and accidents. Since 2000, operators have been responsible for reporting incidents and when reporting new incidents, operators must review previous database records to identify similar incidents on their system for investigation and analysis.

Assumptions, biases, limitations, and data availability. Accident/incident data prior to the creation of the PHMSA database in 2000 is insufficient for long-term trend analysis of failure causation.

Desired improvements. Some commonly used pipeline risk assessment models are many decades old and use outdated curve-based methods. Updating these models using modern computer technology could provide more realistic modeling and better define acceptable deviations from optimal operating conditions. New cross-modal initiatives, such as nondestructive evaluation (NDE), would have wide-ranging benefits. Finally, improvements in modeling and characterization of high-strength steel pipes (e.g., ×80, ×100, and ×120) are needed in order to be able to take full advantage of their improvements in strength and weight.

3.4.3 Department of Homeland Security

3.4.3.1 Science and Technology Directorate (S&T)

Current uses, users, modes, and decision making. DHS S&T includes many components that are relevant to hazmat transportation risk assessment. The Transportation Security Lab was contacted, but did not specifically address risk assessment issues. The key DHS S&T component was the Chemical Security Analysis Center (CSAC).

The component models in the CTRA are used by external (to CSAC) policy makers across government agencies to assess the relative risk of representative scenarios (e.g., what is the riskiest scenario for a given chemical?), the relative risk of representative chemicals, and how chemical risks change in the context of different scenarios (e.g., different chemicals may be better suited for indoor, outdoor, or food-based scenarios). The purpose of the assessments is to raise awareness as well as determine the relative risks. Examples of uses include HHS for developing medical countermeasures for chemical exposure, DHS for identifying the need for detectors for certain chemicals, and the National Security Council for developing communication processes.

Models, tools, methodologies, approaches. The Chemical Infrastructure Risk Assessment (CIRA) examines the human health risks from chemicals in the chemical supply chain. The program includes a review of atmospheric transport and dispersion models, along with application of the most appropriate model to a release at any point in the supply chain, including transportation using a probabilistic risk assessment.

The CTRA provides an end-to-end assessment of the threat due to terrorist use of toxic chemicals. Specifically, the assessment examines the terrorist use of chemical warfare agents and toxic industrial chemicals as it applies to, but not limited to, the transportation sector.

The CTRA is a combination of separate models that examine all routes of exposure: inhalation, ingestion, and percutaneous, and includes lethal and non-lethal effects. The underlying framework is probabilistic risk assessment (PRA) that includes terrorist intention. The event tree is refined to great detail and each of the branches can be combined as required by the user. Each event tree branch defines a scenario and the frequencies are applied along the path down that branch. Consequences are determined by the appropriate model for that scenario and multiplied by the overall frequency. The methodology supports large and small accidental releases as well as large intentional releases.

Specific models used as part of the CTRA include Health Prediction and Assessment Capability (HPAC) (for outdoor inhalation consequences) and Contaminant Multizone Modeling Software (CONTAM) (for indoor inhalation consequences), the Self Consistent Integral Puff (SCIPUFF) model (which also is a collection of models), a statistical model for percutaneous exposure, and a stock and flow model for ingestion that considers the food supply.

Key sources of data. Expert elicitation is used to gather information about likelihood (combining threat and vulnerability), using a methodology developed at USC's CREATE. Consequence data include toxicity data for over 120 chemicals that are categorized by route of exposure (inhalation, percutaneous, and ingestion) and injury severity (lethal, severely injured, and moderately injured).

Assumptions, limitations, biases, and availability. CSAC will be much improved by probability slopes and the toxic load exponent for LD50 toxicology values. While lethal dose data are more readily available, for the injury categories, CSAC is lacking some of the data related to the severely and moderately injured categories and it makes assumptions where necessary.

CTRA uses average container sizes for the materials as actually transported. It uses a modified Latin hypercube Monte Carlo approach for sampling the range of container sizes possible, centered on the mean, but not using only the mean size.

Addressing uncertainty. The CTRA probabilistic risk assessment allows for computing uncertainties; CSAC identifies unreliable data points and captures uncertainties around that point. It often reports risk with an error range using the *t* distribution.

Updates. The CTRA and CIRA have been updated every two years, but are moving to a four-year cycle to reflect infrequent changes in underlying information.

Risk communication. The CTRA and CIRA are classified models, but outputs are shared with other entities that can take action to address identified risks.

Desired improvements. The CTRA does not currently consider intermodal shipments. Additionally, there can be some improvements in the model components that address transportation. Enhanced ability to share results without compromising security is desired.

Implementation barriers. There are numerous data needs; one of the biggest is the need for better toxicology data.

3.4.3.2 Transportation Security Administration (TSA)

Current uses, users, modes, and decision making. Many elements within TSA are focusing on different aspects of terrorism risk and for different scenarios. Generally, TSA is focused on a broader level than specific countermeasure implementation; it focuses on overarching and intermodal issues such as the relative risks of rail and highway transport, cross-modal comparison of other types of terrorist threats (e.g., rail transit), etc. Resource allocation across regulation, education, and identifying and promoting best practices are issues of primary focus.

Models, tools, methodologies, approaches. TSA uses the traditional threat, vulnerability, consequence construct for risk assessments. Risk assessment models are generally externally developed, but they have built some internally as well. In general, they integrate external models to suit their needs. One toolkit used in the transportation sector is the Terrorism Risk Assessment and Management (TRAM) toolkit. This software-focused approach is geared toward asset owners and operators to "identify their most critical assets, the vulnerability of those assets to attack, the likelihood that a given attack scenario would succeed, and the ultimate impacts of the total loss of the assets on the agency's mission."[10]

Consequence estimation is primarily focused on acute public health impacts. They generally do not consider critical infrastructure/key resources in their risk assessments, but these do inform their activities that directly relate to those entities. They do not consider environmental impacts to a great degree and have the ability to look at economic risk but have some reservations about the available models. They have used IMPLAN, though, for their input-output-based modeling. A fundamental question is determining the endpoint of the analysis, with direct effects, indirect effects, or induced effects.

Key sources of data. Data sources are varied and information is not always available. Most data are obtained from other government sources; however, a lot of recent attention has been focused on obtaining data from industry that would address denominator issues: quantity of material being transported, associated containers, frequency, etc.

Assumptions, limitations, biases, and availability. TSA uses a range of parameters, often by assigning them through Monte Carlo simulation, typically running from 500 to 1,000 simulations for each scenario. TSA attempts to eliminate biases from their assessments, but a source of bias could be the difference in the inputs from some industry representatives. For example, there is more information available to them on arsine and phosphine than on acrylonitrile.

The Likelihood component is prone to more bias than the consequence component, which uses well-known toxicity values and the Monte Carlo simulation approach for varying the release amounts.

Addressing uncertainty. Uncertainty is captured and presented to decision makers through whisker plots that display the mean and the uncertainty band for each resulting value. The Latin hypercube sampling method is also used in their uncertainty analyses. In surveys, responses to questions are captured with the respondent's level of certainty of their response.

Updates. TSA generally updates its risk assessments every two years, but they are now moving to a four-year update cycle as there are relatively fewer changes at the two-year interval. TSA is focusing its updates to the data based on the current state of the art, rather than making adjustments to their models. Barring any revolutionary advancements, it does not have any expectation that that will change.

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[10] National Research Council. "Review of the Department of Homeland Security's Approach to Risk Analysis," National Academy of Sciences. 2010.

Risk communication. Risk communication is generally determined by the DHS decision makers. The relevant federal government agencies are usually briefed, but most of the information is considered sensitive and is not widely distributed.

A significant portion of the industry stakeholders have clearances and can obtain relevant risk assessments. Some data, however, are provided by organizations or communities that do not want it given to others. This particularly applies to the intelligence community.

Desired improvements. The TSA desires more accurate and comprehensive data on the types, quantities, and frequencies of hazmat shipments.

TSA believes that the application of game theory to hazmat transportation risk assessment is an avenue worth pursuing. Currently, game theory cannot yet be used but can potentially reduce the time collecting information from subject matter experts since there are no stand-alone models or capabilities to estimate the activity or intent of "intelligent adversaries."

Implementation barriers. There is a concern about risk assessments that identify areas of potential concern although no action is taken. Understanding the uncertainty is critical because the implementation of risk mitigation strategies relies on assessments that are based on incomplete data.

3.5 State Agencies

3.5.1 California Emergency Management Agency

Current uses, users, modes, and decision making. The California Emergency Management Agency's (Cal EMA) relationship to hazardous material transportation risk assessment lies in the use of an all hazards assessment approach that includes hazmat transport risks. Cal EMA officials use these assessments to develop emergency response and resource plans on a state-wide level. Assessments employed by Cal EMA consider hazmat transport risk by rail, road, and, in coastal areas, intermodal transportation.

Models, tools, methodologies, approaches. Cal EMA approaches risk assessment primarily through the aggregation of risk assessments conducted by subordinate government entities within the state, such as regional, countywide, city, and local emergency planning committees (LEPCs). Both safety and security components are considered, through the use of all-hazards analysis methodologies. There is no common risk assessment methodology or a statewide standard available to all assessors; each local entity individually decides how the assessments are carried out. Because risk assessments are performed using methodologies specific to each local authority, the data required for each approach vary, even when commodity flow information tends to be an essentially shared component.

Assumptions, biases, limitations, and data availability. While commodity flow information is often essential to risk assessments used by Cal EMA, the data currently must be collected "piecemeal, on a local-level," in the absence of statewide commodity flow survey data.

Updates. The update schedule of each assessing entity's analysis varies. In general, rural jurisdictions update their assessments less frequently than major population centers.

Risk communication. The statewide response plan developed from the many risk assessments carried out within the state is available online through Cal EMA. Assessment results and emergency response plans for individual jurisdictions are often made available online, but that may not apply to all jurisdictions.

Desired improvements. Consolidated commodity flow information for the entire state of California is needed. Currently commodity flow information is collected locally, with no continuity across the state. Having a statewide commodity flow survey would help local and rural planners who often lack the resources to conduct these surveys for themselves. This research would similarly benefit local emergency responders who could use it to better prioritize resource utilization and funding while ensuring that they have access to the equipment necessary for potential hazards in their area and that the equipment is efficiently deployed.

Implementation barriers. Impediments to hazmat transportation risk assessment include high expense and lack of local/rural resources and the need to gather proprietary data from private entities such as railroads.

3.5.2 State Transportation Department

Current uses, users, modes, and decision making. The emergency manager for this survey respondent receives the results of hazmat corridor studies performed in their state. These studies have been included in county planning processes for most of the areas analyzed.

These corridor studies have not been performed on all corridors. They are planning on reviewing the data from these studies and from internal data on crash and hazardous materials incidents to determine if any actions are warranted, such as the potential for implementing hazmat route restrictions.

The agency's primary focus is on the highway transportation of hazmat. They hope to employ risk assessments as they develop a better enforcement and rerouting program over the next few years.

Models, tools, methodologies, approaches. The data element mainly utilized is state highway incident data and it is provided to counties on request.

Risk communication. They share the corridor studies done through the state Emergency Response Commission with other governmental agencies to support planning activities.

Desired improvements. They desire further information on how other state departments of transportation or county agencies conduct their risk assessments and how they implement any necessary actions to reduce their risks.

Implementation barriers. Primary barriers include the paucity of time for performing risk assessments, and relative costs that accrue from conducting risk assessments.

3.6 International Organizations

3.6.1 Transport Dangerous Goods (Transport Canada)

Current uses, users, modes, and decision making. Risk assessment tends to be focused on corporate risk (at the program level) and there are separate efforts underway to examine how they think about risk. The Transport Dangerous Goods (TDG) Directorate is interested in the overall risk profile for dangerous goods transported in Canada. They want to use this profile to focus their efforts and integrate their separate programs, which include accident reporting, inspection program, ad hoc requests, emergency response assistance [Canadian Transport Emergency Centre (CANUTEC)], and the emergency response action plan (ERAP) program.

For some programs, such as their certificates of equivalency process (analogous to special permits and approvals in the United States), they are examining what information they need to perform a proper assessment. While risk is a key concept in their regulatory program, risk perception is also given an important role. For example, a specific accident may generate enough emphasis through public attention to support risk reduction measures even if that area was not at the top of the priority list.

Their regulatory-based risk assessments often come into play when publishing proposed regulations. Risk assessments are used to understand potentially viable options and to decide with proceeding on a proposed regulation. Subsequent to a decision to move forward, regulatory impact statements, known aspects of the problem, considered alternatives, and benefit-cost analyses are all simultaneously published for public review.

Models, tools, methodologies, approaches. While the historical record does not provide much statistical basis for analysis on deaths and injuries, TDG tries to focus on the probability of a release. Environmental consequences are rarely considered; most of their scenarios focus on human health and property damage. Their legislative authority is directed to immediate impacts and not long-term impacts, which would include many of the potential environmental impacts.

Key sources of data. Data specifics vary with the nature of the problem being considered. TDG produces a report on the movement and handling of dangerous goods in Canada. That is compiled with the accidents that occurred and provides a context for understanding the relative probability of an accident. Their reported accident statistics are delineated by severity level, mode, contributing factor, phase, type of release, material class, packaging type, and region. These reports are used to help focus enforcement actions at the regional/local levels.

Desired improvements. Two areas of desired improvement are to better understand all of the companies involved in hazmat transportation and to better understand the volumes that are transported. The TDG Directorate also would like to try to define the accidents for which further information is needed.

Implementation barriers. The lack of data is one of the main barriers to conducting risk assessments. For example, they would like to obtain more information on accidents. Police reports would be useful, but would have some variability. For specific issues there might be industry data that is typically not collected by the government.

Other barriers include strategic priorities and a common understanding of risk in the program. Transparency across different departments would allow for better sharing and leveraging data. One potential example is an economic affairs analysis group that might generate a database of electronic shipping documents that would include information that can be used to support risk analyses in the future. This scenario was actually used in the context of airline data.

3.6.2 Foreign Security Agency

Current uses, users, modes, and decision making. This foreign survey respondent has a variety of tools to analyze the various types of risk they deal with, from corporate risk analysis to facility-based assessments and to strategic security risk assessments. This agency examines security risks from a high-level strategic viewpoint and from facility- and operational-level security assessments.

Much of their risk assessment research revolves around methodologies. They are revisiting their strategic security risk assessment methodology in an effort to ensure that it provides current and up-to-date information on security risks.

They assess risk through a process that includes (a) event identification and scenario identification, (b) threat assessment, (c) vulnerability assessment, (d) impact assessment, and (e) risk calculation. The three assessment stages of the process involve workshops where a variety of stakeholders from within the federal government, industry, state and local governments, and other key stakeholders achieve a consensus on the relative risks of each scenario.

The analysis that emerges from these risk assessments is used by senior decision makers to prioritize and efficiently allocate resources. They are also used by the participants to develop a better understanding of the main security risks relevant to their organization.

Models, tools, methodologies, approaches. The main input in their security risk assessment methodology is the combined knowledge and expertise of subject matter experts. For example, in conducting a risk assessment on hazmat transportation, they involve experts from the security and intelligence community, hazmat shippers and carriers, emergency services providers, state and regional government representatives, representatives from the public health agencies, the nuclear safety agency, the natural resources agency, and various other experts in the field of hazardous materials. In a workshop environment, these experts evaluate and discuss various considerations around the relative threat, vulnerability, and impact of the scenarios being considered.

Collecting input this way ensures that the best opinions and insights of subject matter experts are captured. They feel that an issue that needs to be addressed is the ability to collect this type of information in a dynamic fashion.

Assumptions, limitations, biases, and availability. Their largest constraint is the inability to dynamically analyze risk. Since their risk assessment methodology requires subject matter experts in a workshop environment, conducting risk assessments cannot be conducted in a continuous fashion. They are currently exploring options to develop an "evergreen" methodology that would provide information in a timely and cyclical fashion.

Another constraint is the subjectivity of the rating criteria. They broadly look at threat, vulnerability, and impact categories, but they believe that they are not addressing all of the relevant parameters and scenarios. There are uncertain limits within which they analyze economic, health, response and recovery efforts, and other criteria.

Risk communication. Risk assessment results are presented in a classified internal report used by their organization to set future policy and priorities. They also produce a more general report that does not include the security sensitive information and is shared with workshop participants and interested stakeholders. The report highlights some of the largest risks discovered in the risk assessment process, but also examines some of the potential actions that can be taken to mitigate risk levels.

Desired improvements. One recommended improvement is the development of a taxonomy for security risk. Standardized methodologies for looking at risk should be developed and shared among security risk practitioners internationally.

There should be better distinction between high-level strategic security risk assessments (e.g., industry-level), operational security risk assessments (e.g., organization-level), and tactical security risk assessments (e.g., facility-level).

Implementation barriers. The lack of a risk management cycle within which risk assessments are conducted is an important issue. Barriers for using risk assessments are grounded in underdeveloped risk management processes that include identifying, analyzing, evaluating, and mitigating risk. The ability to conduct dynamic risk assessments was mentioned as a barrier as well.

3.6.3 Public Foreign Research Organization

Current uses, users, modes, and decision making. This survey respondent initially focused their hazmat transportation research on road transportation in their country. They are evaluating potential threats during hazmat transportation to people, core infrastructure, and the environment. Most of their research in this area is directly applied to the legislative process; they seek other implementation approaches where that is not possible. Current work relates to finding the safest transport routes for domestic hazmat shipments.

Models, tools, methodologies, approaches. They pay special attention to transport through highway tunnels. Their goal is to prepare a general methodology for evaluating highway tunnels according to international standards [the European Agreement concerning the International Carriage of Dangerous Goods by Road (ADR), in this case].

Assumptions, limitations, biases, and availability. One notable constraint they face is in modeling or estimating transnational transportation flows and those shipments that transit through their country. They have been able to create a model of their main national hazmat flows. They have used estimations for the international flows that have larger deviations than their national hazmat model.

An important, high-priority focus of their risk assessment model development is determining the appropriate importance (weight) for each input. They are developing a set of risk assessments models with different element weights and are trying to determine the best combination for modeling their conditions.

They generally believe that their data are sufficient for their needs, including all the details of domestic hazmat accidents. Some data, however, is restricted to their research focus area.

Risk communication. To date, they have only been communicating internally within their organization. Plans for external communication in the future include publishing their results in scientific journals.

Desired improvements. They believe that research on risk assessment is very scattered throughout the world and they would like to be able to benchmark their approaches with those of other countries.

Implementation barriers. They state that data are always a key aspect of successful risk assessment. After sufficient and accurate data are acquired, the limitation is in terms of funding and availability of personnel. The difference in opinions about the importance of different model inputs can also be a barrier.

3.7 Consulting and Research Organizations

3.7.1 ABS Consulting

Current uses, users, modes, and decision making. ABS Consulting (ABS) primarily builds models in-house for their industry and government clients. They note that the International Standards Organization (ISO) standard 31000 for risk management contains a methodology framework for risk assessment.

Models, tools, methodologies, approaches. Each client's risk assessment needs are different and the models they create are usually designed for a specific purpose. It might be for port security in general, specific facility types, pre-defined criteria. In some cases, their client's focus is entirely on a specific kind of security threat, for example, an al Qaeda-type adversary, rather than an all-hazards approach.

In general, the consequences estimated are targeted to the customer, with some focused primarily on human health impacts and possibly critical infrastructure/key resources while others, such as a facility, might be more interested in the economic consequences of losing operating capability. Some clients are considering altering the monetization of impacts and may consider lesser injuries in addition to more serious injuries and fatalities. Where environmental impacts are considered, they are often included as indirect impacts.

An internal group at ABS has developed custom blast modeling and these models are used for estimating consequences from blasts. All vulnerability estimates are based on the Kent scale, which uses linguistic terms to represent the different values.

Key sources of data. Data feeding their models would vary based on the industry and client they are working for. Some of their work includes estimating the direct and indirect consequences from potential attacks, such as the impacts on tourism and on the freight industry.

Assumptions, limitations, biases, and availability. Data requests often require some form of authority to be effective. This can be regulatory authority, legislation, or in return for grant funds.

All threats are based on reporting and the subjective interpretation of the reports. The assumption is that the threats are from an intelligent adversary able to achieve maximum impacts. Assessments therefore assume reasonable worst-case consequences with representative assets. In addition, there is a modal bias with respect to threat as the highway mode has the most incidents (not necessarily hazmat specific) and the greatest terrorist capability. At the other extreme, aviation has the most bias.

As with many other entities, there is a bias introduced by the primary focus on human health impacts for some clients, including the U.S. Coast Guard and the Maritime Security Risk Analysis Model (MSRAM).

ABS notes an observed bias between the private and public sectors. The private sector tends to rate things higher and worse than does the public sector.

If a risk assessment is for strategic planning and is scenario based, there would be some assumptions about the applicable scenarios and others would be ruled out.

Addressing uncertainty. Addressing uncertainty is dependent on the purpose of the assessment. In some elicitations where there is particular concern, low, best, and high estimates are obtained to offset the uncertainty introduced by the subjectivity of the input. In some cases, it is still appropriate to estimate the consequences of a *failed* attack. There may be significant economic impacts, for example.

Risk communication. For some of the federal, crosscutting work, each mode can only see the generated reports for their mode. Full reports may only be available to DHS and Congress.

Risk communication is a necessary step whenever risk assessments are used as an explanation for a decision or action. Corporations regularly engage in risk tolerance discussions to support making hard decisions and tend to be more advanced than the public sector in this area.

Desired improvements. The biggest challenge is the lack of a knowledge capture effort. There is so much related work, but there is a lot of "rebuilding the wheel." A repository of knowledge to build from would be helpful.

3.7.2 Booz Allen Hamilton

Models, tools, methodologies, approaches. Booz Allen Hamilton believes that when considering risk assessment from a government perspective, the process encompasses a general, high-level quantification of risk and a carefully done prioritization of specific incident risks, which are required for the process to be useful. This includes estimating probabilities and consequences at a granular level in terms of specific failure modes—in other words, breaking problems down to specific failure modes and assessing the relative risks of various failure modes; absolute risks are not all that important.

Current uses, users, modes, and decision making. When applying risk assessment to hazardous materials, they have incorporated elements of work done for other agencies and clients in non-hazmat areas, such as FAA or National Aeronautics and Space Administration (NASA) or in general engineering processes (design and development). For example, they have modified the traditional frequency (F), probability (P), and consequence (C) models based on their work for FAA on airframe airworthiness issues, particularly with respect to failure modes.

The risk tolerance for hazardous materials transportation is still focused primarily on fatalities, but does consider injuries as well. For pipeline, environmental consequences are given much greater consideration than on the general hazmat side; this applies to economic impact as well.

Key sources of data. Most of the company's hazardous materials work uses existing PHMSA data. They mine that data and use additional research to augment samples. Their current work includes developing a sampling basis.

Assumptions, limitations, biases, and availability. Research on prior work can lead to appropriate assumptions in areas such as the uniform distribution of accidents. In their regulatory work, they use assumptions on costs based on the standards that the government uses, including the value of a life, the proportional value of cargo in an airplane (passenger and freight). Also, unique distributions are likely for each failure mode analyzed.

Biases include the focus on fatalities and the lack of focus on some modes—maritime, for example. There is a significant attention on the rail mode that is centered on the containment of materials in tank cars—a fairly narrow focus.

Addressing uncertainty. Sensitivity analysis is important as is the consideration of significant digits. The latter is important because much of the risk computation uses estimates. Booz Allen Hamilton believes that there is a need to test for a wide range of estimates to see how they impact the final results.

3.7.3 Engineering Systems Inc. (ESI)

Current uses, users, modes, and decision making. ESI relies on risk assessments done by others to support different positions in their work, but do not conduct these assessments themselves. This includes understanding the true risk of an accident occurring and what factors are most influential. When looking at a case, were the right things appropriately considered? They do, however, develop and evaluate database processes related to hazmat container performance.

Key sources of data. When working with specific cases, literature searches can often find relevant academic or industry-published works. Sometimes, the parties to a legal case have prepared proprietary research or analyses.

Assumptions, limitations, biases, and availability. There are institutional barriers that can affect the quality, accuracy, and completeness of data and assumptions need to account for these barriers. In addition, biases are introduced because of the various parties' willingness to contribute complete data.

Data are often incomplete and not updated as new information is discovered. This necessitates the use of inferred information from sources like clipping services.

Risk communication. They communicate externally through research reports made public through the TRB and provided directly to clients.

Desired improvements. They recommend a set of tools to communicate the risk assessment process to business people to help them understand how risk assessments can benefit and improve their businesses.

Implementation barriers. There can be some fear in the industry about how the data in a risk assessment can or will be used. They focus on the potential uses against them rather than focusing on the benefits that might accrue. Many of the individuals that they have contacted in their work are reluctant and fearful. The business management aspects of the process are the stumbling blocks. Providing a better understanding of the process, how the data would be collected, and how they would be used would help.

Industry consensus standards, options, and guidelines are needed that provide a framework for industry members to complete risk assessments while providing a basis for protection in the event of litigation related to decisions informed by the assessments.

3.7.4 Private Consulting Firm

Current uses, users, modes, and decision making. The current risk assessment focus for this survey respondent is targeted at emergency managers and LEPCs to better understand the quantity and volume of priority hazardous materials transported and stored in a specific study area.

Efforts include identifying and mapping critical facilities, activity centers, chemical companies, and transportation networks as well an identifying and mapping chemical shipments to and from chemical companies and other critical facilities by motor carrier, rail, pipeline, and barge.

Models, tools, methodologies, approaches. The primary data used in the company's analyses include chemical facility locations, chemical storage quantities, chemical transportation volumes, direction, frequency, and mode. The company uses published research to help improve their assessments and hope that the TRB will continue to sponsor and publish in this area.

Assumptions, limitations, biases, and availability. Obtaining proprietary data needed to support analyses is a significant issue.

Risk communication. Internal communication is for emergency planning purposes only. Their information is proprietary and not shared with third parties or the public. They aggregate their results by chemical and mode to show annual volumes only.

Implementation barriers. The data limitations due to proprietary issues are their biggest barrier to implementing hazmat transportation risk assessments.

3.7.5 Private Consultant

Current uses, users, modes, and decision making. This survey respondent works with clients to evaluate different practices and to develop the best alternatives that combine all the aspects that have the potential for harm or negative outcomes. They include safety, security, productivity, and morale in their risk assessments.

Models, tools, methodologies, approaches. A major consideration in their analyses is weighing frequency and probability with the severity of consequences. The data to show short- and long-term costs of low-probability/high-consequence scenarios or events are difficult to find.

Risk communication. Their results are communicated internally to clients, usually at the mid-manager level and to workers during their regular training.

Desired improvements. A requested improvement is the development of easy-to-follow guidelines for workers, supervisors, and mid-level managers so they can conduct some basic risk assessments on their own and integrate them into the regular project preparation process.

Implementation barriers. Time to do a proper analysis can be a barrier since many of their clients want quick results and do not want to take the required amount of time.

3.7.6 National Center for Risk and Economic Analysis of Terrorism Events (CREATE)

Current uses, users, modes, and decision making. The CREATE is conducting research and developing a risk assessment model to inform emergency management and terrorism officials' decisions about the type and placement of radiological/nuclear detection devices in order to prevent or deter terrorist attacks using these materials. The CREATE approach can be used for detection resource deployment on a local level, such as at a port or airport, or for building a systemwide detection network on a statewide or multiple metropolitan area level.

Models, tools, methodologies, approaches. The general risk methodology employed by CREATE is a Threat × Vulnerability × Consequence scheme. This approach is used to construct a detection resource allocation strategy that optimizes any of a variety of parameters including the probability of detection, the costs associated with deployment of equipment or traffic congestion/delays, or the human and economic costs of the failure to detect or deter.

Data requirements vary depending upon the application of the model and the desired output metrics, but can include traffic flow information, population and population density data, iconic target locations, economic statistics, and spatial transportation network information.

Key sources of data. The U.S. Census Bureau is a source of data for population, demographic, and traffic flow information.

3.7.7 National Pipeline Safety and Operations Research Center

Current uses, users, modes, and decision making. The National Pipeline Safety and Operations Research Center conducts risk assessments that are focused exclusively on safety and applicable only to pipeline hazmat transportation. These assessments are used to gauge the risk to the holistic environment surrounding pipelines, as opposed to the pipeline itself. Pipeline risk assessments by the Research Center are generally carried out to support governmental planning decisions and legal reviews.

Models, tools, methodologies, approaches. The Research Center follows the general industry-standard methodology for pipeline risk assessment outlined in the Pipeline Risk Management Manual. The Research Center's approach evaluates risks to the environment, human health, society, infrastructure, etc., and varies model parameter weightings as appropriate to the focus of their assessment.

Key sources of data. Model input data is generated through research for each assessment and, to a lesser extent, sourced from publicly available PHMSA databases. Rarely, a pipeline operator may provide information in support of an assessment, typically at the request of the funding entity's legal representation.

Assumptions, biases, limitations, and data availability. The Research Center generally assumes that assessed pipelines are buried. This assumption is due to above-ground pipeline tending to be located far from developed areas, precluding the need for risk analyses.

Addressing uncertainty. Where data is unknown, the most conservative risk value is used.

Updates. Risk assessments carried out by the Research Center are not updated.

Risk communication. Risk analyses carried out by the Research Center tend to be covered under attorney-client privilege, prohibiting the sharing of analysis results.

Implementation barriers. A lack of public funding is the main barrier to more widespread pipeline risk analysis.

3.7.8 Security Analysis and Risk Management Association (SARMA)

Current uses, users, modes, and decision making. The focus of risk assessment from the SARMA perspective is to consider a broad all-hazards approach (which still generally focuses on security risk) and identify and measure the needed investments to drive them down or move them to another sector. A past survey conducted by SARMA determined that the security risk assessment discipline was not well defined. Even the focus of the analysis varied substantially, from a broad brush strategic level to a tactical approach at a facility level.

Models, tools, methodologies, approaches. Generally population and population density are used as proxy measures for both vulnerability and population consequence. Creating a risk baseline is difficult. One project examined using the Target Capabilities List (TCL) and optimizing response and recovery capability with the dollars available. The issue was determining whether the right capability had been identified in the first place.

TSA's scenario-based TSSRA is designed to identify the biggest risks and this is one of the key sources of information for some of their members.

Key sources of data. Much of the data to support security risk assessments comes from the owner-operator of the facility or operation. Having the proper regulatory authority is often crucial to obtaining that information, but providing grant money in exchange for it can also be effective and is a much softer approach.

Consequence estimates are determined from models, research, and reports. Economic consequences are often obtained from REMI and similar models.

Assumptions, limitations, biases, and availability. Fundamental areas of assumption are about the nature of the risk being evaluated and the nature of the various scenarios (which are informed by subject matter experts). While vulnerabilities can be more accurately estimated, understanding the full nature of the threats can be difficult. Consequences also present some assumptions, such as the value of a human life and how to account for the psychological impacts of lethal attacks.

Updates. SARMA believes that using risk as a decision support tool needs to be an ongoing process. This includes accounting for the risk buy-down from implementing security countermeasures and then seeing what happens to the risk for other segments of the organization's operations.

Risk communication. Communicating risk can be a challenge. In one example, a federal grant program's approach changed dramatically and there was the need for a hard conversation with the stakeholders about risk tolerance on the front end and a discussion on how to communicate the results on the back end. These were both difficult conversations to have in the public policy context.

Desired improvements. The biggest challenge is to get the data needed to do risk assessments. Solving this problem is very complex from the state or national perspective. It is less challenging at the local level. This is why it is hard to establish a risk baseline. The state fusion centers could be leveraged to capture some of these data.

At a higher level, there is a need for better information and guidance on data collection and how to make the best use of the data.

There has been a lot of discussion about the time horizons for risk assessments. Generally, they focus on a single year. It would be beneficial to use a five-year time period and compare against organizational objectives.

3.7.9 The Kentucky Transportation Center (KTC) at the University of Kentucky

Current uses, users, modes, and decision making. KTC is conducting research and development of a methodology and tool to provide data and information for use by the federal government for real-time situational awareness of high-security risk highway hazmat shipments. Both safety and security are being considered, but the focus is on security. By understanding the relative risks of different shipments, the users of the methodology (law enforcement and anti-terrorism officials) can make better decisions about the appropriate security countermeasures that would help reduce risk.

Models, tools, methodologies, approaches. The methodological basis for the approach derives from the best practices used across a number of different systems, including the RCRMS.

Safety methodology considers frequency, probability, and consequence and security methodology considers threat, vulnerability, and consequence. Both risk measures are relative scores and are not combined together, but considered separately. Security risk would be dynamically computed and the safety risk would be static for a given planned route.

As with most safety based route risk assessment approaches, this work utilizes roadway type to apply appropriate per-mile accident rates that are applicable and consistent across the country. New work is being considered to update the probability of release given an accident for different types of material and packaging combinations. Consequences are focused on population exposure, critical infrastructure/key resources, environmentally sensitive areas, and economic impact. One of the key benefits of the approach being developed is that it supports identifying the risk reduction potential of various security risk mitigation strategies.

Threat considers the attractiveness of different locations based on both static and dynamic factors, including a range of potential attack modes, hazardous material and packaging, population density, and presence of certain types of targets. Vulnerability is based on the attack mode, material and packaging, and the security posture. Consequences are determined as for safety for consistency.

Key sources of data. The specific elements of this work are still being developed, but population data are Census-based, critical infrastructure and some threat information would be obtained from the federal government, and roadway network data would be used with historical accident data to derive the potential accident frequencies. Other probability and vulnerability information would be elicited from subject matter experts. In addition, implementation of the methodology would include data about vehicle location, shipment characteristics, and dynamic operating conditions.

Assumptions, limitations, biases, and availability. The risk scores will be dynamically changing and will rely a lot on the underlying, geospatially referenced data. The risks of hijacking in rural areas will be overshadowed by high risks influenced by high population areas. Also, there is an initial assumption that the hazard class-specific impacts and consequences are representative of all the materials in that class.

Updates. The situational awareness aspect of the methodology will be updated with each vehicle location update. The methodology itself will be subject to periodic reviews and will consider new and emerging ways to acquire data. Quarterly reviews are expected early in the implementation phase.

Risk communication. In this methodology, risk is presented as numeric values for safety and security. In the situational awareness context, the risk values are displayed by color. Different risk levels are represented by different colors and can provide an easy-to-grasp picture of the distribution of risk across an area of interest.

Desired improvements. Improvements that were mentioned included the ability to better measure uncertainty. At a high level, it would be beneficial to get a nationally accepted methodology to use in similar systems and to conduct research to determine if the methodology is effective and which changes would create additional value.

Implementation barriers. A big barrier is the ability to get funding to implement an accepted, cost-effective system that addresses industry privacy concerns. Industry itself is a barrier to getting overall risk management implemented because of privacy/security concerns.

3.7.10 University of Illinois at Urbana-Champaign (UIUC)

Current uses, users, modes, and decision making. The UIUC evaluates the probability and the consequences of hazmat transportation at both the macro-level (nationwide/regional network) and the micro-level (route or segment-specific). Risk analyses conducted by the university are primarily safety-focused and support a number of national-level research initiatives in the rail industry.

Models, tools, methodologies, approaches. A recent initiative has focused on estimating the risk tradeoffs involved in switching from standard tank cars to alternative designs. This analysis employed a model that considers historical shipment routes and volumes of individual TIH chemicals, the frequency of car derailments along those routes, expected conditional release rates, and potential human receptors along each route. Risks were calculated for a number of high-volume chemicals using their standard tank car configurations and compared against similar calculations using alternative tank car technologies. The results of this study informed decisions made by the AAR on TIH tank car standards and were incorporated into TIH transportation regulations by the U.S. DOT.

Key sources of data. Probability and frequency data are obtained from the FRA Accident Database, the RSI-AAR Tank Car Database, AAR TRAINII Waybills, and Surface Transportation Board (STB) Waybills. Consequences and the potential severity of incidents are derived from U.S. census data, USDOT ERG response guidelines, and GIS analyses.

Assumptions, limitations, biases, and availability. The level of data sufficiency differs across the various data elements employed by UIUC in risk analyses, though "close to 90 percent" of its data needs are satisfied for railroad risk analysis. While much of the data is available through public access of government databases and academic journals, some critical data, such as railroad waybill information, is restricted to government or industry for security reasons.

UIUC describes constraints in data for evaluating new technologies and their effects on risk, such as new railroad wayside defect detectors to reduce mechanical failures and positive train control. There is a need to assume a certain level of effectiveness in improving safety that may or may not exist.

This organization describes difficulties in accounting for litigation costs in their risk models. Another serious limitation is the lack of highway container conditional release probability data.

Risk communication. The results of UIUC risk analyses are reported internally to private carriers and shippers and externally through presentations at major conferences and published research articles and papers.

Desired improvements. A detailed database of damages from accidents involving cargo tanks and ISO tanks would help to better perform multi-modal risk analysis.

Implementation barriers. Data availability is a barrier for conducting risk assessments for highway and multi-modal applications.

SECTION 4

Characterization

The key risk assessment approaches discussed in Section 3 that involve concrete models or methodologies with sufficient documentation or available information are further characterized in the matrices here. These matrices are designed to facilitate selection of a model for application to a hazmat transportation stakeholder's particular needs. Section 4.1 presents matrices of common hazmat transportation-related decisions with a general summary of the models available to support those decisions. Models within each matrix are presented within two broad categories: those that apply to safety decisions and those that apply to security decisions. This categorization reflects the fundamental differences between the two types of decisions, which stem, in part, from focusing on events that are likely to occur at widely different rates, involve different kinds and availabilities of input data, and are often purposefully considered in isolation from one another. If any model appears within the matrices that can be applied to both safety and security decisions, that model is listed in both categories.

Each model listed in the decision matrices is presented in greater detail in Section 4.2. The individual model matrices in that section characterize each risk assessment approach in terms of its uses, model elements, data requirements, outputs, strengths and weaknesses, availability, and potential barriers to its use.

For readers wishing to develop an approach to applying risk assessment to their hazmat transportation issue or problem, the first step is to determine which of the decisions listed in the table below most closely match the decisions they need to make. More than one may apply. The next step is to review the information listed in Section 4.1 to identify a first cut at the models that may be candidates for consideration. Then, reviewing the more detailed information for each model in Section 4.2 may provide additional information to eliminate one or more models. The discussion may identify concerns that can be addressed by making adjustments to a model's approach, collecting additional data, or performing additional analyses to supplement the information that can be obtained from the model(s). Additionally, below the name of each model listed in Sections 4.1 and 4.2, cross-references are provided to facilitate movement among the matrices and the discussions of models' uses in Section 3.

4.1 Decision Matrices

4.1.1 Mode Choice

	Name Sponsor/Developer	Mode	Input(s)	Output(s)	Key Aspects
Safety	CCPS Guidelines: Risk Prioritization Process *See also §3.3.1, 4.2.4* --------------------- Center for Chemical Process Safety	Highway Rail Marine Air Pipeline	Subjective selections for frequency (based on exposure), probability (can be based on past history), and consequence that should not require specialized data or analyses.	The screening model provides a single risk score. Ranges are defined for serious, high, medium, and low.	High-level screening process that can determine whether more detailed assessment is warranted. Would be comparing scores for different modal options.
	CCPS Guidelines: Qualitative Risk Assessment Process *See also §3.3.1, 4.2.2* --------------------- Center for Chemical Process Safety	Highway Rail Marine Air Pipeline	Benchmarking data from other companies or operations. The information that can be included is quite varied and includes chemical hazards, industry experience, container design and operating practices, and safety and security.	List of actions to address, including the need for more detailed analysis.	Benchmarking may indicate whether additional risk mitigation actions are necessary to close gaps as compared to the industry leader. The focus is more on the process used to select among alternatives than on the selection itself. Do peers use risk prioritization or quantitative analyses, for example?
	CCPS Guidelines: Semi-Quantitative Risk Assessment Process *See also §3.3.1, 4.2.7* --------------------- Center for Chemical Process Safety	Highway Rail Marine Air Pipeline	Quantify or weight the frequency-related elements and develop scenarios with accompanying release size and probability estimates. Consequences are quantified from model input data, including the scenario definitions and sensitive areas along the routes.	For risk indexes, the result for each option is a single value. For risk matrices, the result for each option is a single risk priority value.	Adds quantification where needed to make an informed decision. Cost-effective because not all elements need to be quantified. Risk indices or matrices provide easy means to combine the different elements of risk without a formal calculation.
	CCPS Guidelines: Quantitative Risk Assessment Process *See also §3.3.1, 4.2.3* --------------------- Center for Chemical Process Safety	Highway Rail Marine Air Pipeline	Quantity per shipment, annual shipments, loaded vs. empty miles, Infrastructure characteristics needed for accident rate calculations. Conditional probability of release after an incident, the range of release sizes to consider, the probabilities of different release types (e.g., jet fire, pool fire, flash fire, toxic gas, explosion, or no impact). Population characteristics (including representative densities or detailed Census data) along the route, material hazard information, impact area; the ‘endpoint’ criteria for the different types of hazards: • Toxic chemical exposure • Vapor cloud explosion • Flammability hazards • Flash fires	Generally, three types: • Risk indices • Individual risk (contours, maximums, averages for exposed or total population) • Societal risk (usually expressed as F-N curves)	Depending on the form of the output, can provide annual risk values, distribution of people exposed to different risk levels, or societal risks. High-consequence/low-probability and low-consequence/high-probability events can be represented.
	Chemical Manufacturer Risk Assessment Framework *See also §3.3.4, 4.2.8* --------------------- Large Chemical/Plastics Manufacturer	Highway Rail Marine Pipeline (inbound only)	Considers trip length, past experience, shipment size, available packaging, third-party consequence data (sensitive areas along their routes, presence of bridges and tunnels). Chemical property information is internal.	Reports are generated for the corporate operations department and sometimes include risk matrices.	Considers all modes for their shipments (at least two are available at all locations). Risk assessments triggered by any change in distribution, and are usually only qualitative.
	RADTRAN *See also §3.4.1.2, 4.2.8* --------------------- Department of Energy, Office of Environmental Management, Sandia National Laboratories	Highway Rail Marine	Users are able to input and adjust over 70 data points to customize how the tool calculates incident-free exposure along with risk of exposure from accident or sabotage. Key inputs with regard to assessing the exposure risk along a set route: • Population density • Fatalities per accident	Expected Radiological Exposure/Consequence over set route during a shipping campaign. Exposure data is output according to: • Groundshine • Cloudshine	*Strengths:* • Highly customizable by user (over 70 individual data points that can be input or adjusted by the user). • Users can adjust the parameters surrounding the probability and effects of an accident.

4.1.1 (Continued).

	Name Sponsor/Developer	Mode	Input(s)	Output(s)	Key Aspects
			• Weather conditions • Probability fractions of event • Packaging data Additionally, TRAGIS data can easily be inputted into RADTRAN.	• Inhalation • Resuspension • Overall Since its inception, RADTRAN has been used in most radiological transportation environmental assessments (EA) and environmental impact statements (EIS). RADTRAN also has the capabilities to conduct specific radiological transportation accident and sabotage scenarios.	• RADTRAN can be used in conjunction with WebTRAGIS and TRAGIS. *Weaknesses:* • Calculates based on maximum-exposed individual • Has been found to use conservative Dose Rates Requires substantial user-input, which can increase user error.
	Transportation Routing Analysis Geographic Information System (TRAGIS) *See also §3.4.1.2, 4.2.19* --------------------- Department of Energy, Oak Ridge National Laboratory	Highway Rail Marine	User-input: • Shipped material data • Route preference (quickest, shortest, or combination) • 'Blocking off' (not include) of: a. Railroad companies b. Nodes c. Links d. Road routes through beltways e. Tunnels f. Roads with limited size clearances TRAGIS uses ORNL-developed LandScan and Census data to calculate the exposed population.	• Population information for risk assessment along potential transportation routes using GIS and three buffer widths: 400m, 800m, and 2500m. • Routes that are compliant with transport regulations. • Table of tribal lands and mileage through those lands. • Route maps contain background data on the transportation network, Census urbanized areas, and Native American tribal lands.	*Strengths:* • Users can adjust routes to their preferences. • TRAGIS performs population calculations on alternative, compliant routes. • Trucking routes can be optimized based on travel time, distance, or a combination of those two. • The routes and population data can be inputted into DOE's RADTRAN tool, which includes probability inputs. *Weaknesses:* • Intermodal routing is not automatic. • Only calculates exposed population. It does not factor in probability or frequency.
Security	CCPS Guidelines: Security Risk Prioritization Process *See also §3.3.1, 4.2.5* --------------------- Center for Chemical Process Safety	Highway Rail Marine Air Pipeline	Chemical hazards, quantity transported per container, number of shipments, mode, interim storage, specific threat information, and the proximity to people, sensitive environmental areas, critical assets or infrastructure are all considered subjectively.	Identification of the issues that require additional analysis, such as transportation vulnerability security assessments (TVSA).	Easy to implement; ensures that resources are placed on the issues that require the most attention. This subjective review elevates issues to a formal TVSA and includes a security review for those elements that are not elevated.
	CCPS Guidelines: Security Vulnerability Assessment Process *See also §3.3.1, 4.2.6* --------------------- Center for Chemical Process Safety	Highway Rail Marine Air Pipeline	Both internal and external threat information is combined with relative target attractiveness factors. Vulnerability is qualitatively assessed based on how well existing countermeasures can withstand or eliminate an attack. Consequences considered can include casualties, theft of hazmat, disruption of the economy or company operations, environmental damage, financial loss, secondary damage to critical infrastructure, loss of critical data, and erosion of company reputation.	For risk indexes, the result for each option is a single value. For risk matrices, the result for each option is a single risk priority value. A list of prioritized countermeasures is also produced.	Can allow companies to cost-effectively allocate their security mitigation resources. Relies a lot on subject matter experts and outside threat information.

4.1.2 Route Choice

	Name Sponsor/Developer	Mode	Input(s)	Output(s)	Key Aspects
Safety	Boston Hazmat Route Evaluation *See also §3.1.3, 4.2.1* -------------------- City of Boston	Highway	Truck accident rates and roadway functional classifications, transported commodities [commodity flow studies (CFS) data, shipper survey, PHMSA hazmat registrants, HMRIS incident reports, and city permits], population data along the routes (Census-derived), special population data, state environmental data.	Risk scores and day and night population estimates for each route alternative.	Based on one approach in the current (1996) FMCSA routing guidelines for non-radioactive hazmat. Through-route alternatives with ratio of risk indices greater than 1.5 were selected.
	CCPS Guidelines: Risk Prioritization Process *See also §3.3.1, 4.2.4* --------------------- Center for Chemical Process Safety	Highway Rail Marine Air Pipeline	Subjective selections for frequency (based on exposure), probability (can be based on past history), and consequence that should not require specialized data or analyses.	The screening model provides a single risk score. Ranges are defined for serious, high, medium, and low.	High-level screening process that can determine whether more detailed assessment is warranted. Would be comparing scores for different route options.
	CCPS Guidelines: Qualitative Risk Assessment Process *See also §3.3.1, 4.2.2* --------------------- Center for Chemical Process Safety	Highway Rail Marine Air Pipeline	Benchmarking data from other companies or operations. The information that can be included is quite varied and includes chemical hazards, industry experience, container design and operating practices, and safety and security.	List of actions to address, including the need for more detailed analysis.	Benchmarking may indicate whether additional risk mitigation actions are necessary to close gaps as compared to the industry leader. The focus is more on the process used to select among alternatives than on the selection itself. Do peers use risk prioritization or quantitative analyses, for example?
	CCPS Guidelines: Semi-Quantitative Risk Assessment Process *See also §3.3.1, 4.2.7* --------------------- Center for Chemical Process Safety	Highway Rail Marine Air Pipeline	Quantify or weight the frequency-related elements and develop scenarios with accompanying release size and probability estimates. Consequences are quantified from model input data, including the scenario definitions and sensitive areas along the routes.	For risk indexes, the result for each option is a single value. For risk matrices, the result for each option is a single risk priority value.	Adds quantification where needed to make an informed decision. Cost-effective because not all elements need to be quantified. Risk indices or matrices provide easy means to combine the different elements of risk without a formal calculation.
	CCPS Guidelines: Quantitative Risk Assessment Process *See also §3.3.1, 4.2.3* --------------------- Center for Chemical Process Safety	Highway Rail Marine Air Pipeline	Quantity per shipment, annual shipments, loaded vs. empty miles, Infrastructure characteristics needed for accident rate calculations. Conditional probability of release after an incident, the range of release sizes to consider, the probabilities of different release types (e.g., jet fire, pool fire, flash fire, toxic gas, explosion, or no impact). Population characteristics (including representative densities or detailed Census data) along the route, material hazard information, impact area; the 'endpoint' criteria for the different types of hazards: • Toxic chemical exposure • Vapor cloud explosion • Flammability hazards • Flash fires	Generally, three types: • Risk indices • Individual risk (contours, maximums, averages for exposed or total population) • Societal risk (usually expressed as F-N curves)	Depending on the form of the output, can provide annual risk values, distribution of people exposed to different risk levels, or societal risks. High-consequence/low-probability and low-consequence/high-probability events can be represented.

4.1.2 (Continued).

Name Sponsor/Developer	Mode	Input(s)	Output(s)	Key Aspects
Chemical Manufacturer Risk Assessment Framework *See also §3.3.4, 4.2.8* --------------------- Large Chemical/Plastics Manufacturer	Highway Rail Marine Pipeline (inbound only)	Considers trip length, past experience, shipment size, available packaging, third-party consequence data (sensitive areas along their routes, presence of bridges and tunnels). Chemical property information is internal.	Reports are generated for the corporate operations department and sometimes include risk matrices.	Route options would be considered in conjunction with mode choice. Risk assessments triggered by any change in distribution, and are usually only qualitative.
Fedtrak *See also §3.7.9, 4.2.10* --------------------- The Kentucky Transportation Center at the University of Kentucky for Transportation Security Administration	Highway	Accident data included in the model's network. Packaging provides a qualitative conditional probability of release or uses dated values. Consequences include population, critical infrastructure/key resources (CIKR), environmentally sensitive areas, and economic impact (most determined from model data).	Safety risk scores are computed for the planned route and remain static.	Model is designed for security but supports estimation and mitigation of safety risk. Alternate routes can be assessed and the safety risk scores can be compared.
GeoCTA *See also §3.4.1.3, 4.2.11* --------------------- Oak Ridge National Laboratory Center for Transportation Analysis	Highway Rail Marine Air Pipeline	Input data is self-contained within the tool and consists of GIS-based spatial data layers for describing incident locations and U.S. Census population data for calculating incident consequences.	Outputs include a consequence index based on the magnitude of population at risk and GIS-based maps with information on critical and high-value locations.	This software focuses on gauging human consequences within the framework of transportation and critical infrastructure in high-threat urban areas. GeoCTA contains a large number and variety of spatial data layers, including all of the data necessary for use of the system. Output includes GIS-based maps, which facilitate quick, informed decision making. Risk-related output is currently focused solely on estimations of affected population. The tool can be applied to any location within the United States and has been designed for easy integration of new spatial analysis functions. Presently, the tool is unavailable for public distribution, but could theoretically be made available with the exclusion / substitution of restricted data.
IME Safety Analysis for Risk (IMESAFR) *See also §3.3.3, 4.2.12* --------------------- Institute of Makers of Explosives	Highway Rail Marine Air Pipeline	Many of the input variables are stored within the software database. System data include event frequencies sourced from military and commercial sources and blast effect probability data sourced largely from military sources. Users must enter information including the location of personnel with regard to an explosion and construction characteristics of structures in the vicinity.	A measure of the probability from an explosion along with a GIS-based map of explosive effects and risks to surrounding infrastructure. While designed for safety applications, security may be considered by multiplying frequencies by scaling factors to account for threat level increases.	While IMESAFR is traditionally used for fixed facilities explosive risks analysis, the model could be employed in route comparisons. Such comparisons could make use of facilities analyses with respect to stations and ports and could be used to analyze any distinct location along routes of interest. The storage of model parameter values within the system reduces the data gathering requirements of users and allows selection of appropriate input values simply by being on-site. Map output aids in user comprehension and communication of model results. By default, model calculations are strongly conservative. In the most recent version of the software, however, uncertainty is calculated and presented separately and conservative model assumptions may be switched on or off. Other assumptions include the transferability of military frequency and explosive effects data to commercial applications.

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4.1.2 (Continued).

Name Sponsor/Developer	Mode	Input(s)	Output(s)	Key Aspects
RADTRAN *See also §3.4.1.2, 4.2.8* --------------------- Department of Energy, Office of Environmental Management, Sandia National Laboratories	Highway Rail Marine	Users are able to input and adjust over 70 data points to customize how the tool calculates incident-free exposure along with risk of exposure from accident or sabotage. Key inputs with regard to assessing the exposure risk along a set route: • Population density • Fatalities per accident • Weather conditions • Probability fractions of event • Packaging data Additionally, TRAGIS data can easily be inputted into RADTRAN.	Expected Radiological Exposure/ Consequence over set route during a shipping campaign. Exposure data is output according to: • Groundshine • Cloudshine • Inhalation • Resuspension • Overall Since its inception, RADTRAN has been used in most radiological transportation EA and EIS. RADTRAN also has the capabilities to conduct specific radiological transportation accident and sabotage scenarios.	*Strengths:* • Highly customizable by user (over 70 individual data points that can be input or adjusted by the user). • Users can adjust the parameters surrounding the probability and effects of an accident. • RADTRAN can be used in conjunction with WebTRAGIS and TRAGIS. *Weaknesses:* • Calculates based on maximum-exposed individual. • Has been found to use conservative Dose Rates. • Requires substantial user-input, which can increase user error.
Rail Corridor Risk Management System (RCRMS) *See also §3.2.1, 3.4.2.3, 4.2.15* --------------------- Railroad Research Foundation / Association of American Railroads	Rail	Annual volume shipped, route length; mainline accident rates, which are a function of traffic density, method of operation (e.g., signalized or 'dark territory'), and FRA track class combined with historical FRA accident data; and switching yard accident rates. Conditional probabilities of release (CPRs) for each of the DOT tank car specifications were used. The CPR for Isotainers and intermodal portable tanks utilize generic values. Environmental: water bodies, parks Population: daytime and nighttime population Carriers may also consider factors that are not directly embedded in the risk equations: presence of nearby railroad facilities, miles with different levels of passenger traffic, operating speed, mileage, transit time, and any known deficiencies in crew training and skill level. Items that are reported for each route that are not explicitly listed above: miles of each route in each track class, miles with a grade more than 2.5%, miles of signalized and manual operation, listing of wayside detectors, counts of grade crossings and switch points, route miles greater than 10 miles from police and fire stations (data from HAZUS), past incidents (from FRA data)	RCRMS provides a single risk metric that combines safety and security as well as the two individual risk scores. All risk scores are rounded and an attractiveness measure helps users distinguish between routes with similar risk scores. It also provides route-level totals for each of the 27 metrics that the federal regulations require carriers to consider.	Leverages the FRA national rail network and railroad-specific data to provide carriers with a routing decision support tool with a government-vetted risk methodology. The integration of safety and security risks is useful for railroads with a very large number (thousands) of analyses to run. The best available data on rail accident rates, container release probabilities, and network link characteristics are used. Implemented by all Class I railroads and many others. FRA uses the model to verify industry compliance. There is no methodological approach for including some data that are available.

4.1.2 (Continued).

	Name Sponsor/Developer	Mode	Input(s)	Output(s)	Key Aspects
	Transportation Routing Analysis Geographic Information System (TRAGIS) *See also §3.4.1.2, 4.2.19* --------------------- Department of Energy, Oak Ridge National Laboratory	Highway Rail Marine	User input: • Shipped material data • Route preference (quickest, shortest, or combination) • 'Blocking off' (not include) of: a. Railroad companies b. Nodes c. Links d. Road routes through beltways e. Tunnels f. Roads with limited size clearances TRAGIS uses ORNL-developed LandScan and Census data to calculate the exposed population.	• Population information for risk assessment along potential transportation routes using GIS and three buffer widths: 400m, 800m, and 2500m. • Routes that are compliant with transport regulations • Table of tribal lands and mileage through those lands • Route maps contain background data on the transportation network, Census urbanized areas, and Native American tribal lands.	*Strengths:* • Users can adjust routes to their preferences. • TRAGIS performs population calculations on alternative, compliant routes. • Trucking routes can be optimized based on travel time, distance, or a combination of those two. • The routes and population data can be inputted into DOE's RADTRAN tool, which includes probability inputs. *Weaknesses:* • Intermodal routing is not automatic. • Only calculates exposed population. It does not factor in probability or frequency.
	UIUC Tank Car Risk Analysis *See also §3.7.10, 4.2.22* --------------------- University of Illinois at Urbana-Champaign	Rail, Intermodal	Inputs include rail car derailment rates, conditional release probabilities for individual tank car types, tank car capacity values, historical rail accident information, origin/destination locations and mileages, spatially located population estimates, and evacuation / isolation distances for chemicals being modeled.	Expected risk, in terms of number of people affected by releases of a given chemical transported in a specific tank car type. Alternative consequence metrics can be incorporated to reorient the model toward environmental risk analysis and remediation cost analysis.	This risk assessment approach estimates the expected U.S. population affected by releases of individual TIH chemicals from specific rail tank car designs. This approach has been demonstrated for the comparison of risks associated with current tank car designs to potential alternative designs, but could also be employed for reducing transport risk through targeted infrastructure improvements and route selection. The model relies on academic, government, and industry data, some of which is widely available, and some of which is security-sensitive or restricted to industry use.
Security	CCPS Guidelines: Security Risk Prioritization Process *See also §3.3.1, 4.2.5* --------------------- Center for Chemical Process Safety	Highway Rail Marine Air Pipeline	Chemical hazards, quantity transported per container, number of shipments, mode, interim storage, specific threat information, and the proximity to people, sensitive environmental areas, critical assets or infrastructure are all considered subjectively.	Identification of the issues that require additional analysis, such as transportation vulnerability security assessments (TVSA).	Easy to implement; ensures that resources are placed on the issues that require the most attention. This subjective review elevates issues to a formal TVSA and includes a security review for those elements that are not elevated.
	CCPS Guidelines: Security Vulnerability Assessment Process *See also §3.3.1, 4.2.6* --------------------- Center for Chemical Process Safety	Highway Rail Marine Air Pipeline	Both internal and external threat information is combined with relative target attractiveness factors. Vulnerability is qualitatively assessed based on how well existing countermeasures can withstand or eliminate an attack. Consequences considered can include casualties, theft of hazmat, disruption of the economy or company operations, environmental damage, financial loss, secondary damage to critical infrastructure, loss of critical data, and erosion of company reputation.	For risk indexes, the result for each option is a single value. For risk matrices, the result for each option is a single risk priority value. A list of prioritized countermeasures is also produced.	Can allow companies to cost-effectively allocate their security mitigation resources. Relies a lot on subject matter experts and outside threat information.

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4.1.2 (Continued).

Name Sponsor/Developer	Mode	Input(s)	Output(s)	Key Aspects
Fedtrak *See also §3.7.9, 4.2.10* --------------------- The Kentucky Transportation Center at the University of Kentucky for Transportation Security Administration	Highway	Attack mode, type of hazmat, and trailer/container type, nearby high-population density areas (Census data) and CIKR (from DHS or the states). Two separate vulnerability measures are estimated, the likelihood that the terrorists do not fail on their own due to the inherent nature of the scenario and the likelihood that the terrorists will be able to overcome security measures. Consequences include population, CIKR, environmentally sensitive areas, and economic impact (most determined from model data).	The model will provide both static safety and dynamic security risk scores for each shipment along a planned route. Security risk scores can be computed for a route at the planning stage (identifying the locations of high risk along the route), but will be automatically computed as each new location coordinates are received, providing a near-real time view of each shipment's risk.	The security risk methodology supports the quantification of risk reduction through countermeasures or risk mitigation strategies. This includes reduction of the maximum risk and the cumulative reduction of route risk. The system relies on a complete picture of Tier 1 Highway Security Sensitive Materials (HSSM) shipments across the country for overall situational awareness. Still in the development stage.
IME Safety Analysis for Risk (IMESAFR) *See also §3.3.3, 4.2.12* --------------------- Institute of Makers of Explosives	Highway Rail Marine Air Pipeline	Many of the input variables are stored within the software database. System data include event frequencies sourced from military and commercial sources and blast effect probability data sourced largely from military sources. Users must enter information including the location of personnel with regard to an explosion and construction characteristics of structures in the vicinity.	A measure of the probability from an explosion along with a GIS-based map of explosive effects and risks to surrounding infrastructure. While designed for safety applications, security may be considered by multiplying frequencies by scaling factors to account for threat level increases.	While IMESAFR is traditionally used for fixed facilities explosive risks analysis, the model could be employed in route comparisons. Such comparisons could make use of facilities analyses with respect to stations and ports and could be used to analyze any distinct location along routes of interest. The storage of model parameter values within the system reduces the data gathering requirements of users and allows selection of appropriate input values simply by being on-site. Map output aids in user comprehension and communication of model results. By default, model calculations are strongly conservative. In the most recent version of the software, however, uncertainty is calculated and presented separately and conservative model assumptions may be switched on or off. Other assumptions include the transferability of military frequency and explosive effects data to commercial applications. While primarily focused on safety, security risks can be analyzed through use of multiplying factors to account for the likelihood of attacks.
Rail Corridor Risk Management System (RCRMS) *See also §3.2.1, 3.4.2.3, 4.2.15* --------------------- Railroad Research Foundation / Association of American Railroads	Rail	Threat estimates consider factors such as availability of hazmat for attack, proximity to iconic targets, venues, or other Critical Infrastructure/Key Resources (CIKR), and presence in TSA-specified High-Threat Urban Areas (HTUAs). Other sources: daytime and nighttime population from FEMA HAZUS data that are in High Threat Urban Areas (HTUAs),	RCRMS provides a single risk metric that combines safety and security as well as the two individual risk scores. All risk scores are rounded and an attractiveness measure helps users distinguish between routes with similar risk scores. It also provides route-level totals for each of the 27 metrics that the federal regulations require carriers to consider.	Leverages the FRA national rail network and railroad-specific data to provide carriers with a routing decision support tool with a government-vetted risk methodology. The integration of safety and security risks is useful for railroads with a very large number (thousands) of analyses to run. The best available data on rail accident rates, container release probabilities, and network link characteristics are used. Implemented by all Class I railroads and many others. FRA uses the model to verify

4.1.2 (Continued).

Name Sponsor/Developer	Mode	Input(s)	Output(s)	Key Aspects
		other urban areas, or non-urban areas. Environmental: water bodies, parks Population: daytime and nighttime population Carriers may also consider factors that are not directly embedded in the risk equations: presence of nearby railroad facilities, miles with different levels of passenger traffic, operating speed, mileage, transit time, and any known deficiencies in crew training and skill level. Items that are reported for each route that are not explicitly listed above: miles of each route in each track class, miles with a grade more than 2.5%, miles of signalized and manual operation, listing of wayside detectors, counts of grade crossings and switch points, route miles greater than 10 miles from police and fire stations (data from HAZUS), past incidents (from FRA data).		industry compliance. There is no methodological approach for including some data that are available.

4.1.3 Facility Siting

	Name Sponsor/Developer	Mode	Input(s)	Output(s)	Key Aspects
Safety	CCPS Guidelines: Risk Prioritization Process *See also §3.3.1, 4.2.4* --------------------- Center for Chemical Process Safety	Highway Rail Marine Air Pipeline	Subjective selections for frequency (based on exposure), probability (can be based on past history), and consequence that should not require specialized data or analyses.	The screening model provides a single risk score. Ranges are defined for serious, high, medium, and low.	High-level screening process that can determine whether more detailed assessment is warranted. Would be comparing scores for different facility locations.
	CCPS Guidelines: Qualitative Risk Assessment Process *See also §3.3.1, 4.2.2* --------------------- Center for Chemical Process Safety	Highway Rail Marine Air Pipeline	Benchmarking data from other companies or operations. The information that can be included is quite varied and includes chemical hazards, industry experience, container design and operating practices, and safety and security.	List of actions to address, including the need for more detailed analysis.	Benchmarking may indicate whether additional risk mitigation actions are necessary to close gaps as compared to the industry leader. The focus is more on the process used to select among alternatives than on the selection itself. Do peers use risk prioritization or quantitative analyses, for example?
	CCPS Guidelines: Semi-Quantitative Risk Assessment Process *See also §3.3.1, 4.2.7* --------------------- Center for Chemical Process Safety	Highway Rail Marine Air Pipeline	Quantify or weight the frequency-related elements and develop scenarios with accompanying release size and probability estimates. Consequences are quantified from model input data, including the scenario definitions and sensitive areas along the routes.	For risk indexes, the result for each option is a single value. For risk matrices, the result for each option is a single risk priority value.	Adds quantification where needed to make an informed decision. Cost-effective because not all elements need to be quantified. Risk indices or matrices provide easy means to combine the different elements of risk without a formal calculation.

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4.1.3 (Continued).

	Name Sponsor/Developer	Mode	Input(s)	Output(s)	Key Aspects
	CCPS Guidelines: Quantitative Risk Assessment Process *See also §3.3.1, 4.2.3* --------------------- Center for Chemical Process Safety	Highway Rail Marine Air Pipeline	Quantity per shipment, annual shipments, loaded vs. empty miles, Infrastructure characteristics needed for accident rate calculations. Conditional probability of release after an incident, the range of release sizes to consider, the probabilities of different release types (e.g., jet fire, pool fire, flash fire, toxic gas, explosion, or no impact). Population characteristics (including representative densities or detailed Census data) along the route, material hazard information, impact area; the 'endpoint' criteria for the different types of hazards: • toxic chemical exposure • vapor cloud explosion • flammability hazards • flash fires	Generally, three types: • Risk indices • Individual risk (contours, maximums, averages for exposed or total population) • Societal risk (usually expressed as F-N curves)	Depending on the form of the output, can provide annual risk values, distribution of people exposed to different risk levels, or societal risks. High-consequence/low-probability and low-consequence/high-probability events can be represented.
	Chemical Manufacturer Risk Assessment Framework *See also §3.3.4, 4.2.8* --------------------- Large Chemical/Plastics Manufacturer	Highway Rail Marine Pipeline (inbound only)	Considers trip length, past experience, shipment size, available packaging, third-party consequence data (sensitive areas along their routes, presence of bridges and tunnels). Chemical property information is internal.	Reports are generated for the corporate operations department and sometimes include risk matrices.	Risk assessments triggered by any change in distribution, and are usually only qualitative. Where risks were assessed to be too high in the past, on-site manufacturing was used to eliminate transportation risk.
	IME Safety Analysis for Risk (IMESAFR) *See also §3.3.3, 4.2.12* --------------------- Institute of Makers of Explosives	Highway Rail Marine Air Pipeline	Many of the input variables are stored within the software database. System data include event frequencies sourced from military and commercial sources and blast effect probability data sourced largely from military sources. Users must enter information including the location of personnel with regard to an explosion and construction characteristics of structures in the vicinity.	A measure of the probability of an explosion along with a GIS-based map of explosive effects and risks to surrounding infrastructure. While designed for safety applications, security may be considered by multiplying frequencies by scaling factors to account for threat level increases.	IMESAFR is a software tool for fixed facilities explosive risks analysis. The storage of model parameter values within the system reduces the data gathering requirements of users and allows selection of appropriate input values simply by being on-site. Map output aids in user comprehension and communication of model results. By default, model calculations are strongly conservative. In the most recent version of the software, however, uncertainty is calculated and presented separately and conservative model assumptions may be switched on or off. Other assumptions include the transferability of military frequency and explosive effects data to commercial applications.
Security	IME Safety Analysis for Risk (IMESAFR) *See also §3.3.3, 4.2.12* --------------------- Institute of Makers of Explosives	Highway Rail Marine Air Pipeline	Many of the input variables are stored within the software database. System data include event frequencies sourced from military and commercial sources and blast effect probability data sourced largely from military sources. Users must enter information including the location of personnel with regard to an explosion and construction characteristics of structures in the vicinity.	A measure of the probability of an explosion along with a GIS-based map of explosive effects and risks to surrounding infrastructure. While designed for safety applications, security may be considered by multiplying frequencies by scaling factors to account for threat level increases.	IMESAFR is a software tool for fixed facilities explosive risks analysis. The storage of model parameter values within the system reduces the data gathering requirements of users and allows selection of appropriate input values simply by being on-site. Map output aids in user comprehension and communication of model results. By default, model calculations are strongly conservative. In the most recent version of the software, however, uncertainty is calculated and presented separately and conservative model assumptions may be switched on or

4.1.3 (Continued).

	Name Sponsor/Developer	Mode	Input(s)	Output(s)	Key Aspects
					off. Other assumptions include the transferability of military frequency and explosive effects data to commercial applications. While primarily focused on safety, security risks can be analyzed through use of multiplying factors to account for the likelihood of attacks.
	CCPS Guidelines: Security Risk Prioritization Process *See also §3.3.1, 4.2.5* --------------------- Center for Chemical Process Safety	Highway Rail Marine Air Pipeline	Chemical hazards, quantity transported per container, number of shipments, mode, interim storage, specific threat information, and the proximity to people, sensitive environmental areas, critical assets or infrastructure are all considered subjectively.	Identification of the issues that require additional analysis, such as TVSA.	Easy to implement; ensures that resources are placed on the issues that require the most attention. This subjective review elevates issues to a formal TVSA and includes a security review for those elements that are not elevated.
	CCPS Guidelines: Security Vulnerability Assessment Process *See also §3.3.1, 4.2.6* --------------------- Center for Chemical Process Safety	Highway Rail Marine Air Pipeline	Both internal and external threat information is combined with relative target attractiveness factors. Vulnerability is qualitatively assessed based on how well existing countermeasures can withstand or eliminate an attack. Consequences considered can include casualties, theft of hazmat, disruption of the economy or company operations, environmental damage, financial loss, secondary damage to critical infrastructure, loss of critical data, and erosion of company reputation.	For risk indexes, the result for each option is a single value. For risk matrices, the result for each option is a single risk priority value. A list of prioritized countermeasures is also produced.	Can allow companies to cost-effectively allocate their security mitigation resources. Relies a lot on subject matter experts and outside threat information.

4.1.4 Packaging Selection

	Name Sponsor/Developer	Mode	Input(s)	Output(s)	Key Aspects
Safety	CCPS Guidelines: Risk Prioritization Process *See also §3.3.1, 4.2.4* --------------------- Center for Chemical Process Safety	Highway Rail Marine Air Pipeline	Subjective selections for frequency (based on exposure), probability (can be based on past history), and consequence that should not require specialized data or analyses.	The screening model provides a single risk score. Ranges are defined for serious, high, medium, and low.	High-level screening process that can determine whether more detailed assessment is warranted. Would be comparing scores for different packages.
	CCPS Guidelines: Qualitative Risk Assessment Process *See also §3.3.1, 4.2.2* --------------------- Center for Chemical Process Safety	Highway Rail Marine Air Pipeline	Benchmarking data from other companies or operations. The information that can be included is quite varied and includes chemical hazards, industry experience, container design and operating practices, and safety and security.	List of actions to address, including the need for more detailed analysis.	Benchmarking may indicate whether additional risk mitigation actions are necessary to close gaps as compared to the industry leader. The focus is more on the process used to select among alternatives than on the selection itself. Do peers use risk prioritization or quantitative analyses, for example?
	CCPS Guidelines: Semi-Quantitative Risk Assessment Process *See also §3.3.1, 4.2.7* --------------------- Center for Chemical Process Safety	Highway Rail Marine Air Pipeline	Quantify or weight the frequency-related elements and develop scenarios with accompanying release size and probability estimates. Consequences are quantified from model input data, including the scenario definitions and sensitive areas along the routes.	For risk indexes, the result for each option is a single value. For risk matrices, the result for each option is a single risk priority value.	Adds quantification where needed to make an informed decision. Cost-effective because not all elements need to be quantified. Risk indices or matrices provide easy means to combine the different elements of risk without a formal calculation.

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4.1.4 (Continued).

	Name Sponsor/Developer	Mode	Input(s)	Output(s)	Key Aspects
	CCPS Guidelines: Quantitative Risk Assessment Process *See also §3.3.1, 4.2.3* --------------------- Center for Chemical Process Safety	Highway Rail Marine Air Pipeline	Quantity per shipment, annual shipments, loaded vs. empty miles, Infrastructure characteristics needed for accident rate calculations. Conditional probability of release after an incident, the range of release sizes to consider, the probabilities of different release types (e.g., jet fire, pool fire, flash fire, toxic gas, explosion, or no impact). Population characteristics (including representative densities or detailed Census data) along the route, material hazard information, impact area; the 'endpoint' criteria for the different types of hazards: • Toxic chemical exposure • Vapor cloud explosion • Flammability hazards • Flash fires	Generally, three types: • Risk indices • Individual risk (contours, maximums, averages for exposed or total population) • Societal risk (usually expressed as F-N curves)	Depending on the form of the output, can provide annual risk values, distribution of people exposed to different risk levels, or societal risks. High-consequence/low-probability and low-consequence/high-probability events can be represented.
	Chemical Manufacturer Risk Assessment Framework *See also §3.3.4, 4.2.8* --------------------- Large Chemical/Plastics Manufacturer	Highway Rail Marine Pipeline (inbound only)	Considers trip length, past experience, shipment size, available packaging, third-party consequence data (sensitive areas along their routes, presence of bridges and tunnels). Chemical property information is internal.	Reports are generated for the corporate operations department and sometimes include risk matrices.	Risk assessments triggered by any change in distribution, and are usually only qualitative. For example, if the shipped quantities increased, they would look at bigger packages to keep the number of shipments down.
	UIUC Tank Car Risk Analysis *See also §3.7.10, 4.2.22* --------------------- University of Illinois at Urbana-Champaign	Rail, Intermodal	Inputs include rail car derailment rates, conditional release probabilities for individual tank car types, tank car capacity values, historical rail accident information, origin/destination locations and mileages, spatially located population estimates, and evacuation/isolation distances for chemicals being modeled.	Expected risk, in terms of number of people affected by releases of a given chemical transported in a specific tank car type. Alternative consequence metrics can be incorporated to reorient the model toward environmental risk analysis and remediation cost analysis.	This risk assessment approach estimates the expected U.S. population affected by releases of individual TIH chemicals from specific rail tank car designs. This approach has been demonstrated for the comparison of risks associated with current tank car designs to potential alternative designs, but could also be employed for reducing transport risk through targeted infrastructure improvements and route selection. The model relies on academic, government, and industry data, some of which is widely available, and some of which is security-sensitive or restricted to industry use.
Security	CCPS Guidelines: Security Risk Prioritization Process *See also §3.3.1, 4.2.5* --------------------- Center for Chemical Process Safety	Highway Rail Marine Air Pipeline	Chemical hazards, quantity transported per container, number of shipments, mode, interim storage, specific threat information, and the proximity to people, sensitive environmental areas, critical assets or infrastructure are all considered subjectively.	Identification of the issues that require additional analysis, such as TVSA.	Easy to implement; ensures that resources are placed on the issues that require the most attention. This subjective review elevates issues to a formal TVSA and includes a security review for those elements that are not elevated.

4.1.4 (Continued).

Name Sponsor/Developer	Mode	Input(s)	Output(s)	Key Aspects
CCPS Guidelines: Security Vulnerability Assessment Process *See also §3.3.1, 4.2.6* --------------------- Center for Chemical Process Safety	Highway Rail Marine Air Pipeline	Both internal and external threat information is combined with relative target attractiveness factors. Vulnerability is qualitatively assessed based on how well existing countermeasures can withstand or eliminate an attack. Consequences considered can include casualties, theft of hazmat, disruption of the economy or company operations, environmental damage, financial loss, secondary damage to critical infrastructure, loss of critical data, and erosion of company reputation.	For risk indexes, the result for each option is a single value. For risk matrices, the result for each option is a single risk priority value. A list of prioritized countermeasures is also produced.	Can allow companies to cost-effectively allocate their security mitigation resources. Relies a lot on subject matter experts and outside threat information.

4.1.5 Alternate Product Selection

	Name Sponsor/Developer	Mode	Input(s)	Output(s)	Key Aspects
Safety	CCPS Guidelines: Risk Prioritization Process *See also §3.3.1, 4.2.4* --------------------- Center for Chemical Process Safety	Highway Rail Marine Air Pipeline	Subjective selections for frequency (based on exposure), probability (can be based on past history), and consequence that should not require specialized data or analyses.	The screening model provides a single risk score. Ranges are defined for serious, high, medium, and low.	High-level screening process that can determine whether more detailed assessment is warranted. Would be comparing scores for different products and the entire supply chain risk implications that would have.
	CCPS Guidelines: Qualitative Risk Assessment Process *See also §3.3.1, 4.2.2* --------------------- Center for Chemical Process Safety	Highway Rail Marine Air Pipeline	Benchmarking data from other companies or operations. The information that can be included is quite varied and includes chemical hazards, industry experience, container design and operating practices, and safety and security.	List of actions to address, including the need for more detailed analysis.	Benchmarking may indicate whether additional risk mitigation actions are necessary to close gaps as compared to the industry leader. The focus is more on the process used to select among alternatives than on the selection itself. Do peers use risk prioritization or quantitative analyses, for example?
	CCPS Guidelines: Semi-Quantitative Risk Assessment Process *See also §3.3.1, 4.2.7* --------------------- Center for Chemical Process Safety	Highway Rail Marine Air Pipeline	Quantify or weight the frequency-related elements and develop scenarios with accompanying release size and probability estimates. Consequences are quantified from model input data, including the scenario definitions and sensitive areas along the routes.	For risk indexes, the result for each option is a single value. For risk matrices, the result for each option is a single risk priority value.	Adds quantification where needed to make an informed decision. Cost-effective because not all elements need to be quantified. Risk indices or matrices provide easy means to combine the different elements of risk without a formal calculation.
	CCPS Guidelines: Quantitative Risk Assessment Process *See also §3.3.1, 4.2.3* --------------------- Center for Chemical Process Safety	Highway Rail Marine Air Pipeline	Quantity per shipment, annual shipments, loaded vs. empty miles, Infrastructure characteristics needed for accident rate calculations. Conditional probability of release after an incident, the range of release sizes to consider, the probabilities of different release types (e.g., jet fire, pool fire, flash fire, toxic gas, explosion, or no impact). Population characteristics (including representative densities or detailed Census data) along the route, material hazard information, impact area; the 'endpoint' criteria for the different types of hazards: • Toxic chemical exposure • Vapor cloud explosion • Flammability hazards • Flash fires	Generally, three types: • Risk indices • Individual risk (contours, maximums, averages for exposed or total population) • Societal risk (usually expressed as F-N curves)	Depending on the form of the output, can provide annual risk values, distribution of people exposed to different risk levels, or societal risks. High-consequence/low-probability and low-consequence/high-probability events can be represented.

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4.1.5 (Continued).

	Name Sponsor/Developer	Mode	Input(s)	Output(s)	Key Aspects
	Chemical Manufacturer Risk Assessment Framework *See also §3.3.4, 4.2.8* --------------------- Large Chemical/ Plastics Manufacturer	Highway Rail Marine Pipeline (inbound only)	Considers trip length, past experience, shipment size, available packaging, third-party consequence data (sensitive areas along their routes, presence of bridges and tunnels). Chemical property information is internal.	Reports are generated for the corporate operations department and sometimes include risk matrices.	Risk assessments triggered by any change in distribution and are usually only qualitative. Where risks are assessed to be too high, alternate products could be used to alter and reduce transportation risks.
Security	CCPS Guidelines: Security Risk Prioritization Process *See also §3.3.1, 4.2.5* --------------------- Center for Chemical Process Safety	Highway Rail Marine Air Pipeline	Chemical hazards, quantity transported per container, number of shipments, mode, interim storage, specific threat information, and the proximity to people, sensitive environmental areas, critical assets or infrastructure are all considered subjectively.	Identification of the issues that require additional analysis, such as TVSA.	Easy to implement; ensures that resources are placed on the issues that require the most attention. This subjective review elevates issues to a formal TVSA and includes a security review for those elements that are not elevated.
	CCPS Guidelines: Security Vulnerability Assessment Process *See also §3.3.1, 4.2.6* --------------------- Center for Chemical Process Safety	Highway Rail Marine Air Pipeline	Both internal and external threat information is combined with relative target attractiveness factors. Vulnerability is qualitatively assessed based on how well existing countermeasures can withstand or eliminate an attack. Consequences considered can include casualties, theft of hazmat, disruption of the economy or company operations, environmental damage, financial loss, secondary damage to critical infrastructure, loss of critical data, and erosion of company reputation.	For risk indexes, the result for each option is a single value. For risk matrices, the result for each option is a single risk priority value. A list of prioritized countermeasures is also produced.	Can allow companies to cost-effectively allocate their security mitigation resources. Relies a lot on subject matter experts and outside threat information.

4.1.6 Emergency Management Resource Planning

	Name Sponsor/Developer	Mode	Input(s)	Output(s)	Key Aspects
Safety	GeoCTA *See also §3.4.1.3, 4.2.11* --------------------- Oak Ridge National Laboratory Center for Transportation Analysis	Highway Rail Marine Air Pipeline	Input data is self-contained within the tool and consists of GIS-based spatial data layers for describing incident locations and U.S. Census population data for calculating incident consequences.	Outputs include a consequence index based on the magnitude of population at risk and GIS-based maps with information on critical and high-value locations.	This software focuses on gauging human consequences within the framework of transportation and critical infrastructure in high-threat urban areas. GeoCTA contains a large number and variety of spatial data layers, including all of the data necessary for use of the system. Output includes GIS-based maps, which facilitate quick, informed decision making. Risk-related output is currently focused solely on estimations of affected population. The tool can be applied to any location within the United States and has been designed for easy integration of new spatial analysis functions. Presently, the tool is unavailable for public distribution, but could theoretically be made available with the exclusion/substitution of restricted data.
	Pipeline Risk Management Manual *See also §3.4.2.5, 3.7.7, 4.2.13* --------------------- W. Kent Muhlbauer	Pipeline	Input parameters can vary according to the specific goals of risk assessors and tend to require on-site data collection through inspections and surveys. Inputs include a wide array of data, examples of which include pipeline location, proximity to	Outputs include indices for probabilities of third-party damage, corrosion, design issues, and incorrect operations; a leak impact (consequence) factor; and a relative risk score for each section of pipeline being studied.	This approach, which focuses on risks associated with pipeline releases, can be employed to determine high-risk pipeline locations in order to guide emergency response training and resource allocation. As a scoring/index model, the model provides easily understandable and comparable output relatively quickly, but results may be affected by subjectivity and are not readily comparable to assessments of other modes of

4.1.6 (Continued).

	Name Sponsor/Developer	Mode	Input(s)	Output(s)	Key Aspects
			aboveground activities, atmospheric exposure, soil corrosivity, coating type and condition, fatigue, land movements, operations and procedures, maintenance, characteristics of transported chemicals, and the location of potential human and environmental receptors.		transportation. The model is flexible, able to use a wide range of input data and data precision, can be modified to consider alternative consequence metrics, and allows for its relative output values to be converted into absolute risk numbers. The model is a standard industry tool, which facilitates communication about the model, data, and results, and increases potential access to model resources through the existence of a user community. While the manual provides guidance and sample input, the model is dependent upon a large amount of user-collected pipeline survey or inspection data.
	RADTRAN *See also §3.4.1.2, 4.2.8* --------------------- Department of Energy, Office of Environmental Management, Sandia National Laboratories	Highway Rail Marine	Users are able to input and adjust over 70 data points to customize how the tool calculates incident-free exposure along with risk of exposure from accident or sabotage. Key inputs with regard to assessing the exposure risk along a set route: • Population density • Fatalities per accident • Weather conditions • Probability fractions of event • Packaging data Additionally, TRAGIS data can easily be inputted into RADTRAN.	Expected Radiological Exposure/ Consequence over set route during a shipping campaign. Exposure data is output according to: • Groundshine • Cloudshine • Inhalation • Resuspension • Overall Since its inception, RADTRAN has been used in most radiological transportation EA and EIS. RADTRAN also has the capabilities to conduct specific radiological transportation accident and sabotage scenarios.	*Strengths:* • Highly customizable by user (over 70 individual data points that can be input or adjusted by the user). • Users can adjust the parameters surrounding the probability and effects of an accident. • RADTRAN can be used in conjunction with WebTRAGIS and TRAGIS. *Weaknesses:* • Calculates based on maximum-exposed individual. • Has been found to use conservative Dose Rates. • Requires substantial user input, which can increase user error.
	TRACC *See also §3.4.1.3, 4.2.18* --------------------- Oak Ridge National Laboratory Center for Transportation Analysis and Mississippi State University	Marine	Current and historical vessel positions are reported by barge and tow companies using GPS devices; high population locations and points of critical infrastructure are stored within the system database.	GIS, web-based reports of anomalous/barge movements are disseminated to governmental agencies, responders, and route managers.	This software identifies high-risk or anomalous barge activity and alerts authorities and other shipment stakeholders. With the exception of vessel-specific information, data needed to use the tool is stored within the system database. Output is web-based and delivered as graphics (map) and text, facilitating quick, informed comprehension and decision making. Application of the tool is limited until continuous GPS location transmission systems are more widely employed by tow and barge operators.
Security	GeoCTA *See also §3.4.1.3, 4.2.11* --------------------- Oak Ridge National Laboratory Center for Transportation Analysis	Highway Rail Marine Air Pipeline	Input data is self-contained within the tool and consists of GIS-based spatial data layers for describing incident locations and U.S. Census population data for calculating incident consequences.	Outputs include a consequence index based on the magnitude of population at risk and GIS-based maps with information on critical and high-value locations.	This software focuses on gauging human consequences within the framework of transportation and critical infrastructure in high-threat urban areas. GeoCTA contains a large number and variety of spatial data layers, including all of the data necessary for use of the system. Output includes GIS-based maps, which facilitate quick, informed decision making. Risk-related output is currently focused solely on estimations of affected population. The tool can be applied to any location within the United States and has been designed for easy integration of new spatial analysis functions. Presently, the tool is unavailable for public distribution, but could theoretically be made available with the exclusion/substitution of restricted data.

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4.1.6 (Continued).

Name Sponsor/Developer	Mode	Input(s)	Output(s)	Key Aspects
Readiness and Resiliency Assessment System (RRAS) *See also §3.4.1.3, 4.2.16* --------------------- Oak Ridge National Laboratory Center for Transportation Analysis	Highway Rail Marine Air Pipeline	Input data is largely security sensitive and non-distributable. Necessary inputs include spatial transportation system infrastructure data, security and response resources and capabilities, and population counts and locations.	RRAS outputs are relative values describing readiness and resiliency that categorize a transportation asset or system as "Fully Prepared," "Moderately Prepared," or "Unprepared."	RRAS is capable of assessing readiness and resiliency of a transportation network on a national scale, but is applicable across all levels and modes of transportation systems. The framework has not been publicly distributed, owing to the fact that it was designed to employ data that is sensitive and not publicly available. Distribution of the tool is theoretically possible with the exclusion / substitution of sensitive data, however. RRAS is currently asset- or system-specific, and does not address the interdependence of systems. As such, the framework is more focused on transportation system readiness than resiliency.
TRACC *See also §3.4.1.3, 4.2.18* --------------------- Oak Ridge National Laboratory Center for Transportation Analysis and Mississippi State University	Marine	Current and historical vessel positions are reported by barge and tow companies using GPS devices; high population locations and points of critical infrastructure are stored within the system database.	GIS, web-based reports of anomalous/barge movements are disseminated to governmental agencies, responders, and route managers.	This software identifies high-risk or anomalous barge activity and alerts authorities and other shipment stakeholders. With the exception of vessel-specific information, data needed to use the tool is stored within the system database. Output is web-based and delivered in as graphics (map) and text, facilitating quick, informed comprehension and decision making. Application of the tool is limited until continuous GPS location transmission systems are more widely employed by tow and barge operators.
Transportation Sector Security Risk Assessment (TSSRA) *See also §3.7.8, 4.2.20* --------------------- Department of Homeland Security, Transportation Security Administration, Office of Security Capabilities	Highway Rail Marine Pipeline	For each non-asset specific attack scenario: • *Threat*: Internal data from the Office of Intelligence • *Vulnerability*: Expert elicitation from industry stakeholders, based on countermeasures and target hardness • *Consequence*: DHS-based methodology (historic information with certain expected values) and included: ○ Human ○ Economic ○ Psychological	Relative risk scores between scenarios (including scenarios involving hazardous materials) and across modes. Various analyses that highlight the risk landscape by views of concern such as attack, likelihood, and conditional risk. Additionally, TSSRA can report quantitative values for the threat, vulnerability and consequence components of the risk analysis.	*Strengths:* • Measures relative risk across the full TSA domain using a common framework. • The inclusion of external and internal stakeholders increases the credibility and transparency. *Weaknesses:* • Vulnerability is measured based on human input, which introduces biases and limitations. • The chief threat group analyzed was international extremists. • Representative assets were used instead of specific sites. While sensitivity analysis allows for a better understanding across all sites, it is difficult to map the risk for one specific site. • Threat attack groups do not yet include domestic extremists • The inputs into the consequence component need to be standardized.

4.1.7 Operational Changes

	Name Sponsor/Developer	Mode	Input(s)	Output(s)	Key Aspects
Safety	CCPS Guidelines: Risk Prioritization Process *See also §3.3.1, 4.2.4* --------------------- Center for Chemical Process Safety	Highway Rail Marine Air Pipeline	Subjective selections for frequency (based on exposure), probability (can be based on past history), and consequence that should not require specialized data or analyses.	The screening model provides a single risk score. Ranges are defined for serious, high, medium, and low.	High-level screening process that can determine whether more detailed assessment is warranted. Appropriate when there is no specific risk mitigation strategy in mind.
	CCPS Guidelines: Qualitative Risk Assessment Process *See also §3.3.1, 4.2.2* ---------------------	Highway Rail Marine Air Pipeline	Benchmarking data from other companies or operations. The information that can be included is quite varied and includes chemical hazards, industry experience,	List of actions to address, including the need for more detailed analysis.	Benchmarking may indicate whether additional risk mitigation actions are necessary to close gaps as compared to the industry leader. The focus is more on the process used to select among alternatives

4.1.7 (Continued).

Name Sponsor/Developer	Mode	Input(s)	Output(s)	Key Aspects
Center for Chemical Process Safety		container design and operating practices, and safety and security.		than on the selection itself. Do peers use risk prioritization or quantitative analyses, for example?
CCPS Guidelines: Semi-Quantitative Risk Assessment Process *See also §3.3.1, 4.2.7* --------------------- Center for Chemical Process Safety	Highway Rail Marine Air Pipeline	Quantify or weight the frequency-related elements and develop scenarios with accompanying release size and probability estimates. Consequences are quantified from model input data, including the scenario definitions and sensitive areas along the routes.	For risk indexes, the result for each option is a single value. For risk matrices, the result for each option is a single risk priority value.	Adds quantification where needed to make an informed decision. Cost-effective because not all elements need to be quantified. Risk indices or matrices provide easy means to combine the different elements of risk without a formal calculation.
CCPS Guidelines: Quantitative Risk Assessment Process *See also §3.3.1, 4.2.3* --------------------- Center for Chemical Process Safety	Highway Rail Marine Air Pipeline	Quantity per shipment, annual shipments, loaded vs. empty miles, Infrastructure characteristics needed for accident rate calculations. Conditional probability of release after an incident, the range of release sizes to consider, the probabilities of different release types (e.g., jet fire, pool fire, flash fire, toxic gas, explosion, or no impact). Population characteristics (including representative densities or detailed Census data) along the route, material hazard information, impact area; the 'endpoint' criteria for the different types of hazards: • Toxic chemical exposure • Vapor cloud explosion • Flammability hazards • Flash fires	Generally, three types: • Risk indices • Individual risk (contours, maximums, averages for exposed or total population) • Societal risk (usually expressed as F-N curves)	Depending on the form of the output, can provide annual risk values, distribution of people exposed to different risk levels, or societal risks. High-consequence/low-probability and low-consequence/high-probability events can be represented.
Chemical Manufacturer Risk Assessment Framework *See also §3.3.4, 4.2.8* --------------------- Large Chemical/Plastics Manufacturer	Highway Rail Marine Pipeline (inbound only)	Considers trip length, past experience, shipment size, available packaging, third-party consequence data (sensitive areas along their routes, presence of bridges and tunnels). Chemical property information is internal.	Reports are generated for the corporate operations department and sometimes include risk matrices.	Considers all modes for their shipments (at least two are available at all locations). Risk assessments triggered by any change in distribution, and are usually only qualitative.
Fedtrak *See also §3.7.9, 4.2.10* --------------------- The Kentucky Transportation Center at the University of Kentucky for Transportation Security Administration	Highway	Accident data included in the model's network. Packaging provides a qualitative conditional probability of release or uses dated values. Consequences include population, CIKR, environmentally sensitive areas, and economic impact (most determined from model data).	Safety risk scores are computed for the planned route and remain static.	Model is designed for security but supports estimation and mitigation of safety risk. Alternate routes can be assessed and the safety risk scores can be compared.
Pipeline Risk Management Manual *See also §3.4.2.5, 3.7.7, 4.2.13* --------------------- W. Kent Muhlbauer	Pipeline	Input parameters can vary according to the specific goals of risk assessors and tend to require on-site data collection through inspections and surveys. Inputs include a wide array of data, examples of which include pipeline location, proximity to above ground activities, atmospheric exposure, soil corrosivity, coating type and condition, fatigue, land movements, operations and	Outputs include indices for probabilities of third-party damage, corrosion, design issues, and incorrect operations; a leak impact (consequence) factor; and a relative risk score for each section of pipeline being studied.	As a scoring/index model, the model provides easily understandable and comparable output relatively quickly, but results may be affected by subjectivity and are not readily comparable to assessments of other modes of transportation. The model is flexible, able to use a wide range of input data and data precision, can be modified to consider alternative consequence metrics, and allows for its relative output values to be converted into

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4.1.7 (Continued).

	Name Sponsor/Developer	Mode	Input(s)	Output(s)	Key Aspects
			procedures, maintenance, characteristics of transported chemicals, and the location of potential human and environmental receptors.		absolute risk numbers. The model is a standard industry tool, which facilitates communication about the model, data, and results, and increases potential access to model resources through the existence of a user community. While the manual provides guidance and sample input, the model is dependent upon a large amount of user-collected pipeline survey or inspection data.
	TRACC *See also §3.4.1.3, 4.2.18* --------------------- Oak Ridge National Laboratory Center for Transportation Analysis and Mississippi State University	Marine	Current and historical vessel positions are reported by barge and tow companies using GPS devices, high population locations and points of critical infrastructure are stored within the system database.	GIS, web-based reports of anomalous/barge movements are disseminated to governmental agencies, responders, and route managers.	This software identifies high-risk or anomalous barge activity and alerts authorities and other shipment stakeholders. With the exception of vessel-specific information, data needed to use the tool is stored within the system database. Output is web-based and delivered as graphics (map) and text, facilitating quick, informed comprehension and decision making. Application of the tool is limited until continuous GPS location transmission systems are more widely employed by tow and barge operators.
Security	CCPS Guidelines: Security Risk Prioritization Process *See also §3.3.1, 4.2.5* --------------------- CCPS	Highway Rail Marine Air Pipeline	Chemical hazards, quantity transported per container, number of shipments, mode, interim storage, specific threat information, and the proximity to people, sensitive environmental areas, critical assets or infrastructure are all considered subjectively.	Identification of the issues that require additional analysis, such as TVSA.	Easy to implement; ensures that resources are placed on the issues that require the most attention. This subjective review elevates issues to a formal TVSA and includes a security review for those elements that are not elevated.
	CCPS Guidelines: Security Vulnerability Assessment Process *See also §3.3.1, 4.2.6* --------------------- CCPS	Highway Rail Marine Air Pipeline	Both internal and external threat information is combined with relative target attractiveness factors. Vulnerability is qualitatively assessed based on how well existing countermeasures can withstand or eliminate an attack. Consequences considered can include casualties, theft of hazmat, disruption of the economy or company operations, environmental damage, financial loss, secondary damage to critical infrastructure, loss of critical data, and erosion of company reputation.	For risk indexes, the result for each option is a single value. For risk matrices, the result for each option is a single risk priority value. A list of prioritized countermeasures is also produced.	Can allow companies to cost-effectively allocate their security mitigation resources. Relies a lot on subject matter experts and outside threat information.
	TRACC *See also §3.4.1.3, 4.2.18* --------------------- Oak Ridge National Laboratory Center for Transportation Analysis and Mississippi State University	Marine	Current and historical vessel positions are reported by barge and tow companies using GPS devices, high population locations and points of critical infrastructure are stored within the system database.	GIS, web-based reports of anomalous/barge movements are disseminated to governmental agencies, responders, and route managers.	This software identifies high-risk or anomalous barge activity and alerts authorities and other shipment stakeholders. With the exception of vessel-specific information, data needed to use the tool is stored within the system database. Output is web-based and delivered as graphics (map) and text, facilitating quick, informed comprehension and decision making. Application of the tool is limited until continuous GPS location transmission systems are more widely employed by tow and barge operators.

4.1.8 Security Measure Identification, Prioritization, and Evaluation

	Name Sponsor/Developer	Mode	Input(s)	Output(s)	Key Aspects
Security	CCPS Guidelines: Security Risk Prioritization Process *See also §3.3.1, 4.2.5* -------------------- Center for Chemical Process Safety	Highway Rail Marine Air Pipeline	Chemical hazards, quantity transported per container, number of shipments, mode, interim storage, specific threat information, and the proximity to people, sensitive environmental areas, critical assets or infrastructure are all considered subjectively.	Identification of the issues that require additional analysis, such as TVSA.	Easy to implement; ensures that resources are placed on the issues that require the most attention. This subjective review elevates issues to a formal TVSA and includes a security review for those elements that are not elevated.
	CCPS Guidelines: Security Vulnerability Assessment Process *See also §3.3.1, 4.2.6* -------------------- Center for Chemical Process Safety	Highway Rail Marine Air Pipeline	Both internal and external threat information is combined with relative target attractiveness factors. Vulnerability is qualitatively assessed based on how well existing countermeasures can withstand or eliminate an attack. Consequences considered can include casualties, theft of hazmat, disruption of the economy or company operations, environmental damage, financial loss, secondary damage to critical infrastructure, loss of critical data, and erosion of company reputation.	For risk indexes, the result for each option is a single value. For risk matrices, the result for each option is a single risk priority value. A list of prioritized countermeasures is also produced.	Can allow companies to cost-effectively allocate their security mitigation resources. Relies a lot on subject matter experts and outside threat information.
	Chemical Terrorism Risk Assessment (CTRA) *See also §3.4.3.1, 4.2.9* -------------------- Department of Homeland Security Science and Technology Directorate Chemical Security Analysis Center	Highway Rail Marine Pipeline	Threat and vulnerability are considered in concert in the assignment of the event tree probabilities. The components are: (1) terrorist capability, (2) intent, (3) ease of acquiring the chemical, (4) terrorist knowledge of the chemical, (5) ability to carry out the attack, (6) probability of interdiction, and (7) probability of failure. For inhalation, HPAC is used for outdoor consequences, and the CONTAM model is used for indoor consequences. The SCIPUFF model is also used. Different population densities and locations are used to get a range of consequences for a given scenario. For percutaneous, CSAC employs a statistical model that looks at the size of the contact area, the permeability of skin, and other materials that may push impermeable materials through skin. For ingestion, CSAC uses a stock and flow model that considers how much can get into the food supply, how it is distributed, and how many people would ultimately be affected. Toxicity values for over 120 chemicals, the three routes of exposure, and three injury severities are used as input data into the event tree.	The outputs from one component model are used to feed subsequent models. Ultimately, there is a single risk number for each scenario or chemical being analyzed. These can be aggregated as needed.	The CTRA is a combination of separate models. The models examine all routes of exposure: inhalation, ingestion, and percutaneous. They examine both lethal and non-lethal effects. The underlying framework is PRA. The event tree is broken out in great detail. The different branches in the event tree can be combined as the user needs. Each event tree branch defines a scenario and the frequencies are applied along the path down that branch. Consequences are determined by the appropriate model for that scenario and multiplied by the overall frequency. The only difference from a traditional PRA is the inclusion of terrorist intention. The methodology supports large and small accidental releases as well as large intentional releases.
	Fedtrak *See also §3.7.9, 4.2.10* -------------------- The Kentucky Transportation Center	Highway	Attack mode, type of hazmat, and trailer/container type, nearby high-population density areas (Census data) and CIKR (from DHS or the states).	The model will provide both static safety and dynamic security risk scores for each shipment along a planned route.	The security risk methodology supports the quantification of risk reduction through countermeasures or risk mitigation strategies. This includes reduction of the maximum risk and the cumulative reduction of route risk.

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4.1.8 (Continued).

Name Sponsor/Developer	Mode	Input(s)	Output(s)	Key Aspects
at the University of Kentucky for Transportation Security Administration		Two separate vulnerability measures are estimated, the likelihood that the terrorists do not fail on their own due to the inherent nature of the scenario and the likelihood that the terrorists will be able to overcome security measures. Consequences include population, CIKR, environmentally sensitive areas, and economic impact (most determined from model data).	Security risk scores can be computed for a route at the planning stage (identifying the locations of high risk along the route), but will be automatically computed as each new location coordinates are received, providing a near-real time view of each shipment's risk.	The system relies on a complete picture of Tier 1 HSSM shipments across the country for overall situational awareness. Still in the development stage.
Risk-Based Preventative Radiological / Nuclear Detection Resource Allocation (CREATE Model) *See also §3.7.6, 4.2.17* --------------------- National Center for Risk and Economic Analysis of Terrorism Events	Highway Ports	Inputs include selection of targets to be assessed, number and spatial layout of access paths to the targets, number and types of detectors within the system, and detector-specific detection probabilities. The data required for describing consequences depends upon the goals of the application of the model and can include traffic volume information and spatial population estimates.	Probability of detecting a radiological or nuclear weapon; cost estimates of system deployment, success, or failure, etc.	This model is a risk-based approach for the placement and operation of radiological and nuclear detectors within a transportation system. Is customizable to a wide array of outputs depending on user interests, and a majority of necessary data can be acquired from public sources.
Transportation Sector Security Risk Assessment (TSSRA) *See also §3.7.8, 4.2.20* --------------------- Department of Homeland Security, Transportation Security Administration, Office of Security Capabilities	Highway Rail Marine Pipeline	For each non-asset specific attack scenario: • *Threat*: Internal data from the Office of Intelligence • *Vulnerability*: Expert elicitation from industry stakeholders, based on countermeasures and target hardness • *Consequence*: DHS-based methodology (historic information with certain expected values) and included: o Human o Economic o Psychological	Relative risk scores between scenarios (including scenarios involving hazardous materials) and across modes. Various analyses that highlight the risk landscape by views of concern such as attack, likelihood, and conditional risk. Additionally, TSSRA can report quantitative values for the Threat, Vulnerability and Consequence components of the risk analysis.	*Strengths*: • Measures relative risk across the full TSA domain using a common framework. • The inclusion of external and internal stakeholders increases the credibility and transparency. *Weaknesses*: • Vulnerability is measured based on human input, which introduces biases and limitations. • The chief threat group analyzed was international extremists. • Representative assets were used instead of specific sites. While sensitivity analysis allows for a better understanding across all sites, it is difficult to map the risk for one specific site. • Threat attack groups do not yet include domestic extremists • The inputs into the Consequence component need to be standardized.
Trucking and Hazardous Materials Trucking Risk Assessment (THTRA) *See also §3.4.3.2, 4.2.21* --------------------- Department of Homeland Security, Transportation Security Administration, Highway Motor Carriers Division	Highway	For each non-asset specific attack scenario: • *Threat:* Internal data from the Office of Intelligence • *Vulnerability:* Expert elicitation from industry stakeholders, based on countermeasures and target hardness • *Consequence:* DHS-based methodology (historic information with certain expected values) and included: o Human o Economic o Psychological	The three elements of DHS Risk (Threat, Vulnerability and Consequence) are scaled for each scenario using a modified Kent scale (seven values ranging from very low to critical). Risk is reported out as a relative risk score for each non-asset specific attack scenario.	*Strength:* Vulnerability analysis was driven by expert elicitation, which allowed TSA to identify gaps and potential was to close them. *Weaknesses:* Acuity of qualitative, scaled risk values (what does medium risk mean?). The lack of transparency into the threat component is another identified weakness. The false precision of results.

4.1.9 Security Risk Situational Awareness

	Name Sponsor/Developer	Mode	Input(s)	Output(s)	Key Aspects
Security	Fedtrak *See also §3.7.9, 4.2.10* --------------------- The Kentucky Transportation Center at the University of Kentucky for Transportation Security Administration	Highway	Attack mode, type of hazmat, and trailer/container type, nearby high-population density areas (Census data) and CIKR (from DHS or the states). Two separate vulnerability measures are estimated, the likelihood that the terrorists do not fail on their own due to the inherent nature of the scenario and the likelihood that the terrorists will be able to overcome security measures. Consequences include population, CIKR, environmentally sensitive areas, and economic impact (most determined from model data).	The model will provide both static safety and dynamic security risk scores for each shipment along a planned route. Security risk scores can be computed for a route at the planning stage (identifying the locations of high risk along the route), but will be automatically computed as each new location coordinates are received, providing a near-real time view of each shipment's risk. Viewing the security risk scores for all en route shipments provides nationwide situational awareness.	The security risk methodology supports the quantification of risk reduction through countermeasures or risk mitigation strategies. This includes reduction of the maximum risk and the cumulative reduction of route risk. The system relies on a complete picture of Tier 1 HSSM shipments across the country for overall situational awareness. Still in the development stage.
	TRACC *See also §3.4.1.3, 4.2.18* --------------------- Oak Ridge National Laboratory Center for Transportation Analysis and Mississippi State University	Marine	Current and historical vessel positions are reported by barge and tow companies using GPS devices, high population locations and points of critical infrastructure are stored within the system database.	GIS, web-based reports of anomalous/barge movements are disseminated to governmental agencies, responders, and route managers.	This software identifies high-risk or anomalous barge activity and alerts authorities and other shipment stakeholders. With the exception of vessel-specific information, data needed to use the tool is stored within the system database. Output is web-based and delivered as graphics (map) and text, facilitating quick, informed comprehension and decision making. Application of the tool is limited until continuous GPS location transmission systems are more widely employed by tow and barge operators.
	Transportation Sector Security Risk Assessment (TSSRA) *See also §3.7.8, 4.2.20* --------------------- Department of Homeland Security, Transportation Security Administration, Office of Security Capabilities	Highway Rail Marine Pipeline	For each non-asset specific attack scenario: • *Threat*: Internal data from the Office of Intelligence • *Vulnerability:* Expert elicitation from industry stakeholders, based on countermeasures and target hardness • *Consequence:* DHS-based methodology (historic information with certain expected values) and included: o Human o Economic o Psychological	Relative risk scores between scenarios (including scenarios involving hazardous materials) and across modes. Various analyses that highlight the risk landscape by views of concern such as attack, likelihood, and conditional risk. Additionally, TSSRA can report quantitative values for the Threat, Vulnerability and Consequence components of the risk analysis.	*Strengths*: • Measures relative risk across the full TSA domain using a common framework. • The inclusion of external and internal stakeholders increases the credibility and transparency. *Weaknesses*: • Vulnerability is measured based on human input, which introduces biases and limitations. • The chief threat group analyzed was international extremists. • Representative assets were used instead of specific sites. While sensitivity analysis allows for a better understanding across all sites, it is difficult to map the risk for one specific site. • Threat attack groups do not yet include domestic extremists. • The inputs into the Consequence component need to be standardized.

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4.1.9 (Continued).

Name Sponsor/Developer	Mode	Input(s)	Output(s)	Key Aspects
Trucking and Hazardous Materials Trucking Risk Assessment (THTRA) *See also §3.4.3.2, 4.2.21* --------------------- Department of Homeland Security, Transportation Security Administration, Highway Motor Carriers Division	Highway	For each non-asset specific attack scenario in the Highway Domain: • *Threat*: Internal data from the Office of Intelligence • *Vulnerability:* Expert elicitation from industry stakeholders, based on countermeasures and target hardness • *Consequence:* DHS-based methodology (historic information with certain expected values) and included: ○ Human ○ Economic ○ Psychological	The three elements of DHS Risk (threat, vulnerability and consequence) are scaled for each scenario using a modified Kent scale (seven values ranging from very low to critical). Risk is reported out as a relative risk score for each non-asset specific attack scenario.	*Strength:* Vulnerability analysis was driven by expert elicitation, which allowed TSA to identify gaps and potential was to close them. *Weaknesses:* Acuity of qualitative, scaled risk values (What does medium risk mean?). The lack of transparency into the threat component is another identified weakness. The false precision of results.

4.2 Model Matrices

Model	Sponsor/Developer	Page
Boston Hazmat Route Evaluation	City of Boston	53
CCPS Guidelines: Qualitative Risk Assessment Process	CCP	54
CCPS Guidelines: Quantitative Risk Assessment Process	CCPS	55
CCPS Guidelines: Risk Prioritization Process	CCPS	56
CCPS Guidelines: Security Risk Prioritization Process	CCPS	57
CCPS Guidelines: Security Vulnerability Assessment Process	CCPS	58
CCPS Guidelines: Semi-Quantitative Risk Assessment Process	CCPS	59
Chemical Manufacturer Risk Assessment Framework	Large Chemical/Plastics Manufacturer	60
Chemical Terrorism Risk Assessment (CTRA)	DHS S&T CSAC	61
Fedtrak	The Kentucky Transportation Center at the University of Kentucky for TSA	62
GeoCTA	ORNL CTA	63
IME Safety Analysis for Risk (IMESAFR)	IME	64
Pipeline Risk Management Manual Risk Assessment Method	PHMSA OPS	65
RADTRAN	DOE/Sandia	66
Rail Corridor Risk Management System (RCRMS)	RRF/AAR	67
Readiness and Resiliency Assessment Framework	ORNL CTA	69
Risk-Based Preventative Radiological/Nuclear Detection Resource	CREATE	69
TRACC	ORNL CTA/Miss. State Univ.	70
Transportation Routing Analysis GIS (TRAGIS)	DOE/Oak Ridge	71
Transportation Sector Security Risk Assessment (TSSRA)	DHS, TSA, Office of Security Capabilities (OSC)	72
Trucking and Hazmat Trucking Risk Assessment (THTRA)	DHS, TSA, HMC	73
UIUC Tank Car Risk Analysis	UIUC	74

4.2.1 Boston Hazmat Route Evaluation

See also: §3.3.1

Sponsor/Dev.	Users/Uses/Decisions	Output(s)	Applicable Mode(s)	Methodology or Approach
City of Boston	City officials desired to make changes in the designated hazmat route through Boston and were required to perform an analysis of alternate routes. State officials needed to approve the analysis and the recommendations.	Risk scores for the analyzed routes were provided along with route daytime and nighttime population estimates.	Highway	The analysis was based on one of the options presented in the FMCSA routing guidance. The approach focused on through-route analysis, but provided additional assessments of the risk for other, local routes with different origins/destinations. Potential route alternatives were identified through a consultative process with state and local officials.

Component		Key Sources of Data	Assumptions, Limitations, Biases, and Availability
Safety	Frequency	Roadway truck accident rates are tied to roadway functional classification (determined for each segment from MassDOT data) provided by the University of Mass.	The report provides an uncertainty analysis and prescribes much of the uncertainty to the accident rate component (from uncertainty in truck traffic density). Sensitivity analysis was performed by using a different endpoint for the routes.
	Probability	NA	NA
Security	Threat	NA	NA
	Vulnerability	NA	NA
Consequence		Commodities transported were identified from Hazardous Materials Incident Reporting System (HMIRS) incident reports, city hazmat vehicle inspections, city permits and applications, shipper survey to PHMSA registrants within 75 miles of the study area, and the Census Bureau's CFS. A ½-mile radius impact area for flammables was used to determine consequences (the range was from the FMCSA guidance document). Population data along the routes for TAZs that included day and night estimates were obtained from the Boston Region's Central Transportation Planning Staff (CTPS). These data were derived from Census tract data. Additional sources were used to estimate other, special populations that were added to the Census-derived data: • Employment (CTPS with daytime percentages estimated from the Bureau of Labor Statistics national average) • Schools (locations from state GIS data; enrollment from the state Dept. of Elementary and Secondary Ed.) • Hotels (Google Earth and hotel database website for location; hotel websites for sleeping and meeting rooms; assumptions used to determine occupancy and day/night split) • Hospitals (Board of Registration in Medicine and Google Earth for location; various sources for capacity and occupancy) • Nursing homes (state GIS data and Google Earth for location; various sources for capacity and occupancy) and • Visitors (major National Park Service visitors only) Acres of environmental exposure for elements in 11 different state databases within ½ mile of each route were combined with segment accident rates to determine the environmental risk. Emergency response times were considered, but not quantified in the risk equation. Burden on commerce was also considered by computing the additional cost per year for industry to use each alternate route.	No commodity flow studies were identified for the study region, so the alternate methods listed were used. Ultimately, a single commodity (the most commonly transported) was used as the basis for the analysis. This results in a single scenario driving the risk assessment results. Commodities traveling longer distances through the study region would not be identified through the shipper survey and the other sources do not cover all potential shipments, but do provide a good representation. The CFS data are for a broader region than the study area and not all data meet the reporting threshold. Some additional sensitivity analysis was performed to explore changes to the following parameters: • Halving the percentage of resident population at home during the day • Halving the percentage of employment population working at night The FMCSA guidance document is dated (1996) and more appropriate parameters and approaches are now available.

(continued on next page)

4.2.1 (Continued).

Strengths (including data)	Weaknesses	Availability	Barriers/Desired Improvements
The methodology makes strong use of a 1.5 ratio for decision making when comparing the risks of two alternatives. Above that threshold, cost implications were not considered. With the uncertainty analysis, this was increased to 2.3 (at the 95% confidence interval).	Selection of the route end points can affect the ratio of the relative risks of alternatives and potentially affect the outcome. The analysis focused on Class 3 shipments, the most common in the area. The FMCSA guidance document is dated (1996) and more appropriate parameters and approaches are now available.	FMCSA routing guidelines are publically available from their website. The Boston study and clarifying responses to MassDOT questions are available from the MassDOT website.[1]	None

[1] http://www.massdot.state.ma.us/highway/ProposedHazmatRoute.aspx as of 3/1/2012.

4.2.2 CCPS Guidelines: Qualitative Risk Assessment Process

See also: §3.3.1

Sponsor/Dev.	Users/Uses/Decisions	Output(s)	Applicable Mode(s)	Methodology or Approach
Center for Chemical Process Safety of the American Institute of Chemical Engineers	This model is designed to assist chemical companies manage their global transportation risks in a consistent framework. It includes determining which materials should be considered, the level of analysis appropriate, and the areas where mitigation actions may be warranted. Supported decisions cover a wide range of corporate activities and stakeholders. For any issue that was deemed in the risk prioritization step to require additional analysis, a qualitative risk analysis step is conducted. Benchmarking is particularly useful for companies that are not the industry experts in a particular area. The user must determine whether it is appropriate to close any gaps between each aspect of their operations and those of the industry leader.	List of actions to address, including the need for more detailed analysis.	All modes	Three key areas are usually included: Benchmarking. This can be for internal or external practices, regulations, or standards. The information that can be included is quite varied and includes chemical hazards, industry experience, container design and operating practices, and safety and security. Identifying issues. For each element, the organization compares the operation being evaluated against other data and determines the appropriate response or whether further analysis is needed. Understanding the impacts from changes. Any changes to current operating practices need to be analyzed. Repeat the qualitative analysis with the change in operations included.

Component		Key Sources of Data	Assumptions, Limitations, Biases, and Availability
Safety	Frequency	Benchmarking can consider company operating practices, route mileage and accident rates, and recent incidents. Other factors include: storage proximity of other materials and their potential reactions, container and vehicle types and sizes, container securement, inspection procedures, off-loading personnel qualifications and training, proposed route and restrictions, etc.	Data to benchmark against other companies may be difficult to get; data from surveys might need clarification (which may not be available).
	Probability		
Security	Threat	NA	NA
	Vulnerability	NA	NA
Consequence		Benchmarking can consider proximity to sensitive receptors, the material's potential to cause harm to people, effectiveness of potential evacuation and cleanup along route, etc.	None

4.2.2 (Continued).

Strengths (including data)	Weaknesses	Availability	Barriers/Desired Improvements
Cost-effective approach for considering options that do not require more detailed assessment. Can be tailored to specific carrier's circumstances. Data can feed more detailed analyses.	Benchmarking needs to be planned well if outside sources of data are used; otherwise, the collected information may lead to misleading results.	Publically available by purchasing the book.	None

4.2.3 CCPS Guidelines: Quantitative Risk Assessment Process

See also: §3.3.1

Sponsor/Dev.	Users/Uses/Decisions	Output(s)	Applicable Mode(s)	Methodology or Approach
Center for Chemical Process Safety of the American Institute of Chemical Engineers	This model is designed to assist chemical companies manage their global transportation risks in a consistent framework. It includes determining which materials should be considered, the level of analysis appropriate, and the areas where mitigation actions may be warranted. Supported decisions cover a wide range of corporate activities and stakeholders. Risk assessments can focus on alternatives for a single shipment or be as broad as the entire distribution operation for an organization. Mode and route choice, shipment quantities, and packaging are the typical issues being considered. Generally, risk experts conduct the analysis and present the results to the decision maker(s).	Generally, three types (see strengths and weaknesses below): • Risk indices • Individual risk (contours, maximums, averages for exposed or total population) • Societal risk (usually expressed as F-N curves)	All modes	The general approach includes 5 steps: selecting the scenarios or issues to be evaluated, data collection and evaluation, selecting consequence measures, conducting the analysis, and presenting the results to the decision makers. Optional steps include sensitivity analysis and evaluating different approaches for risk reduction.

Component		Key Sources of Data	Assumptions, Limitations, Biases, and Availability
Safety	Frequency	Quantity per shipment, annual shipments, loaded vs. empty miles Infrastructure characteristics needed for accident rate calculations	Try to use specific carrier accident rates, if specific movements are being considered (and use route-and-carrier-specific rates if there is sufficient volume over specific routes over time). In general, care should be taken to use data that most closely align with the operations being assessed. Where only generic accident rates are available, consider the implications if they do not match up well (the example given is using truck accident rates for hazmat truck accident rates; hazmat rates may be lower). Also, ensure that there is good alignment between the sources for accidents and miles traveled.
	Probability	Conditional probability of release after an accident (or non-accident), the range of release sizes to consider, the probabilities of different release types (e.g., jet fire, pool fire, flash fire, toxic gas, explosion, or no impact)	Only a representative range of release sizes are typically considered. Event trees can be used to estimate probabilities beyond that of whether or not a release occurs. This can include the phase of the material released (gas, liquid, solid), whether there is an ignition (and how soon after release), whether there is an explosion, and the final type of impact.
Security	Threat	NA	NA
	Vulnerability	NA	NA
Consequence		Population characteristics (including representative densities or detailed Census data) along the route, material hazard information, potential release sizes, impact area. As with the probability, the 'endpoint' criteria for the different types of hazards are important to understand: • Toxic chemical exposure: a concentration over the exposure duration • Vapor cloud explosion: blast overpressure	The specific release scenarios play a big role in how the consequences should be estimated. Source elevation may play a role in the concentrations seen at any location. Quantity released may not be linearly correlated to downwind dispersion distance. Terrain and meteorological parameters are also big factors in the dispersion of released materials. Consider the impacts of using endpoints that reflect where detectable effects may occur versus those that would result in serious injury or death. If representative population densities are used, they should at least cover major cities, urban areas, suburban areas, and rural areas.

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4.2.3 (Continued).

Component		Key Sources of Data	Assumptions, Limitations, Biases, and Availability
		• Flammability hazards: ○ Pool fires: steady heat load or thermal radiation load ○ Boiling liquid expanding vapor explosions (BLEVEs) and fireballs: integrated dose criterion ○ Flash fires: the concentration that is in the flammable range for the material	

Strengths (including data)	Weaknesses	Availability	Barriers/Desired Improvements
Risk indices provide single annual risk number. Individual risks can be used to show a distribution of people exposed to differing risk levels (recognizing the dynamics of the risk along the route), the greatest risk that any individual might experience along a route, the average risk for all the exposed population, and the average risk for a fixed population (for comparing several alternatives). Societal risk outputs inform about high-consequence/low-probability and low-consequence/high-probability events. "The greatest value is in providing a relative risk comparison … so that the priorities for action can be set."	Requires risk professional to perform analyses. Risk indices do not inform about high-consequence/low-probability and low-consequence/high-probability events and usually do not provide sufficient information to make risk tolerance decisions. Some individual risk calculations can be difficult or time-consuming to perform. Maximum risks do not provide information on the number of people exposed or how the risk level varies along or away from the route. The average risks do not indicate the number exposed in a release and may be misleading depending on the size of the areas and populations involved. Societal risks can be difficult to interpret.	Publically available by purchasing the book.	None

4.2.4 CCPS Guidelines: Risk Prioritization Process

See also: §3.3.1

Sponsor/Dev.	Users/Uses/Decisions	Output(s)	Applicable Mode(s)	Methodology or Approach
Center for Chemical Process Safety of the American Institute of Chemical Engineers	This process is designed to help industry managers understand the relative risk of different transportation operations at a very high screening level.	The screening model provides a single risk score that will range from 0 to 10,000. Values over 400 are considered serious. Other categories are: high (200 – 400), medium (70 – 200), and low (0 – 70).	All modes and operations.	The generic process starts out with data from a self-assessment of any third party involved (e.g., shipper, customer) and corporate history of the business relationship for context and key issues. A very qualitative process is used to characterize the magnitude of the risk, considering likelihood (0.1 to 10), exposure (0 to 10), and consequences (1 to 100). The risk score is checked to determine if the severity of the risk appears in line with the analyst's understanding of the nature of the activities that are being considered. A flow model outlines the appropriate steps based on the severity of the risk. Where appropriate, a more quantitative assessment and its timing are suggested. Action planning ensures that the risk monitoring and mitigation strategies are implemented.

Component		Key Sources of Data	Assumptions, Limitations, Biases, and Availability
Safety	Frequency	Exposure scale to capture the frequency that that the transportation activity occurs.	The range of values is from no exposure (0) to continuous (10). Daily, weekly, monthly, several times per year, and yearly are the other intermediate options.
	Probability	Likelihood scale to represent how often the adverse event (release of product) can be expected to happen. Past corporate history can be used to determine the appropriate value.	The range of values is from virtually impossible (0.1) to happens often (10). Intermediate values include quite possible, unusual but possible, remotely possible, conceivable but very unlikely (hasn't happened yet), and practically impossible. This relies on very subjective judgment to distinguish between the less likely categories.

4.2.4 (Continued).

	Component	Key Sources of Data	Assumptions, Limitations, Biases, and Availability
Security	Threat	NA	NA
	Vulnerability	NA	NA
Consequence		Consequence scale uses a combination of injuries, fatalities, and damage estimates to categorize the potential impacts.	The range of values is from minor injury and/or damage over $10K to catastrophic, with many fatalities and/or damage over $5M. The other human health consequences include injury, serious injury, 1 fatality, and a few fatalities. The damage levels include $50K, $500K, and $1M.

Strengths (including data)	Weaknesses	Availability	Barriers/Desired Improvements
This is a very simple process that can be implemented with no additional data. It can be used to determine where additional level of analysis detail is warranted (such as for risk scores determined to be high or serious). Because the analysis framework identifies levels of risk, it could be used to determine the risk for a single transportation operation without the need to identify alternates or other activities to compare it against.	This is a very subjective approach. The values listed are dated and can be updated by the user.	None	None listed.

4.2.5 CCPS Guidelines: Security Risk Prioritization Process

See also: §3.3.1

Sponsor/Dev.	Users/Uses/Decisions	Output(s)	Applicable Mode(s)	Methodology or Approach
Center for Chemical Process Safety of the American Institute of Chemical Engineers	Corporate analysts and decision makers use this model to determine the specific issues that require a more detailed TVSA from those that only need a general security review.	Identification of the issues that require additional analysis (TVSA).	All modes	The process includes 6 steps: 1. Identify the chemicals that need to be considered. 2. Review the modes and quantities. 3. Define scope of the evaluation (this may be necessary for complex supply chains, where some grouping may help manage the process). 4. Identify sensitive areas along the route (people, environmental, critical assets). 5. Evaluate the security a. Perform a security review on all items that do not warrant a full TVSA (the security review considers personnel security, unauthorized access, and en route security). b. Conduct a TVSA on those that do. 6. Review the security issues periodically or if there is specific, relevant, and actionable information.

	Component	Key Sources of Data	Assumptions, Limitations, Biases, and Availability
Safety	Frequency	NA	NA
	Probability	NA	NA
Security	Threat	At the screening level, the threat, vulnerability, and potential consequences are conceptually combined when considering the elements that would elevate an item to be a security concern: chemical hazards, quantity transported per container, number of shipments, mode, interim storage, specific threat information, and the proximity to people, sensitive environmental areas, critical assets or infrastructure.	Analyst judgment determines whether an item is moved forward for a full TVSA.
	Vulnerability		
Consequence			

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4.2.5 (Continued).

Strengths (including data)	Weaknesses	Availability	Barriers/Desired Improvements
Easy to implement; ensures that resources are placed on the issues that require the most attention.	Simplified approach relies on the analyst's judgment to determine whether to move items to the next level of analysis.	Publically available by purchasing the book.	None

4.2.6 CCPS Guidelines: Security Vulnerability Assessment Process

See also: §3.3.1

Sponsor/Dev.	Users/Uses/Decisions	Output(s)	Applicable Mode(s)	Methodology or Approach
Center for Chemical Process Safety of the American Institute of Chemical Engineers	Corporate analysts use this model to analyze broad security risks.	For risk indexes, the result for each option is a single value. For risk matrices, the result for each option is a single risk priority value. A list of prioritized countermeasures is also produced.	All modes	The risk is the likelihood that each identified threat can exploit the vulnerabilities of identified targets to achieve the desired consequences. The approach is generally qualitative (due to lack of predictive historical data). It includes 5 steps: 1. Characterize the route using the security prioritization process. 2. Assess the threats and the targets that would be attractive to them. 3. Analyze the vulnerabilities of the targets (segments of the route) identified in Step 2. a. Define scenarios for analysis b. Evaluate consequences. c. Evaluate security countermeasures. d. Estimate the vulnerabilities. 4. Analyze the risk and the need for additional countermeasures. 5. Analyze potential countermeasures and prioritize their implementation.

Component		Key Sources of Data	Assumptions, Limitations, Biases, and Availability
Safety	Frequency	NA	NA
	Probability	NA	NA
Security	Threat	Knowledge from internal and other company sources as well as from federal, state, and local law enforcement agencies can help inform on the nature of the threats that may apply to a company or its transportation routes. To estimate relative target attractiveness, surrogate factors can be used to offset the lack of intelligence data. Otherwise, a general estimate is used for the entire route or chemical. Some models use an estimate for the likelihood of an attack. This would use subject matter experts. Some of the factors identified for target attractiveness include: potential for mass casualties, extensive property damage, proximity to national assets/landmarks, effects on critical transportation infrastructure, effects on the economy, ease of access to the target, extent of media interest, company reputation or brand exposure, iconic or symbolic target.	No historical basis for determining the likelihood of an attack.
	Vulnerability	This is a qualitative assessment of how well the existing countermeasures can withstand or eliminate an attack.	The specific subject matter experts will have a large effect on the relative effectiveness of different countermeasures.
Consequence		Generally, the consequences can be the same or worse than for an accidental release. These consequences include: casualties (public, carrier, shipper, consignee, and responders), theft of hazmat, disruption of the economy or company operations, environmental damage, financial loss, secondary damage to critical infrastructure, loss of critical data, and erosion of company reputation.	The availability of data to support these consequences will vary depending on the company and the specifics of the analysis.

4.2.6 (Continued).

Strengths (including data)	Weaknesses	Availability	Barriers/Desired Improvements
Can allow companies to cost-effectively allocate their security mitigation resources.	Results rely on a lot of subjective information.	Publically available by purchasing the book.	None

4.2.7 CCPS Guidelines: Semi-Quantitative Risk Assessment Process

See also: §3.3.1

Sponsor/Dev.	Users/Uses/Decisions	Output(s)	Applicable Mode(s)	Methodology or Approach
Center for Chemical Process Safety of the American Institute of Chemical Engineers	This model is designed to assist chemical companies manage their global transportation risks in a consistent framework. It includes determining which materials should be considered, the level of analysis appropriate, and the areas where mitigation actions may be warranted. Supported decisions cover a wide range of corporate activities and stakeholders. For any issue that needs more detailed analysis than a qualitative analysis, a semi-quantitative risk analysis step is conducted.	For risk indexes, the result for each option is a single value. For risk matrices, the result for each option is a single risk priority value.	All modes	Adds some quantification to the qualitative approach. Techniques described include risk indexes and risk matrices. Risk index: most often the sum of several values corresponding to the attributes of concern (such as frequency of shipment, previous incidents, shipment quantity, and hazard rating). Values for each attribute might be determined on a scale from 0 to 10 and may be optionally combined with attribute weights. Options are assessed by the resulting single number. The higher the risk index, the greater the risk. Risk mitigation strategies can be easily evaluated by adjusting the attribute values to reflect them and comparing the resulting risk index to the original one. Risk matrix: generally constructed with likelihood on the vertical axis and consequence on the horizontal axis. Categories are used for the likelihood or consequences, rather than actual values. Each cell in the matrix corresponds to a likelihood category and a consequence category and is assigned a risk priority, such as a value from 1 to 4.

Component		Key Sources of Data	Assumptions, Limitations, Biases, and Availability
Safety	Frequency	Quantification (or weighting) of these elements may be appropriate: accident rate, route miles, and trips per year.	It is important to consider the integration of data from different sources or for different modes, variations in data quality, and confidence in data sources.
	Probability	Release probability may be estimated by using route-specific data (infrastructure characteristics and speed information) and the type of accident to develop a set of scenarios, including the release size, with probabilities.	None
Security	Threat	NA	NA
	Vulnerability	NA	NA
Consequence		Quantification (or weighting) of these elements may be appropriate: release types and size, container size, material conditions, range of potential consequences, meteorological conditions, sensitive areas along the route (people, property, and environmental receptors).	Models are generally needed to take the input data and estimate the consequences.

Strengths (including data)	Weaknesses	Availability	Barriers/Desired Improvements
Can be performed and used by many different stakeholders (not just risk experts); cost-effective; can consider many risk-related factors, and supports comparative analysis.	It is important to consider the integration of data from different sources or for different modes, variations in data quality, and confidence in data sources.	Publically available by purchasing the book.	None

4.2.8 Chemical Manufacturer Risk Assessment Framework

See also: §3.3.4

Sponsor/Dev.	Users/Uses/Decisions	Output(s)	Applicable Mode(s)	Methodology or Approach
Large Chemical/Plastics Manufacturer	Corporate EHS performs the assessments and makes recommendation to the operations department on packaging, shipping, and mode choice decisions.	Some assessments are summarized in 6- or 9-block risk matrices (likelihood and consequence categories on the axes). Reports are generated to present all risk assessment results.	Primarily highway, rail, and marine. Limited air shipments (discouraged) due to the quantities typically shipped. Pipeline is used for incoming materials only.	The risk assessment process is invoked when there are new movements (from new products, customers, or route options) or when larger quantities result from increased sales. Most assessments are qualitative and focus on identifying the significant additional risks to human health or the environment. They include information from past experience and industry knowledge. In the qualitative approach, they look for ways to reduce handling and transfers, travel through sensitive areas. Quantitative assessments are used occasionally when the risks are perceived to be great enough to warrant them and their focus tends to be on the consequences. Transportation of most of their very high-hazard materials has been eliminated by co-locating manufacturing at the point of use.

Component		Key Sources of Data	Assumptions, Limitations, Biases, and Availability
Safety	Frequency	Trip length is a factor, but most of the focus is on past experience and the amount of handling and transfers that are involved. Internal data are used. Shipment size is considered and if the quantities are sufficient, they will examine building storage capacity onsite so that they can use larger packages and reduce the number of shipments.	Increased mileage is more important in some parts of the country than others, based on where their operations are. For example, increased mileage in snow-prone areas is particularly undesirable. The focus on limiting handling is based on industry consensus that most of the accidents involve loading/unloading operations and transfers.
	Probability	The most stringent container readily available that is appropriate for the product is used, even if it well-exceeds the requirements.	No analysis is performed to quantify the risk reduction of container selection.
Security	Threat	NA	Security is not used as a criterion in their decision processes that involve risk assessment; however, they do ensure that their carriers have adequate security plans.
	Vulnerability	NA	
Consequence		A lot of the information that is used comes from third parties: populations and environmentally sensitive areas along their routes, and the presence of bridges and tunnels are primary factors. Chemical information is critical in assessing the nature of potential impacts (physical and chemical properties are obtained from internal company product information).	Data to support detailed analyses can be difficult to obtain. The consequence analysis often focuses on specific parts of the route to identify a reasonable worst-case scenario rather than developing a score that considers all parts of the route.

Strengths (including data)	Weaknesses	Availability	Barriers/Desired Improvements
Looks at all possible modes for their shipments (all sites have both rail and truck options and some major sites have marine access as well).	The analysis neglects probability and security components that might provide a more comprehensive view of potential risks.	Analyses are business sensitive, but are shared with their carriers.	A single location from which to obtain the specific route-specific information is needed, including GIS information.

4.2.9 Chemical Terrorism Risk Assessment (CTRA) Process

See also: §3.4.3.1

Sponsor/Dev.	Users/Uses/Decisions	Output(s)	Applicable Mode(s)	Methodology or Approach
Department of Homeland Security Science and Technology Directorate Chemical Security Analysis Center	The model is to provide an end-to-end assessment of the threat of terrorist use of toxic chemicals. It examines the terrorist use of chemical warfare agents and toxic industrial chemicals. The scope includes, but goes well beyond transportation. The component models are used by external (to CSAC) policy makers across government to assess the relative risk of representative scenarios (e.g., what is the riskiest scenario for a given chemical?), the relative risk of representative chemicals, how chemical risks change when examining different scenarios (e.g., different chemicals may be more suited for indoor, outdoor, or food-based scenarios). The purpose is to raise awareness, determine the relative risks. Examples of uses: HHS for developing medical countermeasures for chemical exposure; DHS for identifying the need for detectors for certain chemicals; and the National Security Council for developing communication processes.	The outputs from one component model are used to feed subsequent models. Ultimately, there is a single risk number for each scenario or chemical being analyzed. These can be aggregated as needed.	All modes except air: bulk and non-bulk highway, rail, barges, pipeline. They also consider that some storage vessels are transportation vessels. Depending on the specific analysis, pipeline may be considered a fixed site or a transportation facility.	The CTRA is a combination of separate models. The models examine all routes of exposure: inhalation, ingestion, and percutaneous. They examine both lethal and non-lethal effects. The underlying framework is probabilistic risk assessment (PRA). The event tree is broken out in great detail. The different branches in the event tree can be combined as the user needs. Each event tree branch defines a scenario and the frequencies are applied along the path down that branch. Consequences are determined by the appropriate model for that scenario and multiplied by the overall frequency. The only difference from a traditional PRA is the inclusion of terrorist intention. The methodology supports large and small accidental releases as well as large intentional releases.

Component		Key Sources of Data	Assumptions, Limitations, Biases, and Availability
Safety	Frequency	NA	NA
	Probability	NA	NA
Security	Threat	Threat and vulnerability are considered in concert in the assignment of the event tree probabilities. The components are: (1) terrorist capability, (2) intent, (3) ease of acquiring the chemical, (4) terrorist knowledge of the chemical, (5) ability to carry out the attack, (6) probability of interdiction, and (7) probability of failure. CSAC actively engages the law enforcement community regarding the likelihood of the scenario being interdicted. For eliciting expert opinion, CSAC uses the CREATE methodology. Industry tends to prefer GroupThink for this, but CSAC usually does not have an expert for every single chemical they consider in an analysis. The CREATE method is not focused on a single chemical. They generally use the model that the experts they are using are most familiar with, to facilitate obtaining the data.	The PRA allows for computing uncertainties; CSAC identifies unreliable data points and captures uncertainties around that point. It often reports risk with an error range using the *t* distribution.
	Vulnerability		
Consequence		All routes to the consequences are considered, each with their own models. For inhalation, HPAC (for outdoor consequences) and CONTAM (for indoor consequences). CONTAM is a multi-zonal model and the number of zones used is dependent on the scenario. The SCIPUFF model (which also is a collection of models) is also used. CSAC generally uses the default model values as suggested by the scenario. Different population densities and locations are used to get a range of consequences for a given scenario. For percutaneous, CSAC employs a statistical model that looks at the size of the contact area (often the hand), the permeability of skin, and other materials that may push impermeable materials through skin. For ingestion, CSAC uses a stock and flow model that considers how much can get into the food supply, how it is distributed, and how many people would ultimately be affected. Toxicity values for over 120 chemicals, the three routes of exposure, and three injury severities (lethal, severely injured, and moderately injured) are used as input data into the event tree.	For the LD50 values, for example, they need probability slopes and the toxic load exponent. For the injury categories, CSAC is lacking some of the data needed related to the severely and moderately injured categories; it makes assumptions where necessary. The lethal dose data are much more readily available. CTRA uses average container sizes for the materials as actually transported. It uses a modified Latin hypercube Monte Carlo approach for sampling the range of container sizes possible, centered on the mean, but not using only the mean size.

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4.2.9 (Continued).

Strengths (including data)	Weaknesses	Availability	Barriers/Desired Improvements
Because of the Secret classification of the CTRA results, it can use complex, sensitive information. The CTRA is comprehensive, providing an end-to-end assessment. While there are still some items not considered, it does estimate the full nature of chemical risk.	Because of the Secret classification, distribution of any results is limited, so that some entities that could benefit from the results are not able to do so. There are weaknesses in some of the models that are included in the CTRA. Transportation coverage is one of these (leading to the HM-12 project). CTRA treats each mode separately and does not look at intermodal shipments.	The CTRA involves a significant amount of intelligence information, leading its results to be classified Secret. The results are shared with other entities that can take action to address identified risks (see the Users entry).	There are a lot of data needs. The biggest is better toxicology data across the board. These data are needed for the three injury categories and the three routes of exposure for each of the 120+ chemicals (more than 1,080 toxicity values). A desired improvement is to address the weaknesses.

4.2.10 Fedtrak

See also: §3.7.9

Sponsor/Dev.	Users/Uses/Decisions	Output(s)	Applicable Mode(s)	Methodology or Approach
The Kentucky Transportation Center at the University of Kentucky for Transportation Security Administration	Fedtrak is being developed to provide data and information for use by the federal government for real-time situational awareness of high-security risk highway hazmat shipments. The Fedtrak risk methodology will provide decision support: • Help security specialists prioritize the trucks that should be closely monitored. • Help security specialists prioritize which trucks require additional analysis and investigation based on anomalies that may indicate potential security concerns. • Support real-time law enforcement and emergency response through state fusion centers in the event of a crisis situation (e.g., hijacked truck). • Provide situational awareness to local, state, and Federal authorities about the potential for high-risk shipments passing through specific geographic regions. • Quantify risk reduction through identification and assessment of security countermeasure effectiveness and other risk management strategies. • Allow carriers to determine if alternate routes exist that may be preferred to the planned route.	The model will provide both static safety and dynamic security risk scores for each shipment along a planned route. Safety risk scores are computed at the planning stage and remain static. Security risk scores can be computed for a route at the planning stage (identifying the locations of high risk along the route), but will be automatically computed as each new location coordinates are received, providing a near-real time view of each shipment's risk.	Highway	Safety methodology considers frequency, probability, and consequence and security methodology considers threat, vulnerability, and consequence. Both risk measures are relative scores and are not combined together, but considered separately. Security risk would be computed based on the current location of the vehicle using both static and dynamic components and the safety risk would be static for a given planned route. The security risk for an entire route would be the maximum risk at any location along that route. Conversely, the safety risk for a route is a sum of all the risks along that route, calculated at the segment level.

Component		Key Sources of Data	Assumptions, Limitations, Biases, and Availability
Safety	Frequency	Accident frequency is based on national-level data tied to roadway functional classification. Alternately, state-supplied data can be used. The accident rate per mile is multiplied by the length of each segment to get the frequency for that segment.	There is only one scenario for safety risk. Generally, data do not support frequencies (or probability or consequence) by specific type of crash or its cause.
	Probability	The conditional probability of a release, given a crash, is tied to the packaging used for each shipment and the material being shipped. One source is the dated Harwood *et al.* paper from 1993. The proposed approach is to use subject matter expert (SME) elicitation with the assistance of a Kent Scale to assign conditional probabilities. These would range from practically impossible to certain.	Directly applicable data are not readily available. The Harwood paper does not address many of the high-security hazmat that Fedtrak is designed to assess and monitor (e.g., radiological materials and explosives).

4.2.10 (Continued).

Component		Key Sources of Data	Assumptions, Limitations, Biases, and Availability
Security	Threat	Static factors (determine the threat baseline): attack mode, type of hazmat, and trailer/container type. Static factor values would be derived from SME elicitation. Dynamic factors: nearby high-population density areas (Census data) and CIKR (from DHS or the states). SME elicitation will derive a function to correlate different levels of population or CIKR to threat values.	Attack modes that define the style of attack and the weapons used are combined with a hazmat type (or class) and a trailer/container type into a scenario. Ten attack modes and hundreds of scenarios are considered. These scenarios are the basis for estimating the threat, vulnerability, and consequence values. The threat baseline reflects the typical security posture for the various scenarios. The DHS CIKR list is classified Secret and may present issues regarding its availability or the communication of CIKR component values beyond.
	Vulnerability	The likelihood that a terrorist will be successful based on the challenges in carrying out each attack. Two separate vulnerability measures are estimated, the likelihood that the terrorists do not fail on their own due to the inherent nature of the scenario and the likelihood that the terrorists will be able to overcome security measures. These are determined by SME elicitation supported by the use of Kent scales assigning numeric values to the various options for each variable.	The same scenarios that are discussed for threat apply here.
Consequence		Components include the affected population, CIKR, environmentally sensitive areas, and economic impact. A consequence equivalent scale will be used to combine these four components together into a single measure that reflects an order of magnitude difference between the possible values for the overall measure (0 to 4). Data sources include the Emergency Response Guidebook (impact areas), the Census Bureau (affected population), USGS and National Park Service (environmentally sensitive areas), the Gross Domestic Product (GDP, for per-capita economic value), and DHS and the states (CIKR).	The same scenarios that are discussed for threat apply here. The consequence equivalence table will have a significant impact on the relative importance of the four different components. However, this approach allows these different consequence types to be considered in a single assessment without the need for arbitrary weights. The economic impact component is designed to capture the relative difference in the costs that would result from a hazmat release in areas of higher or lower GDP. It does not capture the expected value of the actual economic impact.

Strengths (including data)	Weaknesses	Availability	Barriers/Desired Improvements
The security risk methodology supports the quantification of risk reduction through countermeasures or risk mitigation strategies. This includes reduction of the maximum risk and the cumulative reduction of route risk.	The system relies on a complete picture of Tier 1 HSSM shipments across the country for overall situational awareness. Still in the development stage.	The planned system will be SSI at a minimum and will, most likely, be classified Secret. Onsite operators and designated security officials would have direct access. Carrier-specific data (such as route safety scores and high-level security information) would be available to the carrier via online portals.	Sufficient funding and industry buy-in to develop an operational pilot and subsequent system that addresses industry privacy concerns.

4.2.11 GeoCTA

See also: §3.4.1.3

Sponsor/Dev.	Users/Uses/Decisions	Output(s)	Applicable Mode(s)	Methodology or Approach
Oak Ridge National Laboratory Center for Transportation Analysis	Informs emergency planning and response decisions by security managers and first responders, with a focus on transportation and other critical infrastructure in high-threat urban areas.	Population risk and consequence indices and GIS-based maps with information on critical and high-value locations.	All modes	GeoCTA provides a map of a transportation system of interest to the user, displaying spatial, contact, and descriptive information for sensitive locations in the surrounding area, including population centers, iconic potential targets, hazardous material facilities, etc. The tool calculates the population at risk for a one- or two and one-half mile radius from any user-specified location within the map. Additionally, spatial analysis tools provide summary information on mapped layers based on user-defined lines and polygons.

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4.2.11 (Continued).

Component		Key Sources of Data	Assumptions, Limitations, Biases, and Availability
Safety	Frequency	NA	NA
	Probability	NA	NA
Security	Threat	NA	NA
	Vulnerability	NA	NA
Consequence		Population data is stored within the system.	While much of the data stored within GeoCTA is restricted, population data is freely available from the U.S. Census Bureau and day/night population estimates are available through FEMA as part of the HAZUS database.

Strengths (including data)	Weaknesses	Availability	Barriers/Desired Improvements
The tool contains a large number and variety of spatial data layers, including all of the data necessary for use of the system. Output population metrics include day and nighttime estimates, rather than a single count. Graphical output, in the form of GIS-based maps, facilitates comprehension of a variety of spatially interdependent data layers for quick, informed decision making. The tool can be applied to any location within the United States. The tool has been designed to allow for easy integration of new customized spatial analysis functions.	While the potential exists for modification of the tool, it was developed to be population focused and does not currently account for variables such as type and amount of hazmat, etc., or risks to other receptors.	GeoCTA contains data restricted to Federal use and is not distributable. Theoretically, with the exclusion/substitution of restricted data, the model could be made publically available.	The primary barrier to the widespread use of this tool is the inaccessibility of the tool in its current form. The removal or replacement of sensitive system data for distribution and development of the tool beyond population-focused analyses is desired.

4.2.12 Institute of Makers of Explosives Safety Analysis for Risk (IMESAFR)

See also: §3.3.3

Sponsor/Dev.	Users/Uses/Decisions	Output(s)	Applicable Mode(s)	Methodology or Approach
Institute of Makers of Explosives	IMESAFR is used by explosives manufacturers and regulators to gage explosives risks at ports and industrial facilities.	IMESAFR outputs include a measure of the probability of fatalities and major and minor injuries from an explosion along with a GIS-based map of explosive effects and risks to surrounding infrastructure.	IMESAFR is applicable to facilities (e.g., ports, industrial sites, safe havens, etc.) associated with any mode of transportation.	Probability of fatalities and injuries is calculated based on user input regarding the type of explosive, type of activity, and building placements and characteristics. Users can select from pre-defined, system-stored values to specify input parameters. Casualties are calculated according to the general risk equation: Probability of casualty = Probability of event * Probability of casualty given an event * exposure. While IMESAFR was designed for safety applications, security may be considered by multiplying frequencies by scaling factors to account for threat level increases.

Component		Key Sources of Data	Assumptions, Limitations, Biases, and Availability
Safety	Frequency	IMESAFR internal explosive accidents database.	Data is stored internally and is derived from IME member surveys, an IME explosive accidents database, and ATF data. Frequency data for military uses are used in the absence of reliable commercial frequency data.
	Probability	IMESAFR internal probability data.	Data is sourced from DOD testing data, which typically focuses on quantities of explosives that are larger than those typically on-hand in commercial activities.

4.2.12 (Continued).

Component		Key Sources of Data	Assumptions, Limitations, Biases, and Availability
Security	Threat	IMESAFR internal explosive accidents database. (Frequency can be multiplied by a scaling factor to account for security threats.)	Data is stored internally and is derived from IME member surveys, an IME explosive accidents database, and ATF data. Frequency data for military uses are used in the absence of reliable commercial frequency data. Frequency data used for safety modeling is scaled according to threat levels to model security risks.
	Vulnerability	IMESAFR internal probability data.	Data is sourced from DOD testing data, which typically focuses on quantities of explosives that are larger than those typically on-hand in commercial activities.
Consequence		User input of building locations and personnel.	Consequence estimates are given for expected and worst-case scenarios and, by default, are strongly conservative (e.g., 100% fatalities assumed at an intra-plant level, small quantities of explosive are assumed to behave like large quantities).

Strengths (including data)	Weaknesses	Availability	Barriers/Desired Improvements
The storage of model parameter values within the system reduces the data gathering requirements of users and allows selection of appropriate input values simply by being on-site. Map output aids in user comprehension and communication of model results. In the most recent version of the software uncertainty is calculated and presented separately and conservative model assumptions may be switched on or off.	Commercial explosion frequency and effects are often not characterized well enough to provide reliable data. In the absence of this data, IMESAFR employs data derived from military testing and historical frequencies.	Commercially available	Desired improvements to model data include: 1) additional data on the frequencies of commercial explosive accidents, 2) additional data on the effects of the types and quantities of explosives encountered in commercial applications (vs. military), and 3) data on the probability and characteristics of sympathetic detonation of explosive devices in proximity to one another. IMESAFR is currently not applicable to in-motion explosives.

4.2.13 Pipeline Risk Management Manual Risk Assessment Method

See also: §3.4.2.5, 3.7.7

Sponsor/Dev.	Users/Uses/Decisions	Output(s)	Applicable Mode(s)	Methodology or Approach
W. Kent Muhlbauer	Pipeline industry members and governmental stakeholders use this approach to identify sections of pipe with relatively elevated risks of leakage in order to minimize potential damages to human health and the environment.	Outputs include an overall probability of failure index and its constituent indices for probabilities of third-party damage, corrosion, design issues, and incorrect operations; a leak impact (consequence) factor; and a relative risk score for each section of pipeline being studied.	Pipeline	The Pipeline Risk Management model produces a relative risk score for individual sections of pipeline. The general risk equation is in the form of: Risk = event likelihood x event consequences. Likelihood is based on the potential for third-party damage, corrosion, design issues, and incorrect operations, while consequences focus on human and environmental impacts. Users assign scores to factors within each of the four likelihood categories and the consequence factor. The scores are summed for all likelihood categories and divided by the consequence factor to produce a relative risk rating. The manual provides further guidance on converting relative risks to absolute values; considering alternative consequence measures (i.e., service interruption), and making modifications to model elements.

Component		Key Sources of Data	Assumptions, Limitations, Biases, and Availability
Safety	Frequency	NA	NA
	Probability	Probability of a pipeline failure is broken down into probabilities of third-party damage, corrosion, design issues, and incorrect operations. While selected reference values are provided within the manual text and appendices, data for these factors must primarily be collected by the user through pipeline inspections and surveys.	The model was developed to take advantage of a wide range of levels of data detail and availability. While much of the data discussed in the manual must be acquired through pipeline surveys and inspections, the model allows for the use of sources such as expert knowledge and estimation in place of exact measured values.

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4.2.13 (Continued).

Component		Key Sources of Data	Assumptions, Limitations, Biases, and Availability
Security	Threat	NA	NA
	Vulnerability	NA	NA
Consequence		Consequence values are dependent upon chemical characteristics, spill size, dispersion, and receptors. A variety of critical chemical data is provided within the manual itself and can be supplemented with MSDSs and a variety of publicly available chemical databases. The manual further provides values and methods for estimating spill size and dispersion. Receptor information can be acquired from the U.S. Census Bureau, in the case of population, and from federal data layers on hydrology, park lands, etc., available through the National Atlas.	The data required for calculating consequences are largely publicly available or easily estimated given sample values presented within the manual.

Strengths (including data)	Weaknesses	Availability	Barriers/Desired Improvements
As a scoring/index model, the model provides easily understandable and comparable output relatively quickly. The model is flexible, able to use a wide range of input data and data precision, can be modified to consider alternative consequence metrics, and allows for its relative output values to be converted into absolute risk numbers. The model is a standard industry tool, which facilitates communication about the model, data, and results, and increases potential access to model resources through the existence of a user community.	As with any scoring model, subjectivity may affect model results and results do not lend themselves to comparison with other modes of transportation. While the manual provides a great deal of guidance and sample input, the model, particularly the likelihood component, is dependent upon a large amount of user-collected survey or inspection data.	Available for public purchase	While the model is designed for a wide range of input data precision, the funding required to gather adequate input data is a barrier to the model's wider use.

4.2.14 RADTRAN

See also: §3.4.1.2

Sponsor/Dev.	Users/Uses/Decisions	Output(s)	Applicable Mode(s)	Methodology or Approach
Department of Energy, Office of Environmental Management, Sandia National Laboratories	National and International radiological materials transporters, specifically DOE facilities. Calculates expected radiological consequences of incident-free radioactive materials transportation and associated accident risks. Initially created to calculate consequences for environmental impact assessments.	Expected Radiological Consequence Since its inception, RADTRAN has been used in most radiological transportation EA and EIS. RADTRAN also has the capabilities to conduct specific radiological transportation accident and sabotage scenarios.	Highway, water, rail	RADTRAN combines user-determined demographic, routing, transportation, packaging, materials, and radionuclide data with meteorological data (partly user-determined) and health physics data to calculate expected radiological risk and consequences of incident-free radioactive materials transportation and associated accident and sabotage events. All the user inputs (14 categories) are fed into an algorithm that contains published dose rate data, and expected radiological exposure to persons is calculated with regards to: • Groundshine • Cloudshine • Inhalation • Resuspension • Overall

Component		Key Sources of Data	Assumptions, Limitations, Biases, and Availability
Safety	Frequency	Accident rates along a segment of the route, generally obtained from state DOTs.	The User Guide offers guidance on identifying Accident Rate values along routes through state DOT data or through two national data sets that determine a value for each state. The frequency of an accident is not directly used in the RADTRAN model, but the user can take the expected radiological consequences and combine them with accident frequencies to determine risks.

4.2.14 (Continued).

Component		Key Sources of Data	Assumptions, Limitations, Biases, and Availability
	Probability	Probability data, such as probability fractions for various accident severities, packaging details, and data describing the transporting vehicle, must be supplied by the user. The RADTRAN user manual suggests several sources for estimating these values.	While it is input by the user, the RADTRAN user guide does offer three references from which probability fractions may be obtained.
Security	Threat	NA	NA
	Vulnerability	NA	NA
Consequence		Population data is based on spatial Census data. Shipped material and its dispersion/clean-up data are user inputs. Traffic data in the model was originally sourced from the Bureau of Transportation Statistics (BTS) data and has been updated by Sandia National Laboratories. Dose rate data is built into the model. Users are able to input and vary the following model parameters: • Vehicle density along routes • Population density • Persons per vehicle • Fatalities per accident • Farm fraction, or the fraction of roadway that is used for agriculture (effects ingestion dose) • Data surrounding mid- to long-term stops in transportation • Weather conditions • Release, aerosol, and breathable fractions • Isopleth areas Additionally, users can decide to use average values for parameters involving the exposure levels, such as: • Shielding of buildings • Fraction of people outside • Distance of maximum exposure • Average breathing rates • Distance of vehicle to sidewalk, right-of-way and other vehicles going in either direction	Limitations: A recent study has claimed that the RADTRAN Dose Rates are slightly conservative. The amount of user data points requires a substantial knowledge of where to find certain data sets, their availability and how current the data is. For certain data points, DOE offers some guidance on articles to use or databases to search, such as using Bureau of Transportation Statistics' data to calculate fatality data. In other cases, such as for the Weather or Radionuclide inputs, TRAGIS offers the user the option to input their own data or use data already available in the tool.

Strengths (including data)	Weaknesses	Availability	Barriers/Desired Improvements
Highly customizable by user (over 70 individual data points that can be input or adjusted by the user). Most importantly, users can adjust the parameters surrounding the probability and effects of an accident. Can be used in conjunction with WebTRAGIS and TRAGIS.	Analysis is strongly conservative and is based on maximum-exposed individual. Likewise, the dose rates used have been found to be highly conservative. The model requires substantial user input, which can introduce errors.	Public, including to international entities, but must apply for access.	Interviewee expressed a desire to have RADTRAN validated, and improved upon, by the security and safety community.

4.2.15 Rail Corridor Risk Management System (RCRMS)

See also: §3.2.1, 3.4.2.3

Sponsor/Dev.	Users/Uses/Decisions	Output(s)	Applicable Mode(s)	Methodology or Approach
Railroad Research Foundation / Association of American Railroads	RCRMS is maintained by the rail industry to meet the federal requirements of HM-232E: Enhancing Rail Transportation Safety and Security for Hazardous Materials Shipments. It is designed to support routing determinations for high-hazard materials, considering both safety and security. FRA inspectors can review analysis results to verify that the carrier followed the regulation in making their route choices.	RCRMS provides a single risk metric that combines safety and security as well as the two individual risk scores. All risk scores are rounded and an attractiveness measure helps users distinguish between routes with similar risk scores. It also provides route-level totals for each of the 27 metrics that the federal regulations require carriers to consider.	Rail [only for toxic inhalation hazard (TIH), explosive, and radioactive materials].	Carriers identify all the material origin-destination combinations that require analysis and determine the viable route alternates for each movement. Risks for safety and security are computed at the route segment level and summed for safety; the maximum value (with some adjustments for routes through multiple HTUAs) is taken for security. In addition, the safety risk is comprised of a link (or segment) risk and a switching station risk that are summed together.

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4.2.15 (Continued).

Component		Key Sources of Data	Assumptions, Limitations, Biases, and Availability
Safety	Frequency	Carrier provided: annual volume shipped Rail network-derived attributes: route length; mainline accident rates, which are a function of traffic density, method of operation (e.g., signalized or 'dark territory'), and FRA track class combined with historical FRA accident data; and switching yard accident rates.	Yard accident rates where switching occurs are based on a one-mile distance. Accidents rates are proprietary to AAR.
	Probability	CPRs calculated for each of the DOT tank car specifications by Treichel et al., 2006, are used. The CPR for Isotainers and intermodal portable tanks utilize generic values.	Speed is considered in determining the CPR to account for the reduced likelihood that lower speed derailments would result in a breach of the railcar. Speeds are provided by the railroads or deduced from the track class' maximum allowable speed.
Security	Threat	Threat estimates consider factors such as availability of hazmat for attack, proximity to iconic targets, venues, or other CIKR, and presence in TSA-specified HTUAs. Other sources: daytime and nighttime population from FEMA HAZUZ data that are in HTUAs, other urban areas, or non-urban areas.	Unclassified CIKR data and definitions for HTUAs were provided by TSA. FEMA HAZUS data are available to entities that request a copy and have a legitimate need for the data.
	Vulnerability	Characterized with consideration of any specific detection and deterrence measures in place along a route segment that would reduce the vulnerability.	Scoring for this factor is considered SSI.
Consequence		Environmental: water bodies (USGS National Hydrography Dataset), parks (Administrative Boundaries of National Park System dataset) Population: daytime and nighttime population from FEMA HAZUS data Carriers may also consider factors that are not directly embedded in the risk equations. Carrier provided: presence of nearby railroad facilities (storage and repair facilities), miles with different levels of passenger traffic, operating speed, mileage, transit time, and any known deficiencies in crew training and skill level. Items that are reported for each route that are not explicitly listed above: miles of each route in each track class, miles with a grade more than 2.5%, miles of signalized and manual operation, listing of wayside detectors, counts of grade crossings and switch points, route miles greater than 10 miles from police and fire stations (data from HAZUS), past incidents (from FRA data)	The larger of the daytime or nighttime population values is used for the consequence measure for each route segment. The exposure zone is taken from the Emergency Response Guidebook and adjusted when water-reactive materials are involved, based on the presence of water bodies in close proximity along the route. Similarly, the environmental exposure also considers those areas that are a short distance from the route. Quantities in a single shipment are not directly used to estimate exposure distances, the large spill protection distances in the ERG are used as the basis for all analyses. Users have different perspectives on the value of the unscored factors and may choose to make different decisions based on similar information.

Strengths (including data)	Weaknesses	Availability	Barriers/Desired Improvements
Leverages the FRA national rail network and railroad-specific data to provide carriers with a routing decision support tool with a government-vetted risk methodology. RCRMS provides relative risk scores for comparing alternate routes. The integration of safety and security risks is useful for railroads with a very large number (thousands) of analyses to run. The best available data on rail accident rates, container release probabilities, and network link characteristics are used. The GIS capability allows spatial differences in the routes that affect risk to be assessed.	Implemented by all Class I railroads and many others – the relative risk scores are not as useful to some short line railroads with only one possible route to analyze. The integration of safety and security scores uses a fixed weighting. There is no methodological approach for including some data that are available. These include the presence of wayside detectors and the frequency and location of track turnouts. Some research has been performed to develop methodologies to include these factors, but the research is not yet complete.	Proprietary to the RRF. One railroad cannot see railroad-specific information from any other railroad.	Future work to complete development of an approach to include the attributes listed in the weaknesses section is desired.

4.2.16 Readiness and Resiliency Assessment System

See also: §3.4.1.3

Sponsor/Dev.	Users/Uses/Decisions	Output(s)	Applicable Mode(s)	Methodology or Approach
Oak Ridge National Laboratory Center for Transportation Analysis	RRAS is used by the Transportation Security Network Management office of the TSA to determine the nation's transportation system's ability to prevent, respond to, recover from, and continue operating through any type of terrorist attack (e.g., chemical, biological, explosive, nuclear, etc.). Additional applications of the framework include assessment of threats, vulnerabilities, and protective measures; security resource allocation; dynamic assessment for event mitigation; and transportation system planning.	RRAS outputs are relative values describing readiness and resiliency that categorize a transportation asset or system as "Fully Prepared," "Moderately Prepared," or "Unprepared."	All modes	RRAS assesses relative risks to transportation assets or groups of assets/systems. Measures of the scope, duration, magnitude, and severity of threats to these resources are used in conjunction with asset vulnerabilities, mitigation factors, and consequence metrics to calculate relative risks. Risk values are then combined with measures of domain awareness and response capabilities to calculate a readiness and resiliency score.

	Component	Key Sources of Data	Assumptions, Limitations, Biases, and Availability
Safety	Frequency	NA	NA
	Probability	NA	NA
Security	Threat	Threats and scenarios are user-defined.	TSA utilized input values and data are security-sensitive and unavailable publicly.
	Vulnerability	Transportation infrastructure data can be sourced from ORNL and BTS; security and response resource information can be acquired through FEMA.	Most of the TSA-utilized data is security-sensitive and unavailable publicly; however, ORNL and BTS transportation infrastructure data are freely available.
Consequence		Population and economic information, which can be acquired from the U.S. Census Bureau	Most of the TSA-utilized data is security-sensitive and unavailable publicly; however, U.S. Census data is freely available.

Strengths (including data)	Weaknesses	Availability	Barriers/Desired Improvements
RRAS is capable of assessing readiness and resiliency of a transportation network on a national scale, but is applicable across all levels and modes of transportation systems.	The framework has been designed to employ data that is largely sensitive and not distributable. It is facility or system-specific, does not address the interdependence of systems and, as such, currently focuses more on readiness than resiliency.	RRAS is security-sensitive and not distributable. With the exclusion/substitution of sensitive data, the model could theoretically be made publically available.	Further development of resiliency assessment is desired, as the framework is currently more focused on readiness.

4.2.17 Risk-Based Preventative Radiological/Nuclear Detection Resource Allocation (CREATE Model)

See also: §3.4.1.3

Sponsor/Dev.	Users/Uses/Decisions	Output(s)	Applicable Mode(s)	Methodology or Approach
National Center for Risk and Economic Analysis of Terrorism Events	Informs emergency management and terrorism officials' decisions about the type and placement of radiological/nuclear detection devices in order to prevent or deter terrorist attacks using these materials.	Probability of detection; cost estimates of resource deployment and system success or failure, etc.	Primarily highway, but also entry points for air and barge.	A target, its related transportation network, and proposed detection system are identified and represented as a link and node network. The probability of detection is calculated for each access path to the target, then for the network as a whole. Finally, the impacts and costs associated with system deployment are calculated, enabling comparisons of various detector deployment schemes.

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4.2.17 (Continued).

Component		Key Sources of Data	Assumptions, Limitations, Biases, and Availability
Safety	Frequency	NA	NA
	Probability	NA	NA
Security	Threat	User-defined	Prioritized list of targets is predefined by governmental users; this information is typically not available to the public. Targets may be analyzed individually, making threat constant within the analysis.
	Vulnerability	Number and route of access paths to target can be sourced from governmental sources, such as the BTS or from private GIS vendors. Number/mode of detectors is user-defined. Individual detection probabilities for detectors must be measured or sourced from vendors.	Highway networks are available from governmental and private GIS vendors. Detection, false detection, and false alarm rates may be difficult to obtain/costly to measure or poorly characterized.
Consequence		Data requirements vary depending on user goals. The U.S. Census Bureau and the BTS are key sources for estimating impacts to populations and traffic flow.	Census and BTS data are freely available to the public.

Strengths (including data)	Weaknesses	Availability	Barriers/Desired Improvements
Applicable and transferrable to any highway location; as an economic model, can be used with a focus on minimizing a wide array of consequence (costs of non-detection, cost of traffic delays, etc.)	Detection, false detection, and false alarm rates may be difficult to obtain or poorly characterized.	Is an academic model for government institution (Cal EMA) and has been presented publicly.	Barriers to the use of this model are low, with the primary potential impediment being adequately accurate detection probability information.

4.2.18 TRACC

See also: §3.4.1.3

Sponsor/Dev.	Users/Uses/Decisions	Output(s)	Applicable Mode(s)	Methodology or Approach
Oak Ridge National Laboratory Center for Transportation Analysis / Miss. State University	TRACC monitors positions of hazmat barges and compares them to nearby barges and historical trip information to identify potentially high-risk situations. Identified events are reported to stakeholders, such as Homeland Security, first responders, law enforcement, barge companies, and fleeting managers to aid incident avoidance and response readiness.	GIS, web-based reports of anomalous/barge movements are disseminated to governmental agencies, responders, and route managers.	Barge	TRACC is a web-based tool that gathers GPS reports from barges and determines the barges' positions on a river system. The positional information is used in concert with historical route data to predict the path of each barge. The predicted path is compared against historical route data and location information for nearby barges to detect unexpected stops or movements, communication lapses, or buildups of hazardous materials at a given location.

Component		Key Sources of Data	Assumptions, Limitations, Biases, and Availability
Safety	Frequency	NA	NA
	Probability	Pertinent vessel information (e.g., current / historical positions, commodities, etc.) is reported by barge and tow companies and GPS tracking devices.	Continuous GPS location reporting is not currently standard; many barge reports are submitted manually at frequencies as low as once per day.

4.2.18 (Continued).

Component		Key Sources of Data	Assumptions, Limitations, Biases, and Availability
Security	Threat	High population locations and areas of critical infrastructure are identified by governmental agencies and system stakeholders and stored in an internal system database.	While population information is readily available through the U.S. Census, access to data on government-defined critical infrastructure is restricted.
	Vulnerability	Pertinent vessel information (e.g., current / historical positions, commodities, etc.) is reported by barge and tow companies and GPS tracking devices. Points of interest and river network information are stored in an internal system database.	Continuous GPS location reporting is not currently standard; many barge reports are submitted manually at frequencies as low as once per day.
Consequence		High population locations and areas of critical infrastructure are identified by governmental agencies and system stakeholders and stored in an internal system database.	While population information is readily available through the U.S. Census, access to data on government-defined critical infrastructure is restricted.

Strengths (including data)	Weaknesses	Availability	Barriers/Desired Improvements
With the exception of vessel-specific information, data needed to use the tool are stored within the system database. Output is web-based and delivered in as graphics (map) and text, facilitating quick, informed comprehension and decision making.	Application of the tool is limited until continuous GPS location transmission systems are more widely employed by tow and barge operators.	Still under development.	Application of the tool is limited until continuous GPS location transmission systems are more widely employed by tow and barge operators.

4.2.19 Transportation Routing Analysis Geographic Information System (TRAGIS)

See also: §3.4.1.2

Sponsor/Dev.	Users/Uses/Decisions	Output(s)	Applicable Mode(s)	Methodology or Approach
Department of Energy, Oak Ridge National Laboratory	Federal departments and agencies, national laboratories, federal contractors/sub contractors, and state/regional/tribal users. TRAGIS calculates population data across various routes that comply with hazmat transportation regulations. Users can decide to ship via highway, railway, or waterway. DOE uses TRAGIS to identify legally compliant routes and understand the at-risk population along routes.	Outputs include spatial population information for risk assessment along potential transportation routes, potential routes that are compliant with transport regulations, a table of tribal lands intersected by the routes and mileage through those lands, and route maps.	Truck, rail, water	• Users input routing parameters into WebTRAGIS on their PC. Parameters include: ○ Shipped material data ○ Route preference (quickest, shortest, or combination) ○ Blocking off (not include) of: ▪ Railroad companies ▪ Nodes ▪ Links ▪ Road routes through beltways ▪ Tunnels ▪ Roads with limited size clearances • Information is submitted to TRAGIS server where compliant routes are analyzed • Returns report on available routes with information about: ○ Estimated Travel Time ○ Distance ○ Population along route

Component		Key Sources of Data	Assumptions, Limitations, Biases, and Availability
Safety	Frequency	NA	NA
	Probability	NA	NA
Security	Threat	NA	NA
	Vulnerability	NA	NA

(continued on next page)

4.2.19 (Continued).

Component		Key Sources of Data	Assumptions, Limitations, Biases, and Availability
Consequence		LandScan USA and Census population datasets	Population data is updated every 10 years and is output as: • Table of population density by state • Summary information for input to RADTRAN model • Population count for three buffer widths either side of the entire route and by state: o 400 m o 800 m o 2500 m The ORNL-developed LandScan model spreads the population based on: • Census geographic areas • Proximity to roads • Land use date • Slope of land surface

Strengths (including data)	Weaknesses	Availability	Barriers/Desired Improvements
Users are able to adjust routes to reflect preferences or construction. The model performs population calculations on alternative, compliant routes. It identifies routes between points that comply with transport regulations. Trucking routes can be optimized based on travel time, distance, or a combination of those two. The routes and population data can be input into DOE's RADTRAN tool, which includes probability inputs.	While it analyzes truck, rail, and water transportation options, it does not allow for intermodal linkages between the modes. TRAGIS uses consequence as a proxy for risk; it does not contain information pertaining to frequency or probability of an event during the shipment or at one specific point along the route. Instead, it only focuses on the exposed population.	Access requires screening by Oak Ridge National Laboratory Counterintelligence Not available to commercial or foreign users.	Develop stand-alone system for users in the field without access to server. Develop intermodal analysis.

4.2.20 Transportation Sector Security Risk Assessment (TSSRA)

See also: §3.7.8

Sponsor/Dev.	Users/Uses/Decisions	Output(s)	Applicable Mode(s)	Methodology or Approach
Department of Homeland Security, Transportation Security Administration, Office of Security Capabilities	Users include TSA, Congress, and other government entities with approval of TSA. TSSRA supports the understanding of overall risk landscape across all transportation modes, decisions regarding resource allocation, and compliance with Congressional mandate.	Relative risk scores between scenarios (including scenarios involving hazardous materials) and across modes. Various analyses that highlight the risk landscape by views of concern such as attack, likelihood, and conditional risk. Additionally, TSSRA can report quantitative values for the threat, vulnerability and consequence components of the risk analysis.	All transportation modes.	Based on analyzing scenarios from specified areas of concern by utilizing representative targets as assets. The initial assessment contained roughly 800 scenarios across all modes in TSA's domain. The most recent assessment has dropped to 200 scenarios due to focus on the top 80% of scenarios and scenarios in which security profiles have changed. TSSRA uses the DHS Risk Lexicon that describes risk as a function of threat, vulnerability, and consequence. TSSRA utilizes quantitative and qualitative methods to measure, calculate, and analyze those three components. Uncertainty for key components was captured through triplet analysis (best case, worst case, and best estimate). Also, confidence judgments were captured in the elicitation process.

Component		Key Sources of Data	Assumptions, Limitations, Biases, and Availability
Safety	Frequency	NA	NA
	Probability	NA	NA

4.2.20 (Continued).

Component		Key Sources of Data	Assumptions, Limitations, Biases, and Availability
Security	Threat	Office of Intelligence	Measured as a relative probability against other attack scenarios. Factors included intent, capability, and historical precedence. Threat is based on capability (conditional likelihood an adversary will have ability to undertake the given attack scenario) and intent (conditional likelihood that an adversary will choose a given attack scenario once committed to an attack).
	Vulnerability	Subject-matter expert elicitations that included public and private stakeholders.	Measured as a relative probability against other attacks scenarios. Vulnerability is measured based on the likelihood that an adversary will defeat the countermeasures in place at a particular target. The scenarios were scored on multiple occasions in order to validate the values. Reliance on SME input introduces biases and limitations of human certainty.
Consequence		Developed by various contractors who used historical data, modeling, and elicitations to calculate scores for deaths, injuries, prop damage, indirect consequence (psychological and economic).	Consequences data is divided into two fields: • Direct: deaths, injuries and property damage • Indirect: economic and psychological effects of an attack There was an accepted process to generate each consequence value. Depending on model availability and historical data, a determination was made on how to best assess each factor. Every factor value is distinctly maintained. Hence, the user has the ability to use direct, indirect or total consequence values for their specified use.

Strengths (including data)	Weaknesses	Availability	Barriers/Desired Improvements
Measures relative risk across the full TSA domain using a common framework. The inclusion of external and internal stakeholders increases the credibility and transparency.	Vulnerability is measured based on human input, which introduces biases and limitations. The chief threat group analyzed was international extremists. Representative assets were used instead of specific sites. While sensitivity analysis allows for a better understanding across all sites, it is difficult to map the risk for one specific site.	The overall risk scores are SSI information and are released on a need to know basis. Information derived from the report is submitted to Congress and other approved entities; however, TSSRA data is not released to the public.	Threat data can be improved upon by including other terrorist/attack groups such as domestic extremist groups. Also, updates on threat data have been slow and intermittent and more regular updates are desired. Finally, the interviewee expressed a desire to improve the indirect consequence data by formalizing its use and creating a structure for calculating it.

4.2.21 Trucking and Hazardous Materials Trucking Risk Assessment (THTRA)

See also: §3.4.3.2

Sponsor/Dev.	Users/Uses/Decisions	Output(s)	Applicable Mode(s)	Methodology or Approach
Department of Homeland Security, Transportation Security Administration, Highway Motor Carriers Division	TSA is the primary user, with additional use by various stakeholders. Decisions supported include regulatory/legislative compliance; THTRA was conducted to comply with the 9/11 Act with regard to risk assessments for highway transportation. THTRA's focus included assessment of security risks, the protections already in place, potential security upgrades, industry best practices, and relevant research THTRA also supports situational and risk awareness and allows TSA and stakeholders to understand the risk of various scenarios to the trucking industry.	The three elements of DHS Risk (threat, vulnerability and consequence) are scaled for each scenario using a modified Kent scale (seven values ranging from very low to critical). Congress was mainly briefed on the vulnerability and consequence for approximately 75-100 scenarios, which included some involving Tier 1 and 2 Highway Security Sensitive Materials (HSSM).	Highway	Scenario-based with the overall DHS Risk Assessment Methodology forming the guidelines for THTRA. THTRA combines quantitative and qualitative approaches. The threat component comes from TSA intelligence, vulnerability was based on expert elicitation, and consequence was based on accepted practices within DHS (historic and expected cost of life) All components were then multiplied and vetted with DHS/TSA, with some adjustments made to the final risk categories.

(continued on next page)

4.2.21 (Continued).

Component		Key Sources of Data	Assumptions, Limitations, Biases, and Availability
Safety	Frequency	NA	NA
	Probability	NA	NA
Security	Threat	Internal data from the Office of Intelligence	Unknown threats and scenarios – asymmetric data
	Vulnerability	Expert elicitation from industry stakeholders. Two components are based on the (1) countermeasures and practices in place and (2) target hardness. Scaled components using a modified Kent scale (seven values ranging from impossible to certain) were used to represent the vulnerability category for each scenario.	Limitation: subjectivity of the subject matter experts, uncertainties, the industry itself is so large and complex that comprehensive data do not exist.
Consequence		DHS-based methodology (historic information with certain expected values) Based on reasonable, worst-case outcome. Consequences included: human ($7m per life), economic (based on the cost of attacked asset replacement and remediation/decontamination where appropriate), and psychological (a five-point scale for psychological effect).	There is large variability in the consequences and the effects from the scenarios.

Strengths (including data)	Weaknesses	Availability	Barriers/Desired Improvements
THTRA was an independent assessment that verified lots of the working assumptions in trucking security. THTRA's vulnerability analysis was particularly strong due to using expert elicitation, which allowed TSA to identify gaps and recommend potential ways to close those gaps.	Acuity of qualitative, scaled risk values (What does medium risk mean?). The lack of transparency into the threat component is another identified weakness. The false precision of results.	The THTRA results and methodology are considered Sensitive Security Information. A copy was sent to PHMSA, FMCSA, and various stakeholders through the Sector Coordinator Council (SCC) for trucking.	Additional assessments for sub-sectors, such as hazmat and food/agricultural trucking, to close security gaps. For instance, HMC is working with USDA and FDA to assess the food/agricultural trucking industry since neither USDA nor FDA has looked at security during transportation. Congressional mandates and funding availability affect the ability to implement the recommendations. TSA continues to work toward voluntary adoption of measures to close the identified gaps.

4.2.22 UIUC Tank Car Risk Analysis

See also: §3.7.10

Sponsor/Dev.	Users/Uses/Decisions	Output(s)	Applicable Mode(s)	Methodology or Approach
University of Illinois – Urbana Champaign	The AAR and its constituent members use the results of this approach to help guide their development of tank car technology standards. AAR standards informed by these model results have been incorporated into U.S. DOT tank car regulations for transporting TIH chemicals.	Expected risk, in terms of number of people affected by releases of a given chemical transported in a specific tank car type. Alternative consequence metrics can be incorporated to reorient the model toward environmental risk analysis and remediation cost analysis.	Primarily rail, also rail-highway intermodal	This approach looks at the routes and volumes of individual TIH materials shipped by rail within the United States. The probability of a release of each material is calculated by using historic accident rates and published conditional release probabilities. Exposed populations are calculated using GIS for each material along all routes and within a distance of the track based on emergency response guidelines for that commodity. These data are then compared to analyses of alternative tank cars, whose release probability differs based on differences in the car's tank head, shell, and/or top fittings.

4.2.22 (Continued).

Component		Key Sources of Data	Assumptions, Limitations, Biases, and Availability
Safety	Frequency	The tank car derailment rate is the average railcar derailment value published by Anderson and Barkan	Derailment of cars in the model is assumed to be that of an average rail car, though rates that consider carrier, track class, etc., could be developed and used.
	Probability	Conditional release probabilities of tank cars given derailments are calculated based on published statistical models (e.g., Treichel, et al., 2006) and FRA-reported accident data. Mileage of transport for given commodities is based upon U.S. Surface Transportation Board data. Tank car capacity data is estimated using IlliTank and expert review.	FRA-reported accident data is available to the general public. Surface Transportation Board mileage data is security-sensitive and is restricted.
Security	Threat	NA	NA
	Vulnerability	NA	NA
Consequence		Population exposure is calculated using population density from ESRI/U.S. Census Bureau, potential affected area size, derived from the U.S. DOT ERG. Location data is derived from industry waybills.	Spatial population data is publicly available through the U.S. Census Bureau; likewise, the ERG is publicly available from the U.S. DOT. Affected population areas are assumed to be the size of the ERG-prescribed Protective Action Area for a chemical, plus half of the spill's initial isolation zone. In order to determine the affected areas, spills were considered equally likely to occur during the day or night and small spills were considered to be releases of 5% or less of the tank car's contents. Waybill data is restricted to industry stakeholders and is not publicly available.

Strengths (including data)	Weaknesses	Availability	Barriers/Desired Improvements
The approach is simple, relying primarily on published and publicly available data sources. Data that may be unavailable to public users is primarily descriptive of volumes and exact origins and destination of industry shipments and would not inhibit public users from comparing individual theoretical routes for various tank cars (as opposed to aggregate historical routes). The model's consequence element is flexible and allows for the use of alternative consequence metrics, such as environmental damages.	Not all model data is publicly available – information on historic quantities and locations of specific commodities are difficult for the public to obtain and may be restricted to the rail industry. Data on failure/release rates of new tank car technologies will always be inherently sparse in comparison to in-service technologies.	The approach has been published and is publicly available.	Release rates of new tank cars and their constituent technologies tend to be poorly characterized in comparison to their in-service counterparts. To the extent that this model will be used in comparison of current and proposed tank car technology, the lack of data for new technologies will be an inherent obstacle. One current example of where failure data is needed is for release rates on new top fitting designs.

SECTION 5

Analysis and Recommendations

5.1 General Analysis

5.1.1 Types of Decisions

The types of decisions presented in Section 4.1 show the range of issues that can benefit from either safety or security risk analyses (or both). As stated by the NRC (see Section A.1.7 and page 10 of the reference discussed in that section), "different categories of decisions require different approaches to risk analysis; strict reliance on quantitative models is not always the best approach." In many cases, the types of decisions themselves are more closely tied to the type of decision maker. The strongest delineation between types of decision makers is whether they are in the public or private sector. One of the key objectives for this research effort is to highlight the differences between risk assessments done by government agencies and industry. The fundamental difference in the decisions they must make has led to the differences in the risk assessment approaches that each of these types of stakeholders employ.

Scope and Timeframe for Analyses

One fundamental difference among types of hazmat risk assessment decisions is in the applicability of their scope and the timeframe for implementation. Industry analyses are generally focused on very specific alternatives with short-term timeframes, whereas those performed by public sector entities are generally focused at the system level and may involve implementation timeframes extending several years or more into the future. At another level, industry models tend to be more holistic, covering a wider range of variables than many of the public sector models (DHS CTRA is one notable exception). Using routing as an example, a chemical shipper or carrier may examine all the feasible mode and route alternatives for a shipment between a manufacturing plant and the ultimate customer to determine the choice that best meets its risk/cost tolerance for that product. A routing authority, on the other hand, is limited to only its jurisdiction and may use similar techniques to analyze route risks, but would need to consider a wider range of potential origins and destinations to determine whether any route restrictions or designations through its jurisdiction are warranted.

Decisions Calling for Screening, Semi-Quantitative, and Quantitative Risk Assessments

As evident in the range of component processes in the overall CCPS methodology, the use of quantitative risk assessments in industrial transportation of hazardous materials is reserved for special cases. Depending on the risk levels among the alternatives being assessed, a resource-intensive quantitative risk assessment may not be worth the cost if a less costly (and less detailed) approach is sufficient to discern relative risks. For some decisions, the exact magnitude of the difference in risks between two alternatives is less important than the fact there is a large relative difference. This distinction may be more pronounced when considering the potential effects of low-probability, high-consequence events in which the decision maker may focus less on assessing the risk value and more on managing the transportation operation to reduce the likelihood of the event as much as reasonably possible and preparing to address the consequences should they materialize.

In some cases, where the available data are sufficient across the geographic and operational spectrum for the alternatives under consideration, more quantitative risk assessments can be effectively automated. Models such as RCRMS and Fedtrak, which can be used for route choice, are good examples. While simplifying assumptions are used to determine the extent of the impact area from a potential release (using a bandwidth approach that examines the exposure within an appropriate 'band' or distance on either side of the transportation infrastructure), that impact area can be applied to the entire length of transportation routes, or at any specific location, and used in concert with the most detailed level of population data to estimate potential human exposure.

One example of how different analyses can use varied approaches to address the same element is in assessing environmental consequences. For some models, potential environmental exposure is estimated through counts of river and stream crossings or sizes of sensitive land areas within an impact distance. For others, the counts and land areas are combined with estimated cleanup costs to obtain more quantitative loss estimates.

Specific Decisions

While each of the models used to address the decisions listed in Section 4.1 are presented with specific comments about the approach used and relevant issues for that decision, each of the decision types and how the available models address those decisions is discussed here separately.

Mode Choice. Industry decision makers examining mode choice often have limited options due to the locations of their manufacturing and customer facilities. Many shippers begin with a qualitative risk assessment of the different options they have and only use a quantitative analysis when they determine that their risks are very high. For some companies, the focus is less on mode- and route-choice from a risk minimization perspective and more on ensuring that they are meeting all regulatory requirements in their transportation operations. The step beyond this compliance-level focus is to follow industry best practices that may exceed the regulatory requirements.

Based on the project team's experience, the more quantitative the analysis, the more that mode and route choice decisions are made in concert, with the candidate routes from each mode all being analyzed using the same modeling approach. Care should be taken, however, since the differences in how components, such as accident rates, are measured or estimated across modes can introduce hard-to-measure biases.

Generally, mode choice is a private sector decision process, though there are exceptions. The most notable exception is the movement of high-level radioactive materials, in which the Department of Energy is essentially acting like a shipper rather than a regulator. The same applies to Department of Defense munitions shipments. In other cases, the government may try to understand the relative risks of shipping specific materials to effect policy that encourages or prohibits transportation on various modes in order to reduce public risks. This tactic is evident in the Hazardous Materials Regulations, in which some materials are allowed in highway or rail transportation, but are prohibited in air or marine transportation.

Route Choice. As with mode choice, route choice is generally a decision limited to industry, except where government entities are acting as shippers. In situations in which quantitative risk assessments are determined to be warranted, such as for high-hazard or security-sensitive products, mode-specific routing models and software systems are often used.

The TRAGIS/RADTRAN combination is specific to radioactive materials and includes the measurement of risk from incident-free exposure, which is derived from the radiation that emanates from an intact packaging. Risks from accidents and attacks are included as well.

For explosives, the IMESAFR model can be applied to transportation decisions, but is geared toward fixed-facility risk analysis. The use of IMESAFR in route choice would be mostly focused on modeling the potential consequences from an accident or incident at a specific location and would only consider likelihood components associated with facility activities, such as loading and unloading, rather than those associated with shipments in transit, such as highway accidents.

RCRMS was developed by the rail industry to meet the regulatory mandate to perform a combined safety and security route risk assessment for each of their cargos that met certain high-hazard conditions, primarily radioactive, explosive, and TIH materials. Many factors are considered within the model and some qualitative metrics are provided as additional information for the decision makers, but not included in the risk calculations. The UIUC Tank Car Risk Analysis process can also be applied to routing decisions, as the route information to evaluate national-level risk values for different tank car designs can be applied to compare alternative routes. This model is focused exclusively on safety, however.

The Boston Hazmat Route Evaluation makes use of a wide range of data from different sources and is the most recent known use of the 1996 Federal Routing Guidelines for highway that define the analysis framework and process that states must follow to implement any changes to the Hazardous Materials Route Registry. Where possible, local data were obtained at different levels of precision, based on availability and suitability. Fedtrak is also a highway-specific model that is focused on near-real-time security risk situational awareness, but has a component to compute a planned route's safety risk as well.

The industry processes (CCPS processes the Large Chemical/Plastics Manufacturer's approach) can be used to develop route comparisons at any level from screening to quantitative. Different companies may consider different items in their analyses, such as the presence of bridges and tunnels. As with mode choice, most companies seem to use a qualitative approach for most of their hazmat shipments, elevating the analysis to a more quantitative approach where the material hazards or estimated risks indicate that more details are needed to make an informed decision.

Facility Siting. IMESAFR, the Large Chemical/Plastics Manufacturer's approach, and the CCPS Guidelines were the only models that were suitable to facility siting decisions. This decision was not one that the interviewees focused on or discussed in any detail. In general, where different locations are being considered, the analysis will likely include traditional route choice-based assessment that considers the potential locations as components of different route options.

Packaging Selection. The UIUC Tank Car Risk Analysis was specifically developed to address this decision area. It is used beyond selection for specific shipments, but in analyzing the effects on risk from different tank car designs. The other industry-specific models and approaches are suitable for addressing packaging selection, but would focus only on elements that change with each alternative. Stronger packages may be more costly and have lower capacities due to additional weight from added features, but may reduce risk sufficiently to offset any needed increase in the number of shipments. Such a difference may be discernible at the screening level or may require a semi-quantitative assessment to estimate, for example, assuming sufficient data were available.

Alternate Product Selection. The general models, such as the CCPS Guidelines, can be used to examine the impacts of alternate product selection. Product alternatives will be a function of the manufacturing needs of the customers and the ability to discern the differences in the shipping and material characteristics. In addition to differences in the hazards and the potential consequences in the event of a release, there might be differences in origin, shipment size and number, and other factors to consider. Models that focus on human health consequences (arguably the primary consideration for most decision makers) may not identify significant environmental consequences that may warrant specific attention.

Emergency Management Resource Planning. When local agencies develop their emergency management resource plans, they need to be aware of the types of materials moving through their jurisdictions, the quantities and frequencies in which they are shipped, and the hazards that they present. A key element of this planning is to identify the areas of particular concern and to ensure proper response coverage. Many of the models reviewed can assist public planning agencies and the industry entities that desire to provide assistance. Specific models in this area are material-centric (RADTRAN), mode-specific (Pipeline Risk Management Manual and TRACC), or able to address multiple modes (GeoCTA and RRAS).

Operational Changes. There are many potential operational changes that may be considered. From an industry perspective and not considering the other decisions already mentioned above, these changes can include varying the time of day for shipments and loading/unloading operations, selecting alternative carriers, improving training to reduce human factors-related issues, providing escorts, and many others. To the extent that information about these operational changes can be quantified, they can be used with a more detailed analysis. Otherwise, a screening or qualitative level analysis can be performed.

Security Measure Identification, Prioritization, and Evaluation. There are many different approaches for assessing the appropriateness of security measures. Generally, any of the models that address security risk can be applied to this decision process as long as they accommodate the ability to incorporate the benefits of each measure in terms of reduced vulnerability. In many of the models, including TSSRA, THTRA, CTRA, and Fedtrak, expert elicitation is used to determine the relative vulnerability of different scenarios. These same elicitations can address the changes that would be expected if each of the security measures were applied separately or in combination. Of course, the unmitigated risk values from these models can be used to determine where risk mitigation is best focused and can be the first step in this decision process. The Fedtrak system is specifically designed to measure the reduction in risk from different mitigation strategies. The CREATE Model is designed to assist in determining both the types and best placement of radiological/nuclear detection devices to best prevent or deter terrorist attacks.

One note related to security countermeasures is that the NRC stated that probabilistic risk assessment may not be the right way to deal with adaptive adversaries—those that make adjustments in their strategies as security countermeasures are deployed—resulting in reduced effectiveness of those countermeasures over time.

Security Risk Situational Awareness. There are two high-level approaches for security risk situational awareness: at the systems level and in near-real time. Both THTRA and TSSRA look at the current state of their respective domains that include hazmat transportation. On the other hand, Fedtrak and TRACC attempt to capture and report on the current conditions throughout the country and raise awareness of potential security concerns with specific shipments.

5.1.2 Model Components

The following sections present the various approaches for dealing with each of the major model components. Data sources, assumptions, limitations, biases, and availability are discussed.

Frequency

Safety-related models discussed in Section 4 most often incorporate a frequency element in terms of historical event rates, such as accident rates in the case of highway risk analysis. Quantitative route risk models, regardless of mode, use these rates explicitly, while semi-quantitative and qualitative approaches direct users to approximate the impact of these rates through the use of relative ratings or to otherwise consider their effects on potential safety risks.

Highway accident frequency data, such as that employed in Fedtrak, the Boston Hazmat Route Evaluation, and potentially in RADTRAN, is publicly available through a variety of state and national sources, including state and federal DOT databases. These sources often categorize accident rates according to roadway functional classifications, providing an added level of precision over generic accident rates for a given location. Available data sources generally do not support further segmenting accident rates based on accident type or cause, however, and truck traffic density estimates are a source of uncertainty. In addition, hazmat-specific accident rates are usually not available and truck accident rates are often used as a proxy.

Rail accident frequency data, unlike highway data, is not widely available to the public. While limited accident data are publicly available through the FRA, recent studies supporting the development of RCRMS have produced accident rates specific to individual carriers, methods of operations, track class, and traffic densities. This detailed rate information is proprietary to the AAR and its constituent organizations, however, and is unavailable for public dissemination. Publicly available published estimates of more generalized accident rates exist, however, such as those employed in the UIUC Tank Car Analysis.[11]

The chemical industry risk assessment methods call for consideration of the detailed route and carrier-specific accident frequencies seen in RCRMS, but a lack of detailed public data for all modes of shipment require chemical shippers to rely largely upon carrier-supplied information for such parameters.

Probability

The probability elements of safety models presented in Section 4 focus primarily on the potential for the release of the hazmat being transported. In most cases, these probabilities are conditional release probabilities contingent on the occurrence of an accident, such as in Fedtrak, the CCPS Guidelines, and the UIUC Tank Car analysis, among others. These conditional release probabilities are dependent upon the hazmat container used for the shipment. Typically, however, the risk methodologies include multi-criteria probability elements that go beyond a single prescribed value for conditional container release probabilities to include qualifying factors, such as container speed at impact in the RCRMS model. The more holistic shipping industry models extend multi-dimensional probability factors even further to include, for example, the type of potential release (e.g., pool, BLEVE,[12] jet fire, etc.), as in the CCPS' Quantitative Risk Analysis Process and the size of a potential release in the CCPS' Quantitative and Semi-Quantitative Risk Analysis Processes. In the CCPS' Qualitative Risk Analysis Process, additional consideration is given to elements that may affect release probability but are difficult to quantify, such as methods of container securement, inspection procedures, and personnel qualifications.

Exclusions to the general rule of the use of release-focused probability terms include TRACC, RADTRAN, and IMESAFR. TRACC is intended to gauge the potential for elevated barge-based safety or security risks, rather than calculating the risk of release from an incident. In this way, the model acts as a situational awareness tool and calculates the probability of elevated risk based on deviations in a barge's behavior from historical route paths and proximity to other barges and infrastructure. IMESAFR, while employing a probability term to describe the potential for release (in this case, an explosion), is primarily focused on the potential for injury and loss of life. Thus, the IMESAFR probability term ultimately represents the conditional probability of fatalities or injuries given a release event. RADTRAN was originally designed to calculate the risk of transporting radiological materials in the absence of transportation accidents or releases. The model is flexible enough to be applied to accident risk calculations, however, and several sources exist that define conditional probabilities for various user-defined accident scenarios.[13, 14, 15]

The probability data that supports these safety models tend to fall into two categories: those that are publicly available or built into the analysis tool and those that must be provided by the user, either through measurement or institutional knowledge. Publicly available release probabilities include rail car release rates used in the UIUC Tank Car Analysis method and built into the RCRMS tool (sourced from Treichel et al.,

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[11] Anderson, R. and C. P. L. Barkan 2004. Railroad Accident rates for use in rail transportation risk analysis. *Transportation Research Record: Journal of the Transportation Research Board, No. 1863:* 88-98.

[12] Boiling Liquid Expanding Vapor Explosion

[13] Sprung, J. L., D. J. Ammerman, N. L. Breivik, R. J. Dukart, and F. L. Kanipe, 2000, "Reexamination of Spent Fuel Shipment Risk Estimates," NUREG/CR-6672, Washington, DC: US NRC. pp. 7-73 to 7-76.

[14] US DOE, 2002, "Final Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada," DOE/EIS-0250F, Washington, DC: US DOE. Appendix J and Transportation Health and Safety Calculation/Analysis Documentation, CAL-HSS-ND-000003, Section 5.3.2.

[15] Fischer, L. E., C. K. Chou, and M. A. Gerhard, 1987, Shipping Container Response to Severe Highway and Railway Accident Conditions. NUREG/CR-4829. Two volumes. Washington, D.C.: U.S. Nuclear Regulatory Commission.

2006[16]) and truck release rates incorporated into the Fedtrak system (sourced from Harwood et al., 1993[17]). The latter of these two sources, while continuing to be widely used in highway transportation research, presents an opportunity for the development of improved data for use in contemporary risk analyses, owing to its age and lack of information on many high-priority hazmat transportation packaging options. Similarly, a portion of the probability data required by the IMESAFR tool is supplied by the software's database. This information is derived primarily from military use and testing data, however, and could be improved for commercial analyses through expansion of the data to include probability information for commodities and quantities typically found in industrial uses.

User-supplied probability data is a component of a majority of the available safety approaches. In some cases the supporting data is easily estimated simply by being on-site or having operational experience with the analyzing institution, like in the case of estimating building characteristics in IMESAFR and various operational considerations in the qualitative, semi-qualitative, and ranking methods of the CCPS Guidelines. In other cases, like in RADTRAN and the Pipeline Risk Management Manual approach, probability information may require difficult or costly measurements or calculations, but may be easily estimated by using values or sources suggested in the model methodology documents. The chemical industry models all require a high degree of user input to calculate or estimate probabilities, with quantitative methods tending to rely more heavily on in-house databases and more qualitative approaches drawing more from institutional or expert knowledge. While large chemical manufacturers often have the needed information on hand, or available through their carriers, to support these kinds of probability determinations, obstacles, such the proprietary nature of data and reluctance to share data, can make external data collection for analyses arduous.

In general, hazmat transportation safety models handle uncertainty in probability data sources through the selection of conservative model parameter estimates or the use of conservative operational procedures or equipment. For example, IMESAFR allows users to employ highly conservative modeling of blast particle movements and intra-facility casualties to determine fatality probabilities. The large chemical/plastics manufacturer, whose methodology is profiled, meanwhile, deals with probability uncertainties through operational practices, such as using the most protective containers available for a given product, even if the container exceeds regulatory requirements.

Threat

Whereas safety risk methodologies most often determine the likelihood of an accident based on historical data to calculate frequency and/or probability, security risk models and methodologies tend to use qualitative data to define an event's likelihood as a function of threat and vulnerability. The most common sources of threat data tend to be from elicitations of internal or external subject-matter experts (SMEs) or internal intelligence agencies/divisions, due to a scarcity of or sensitive nature of historical event data.

SME Elicitation. SME elicitations can come in many variations, but the core characteristic of the elicitation is to convene a discussion among several experts within the field of interest. For hazardous materials transportation, an elicitation may include first-responders, hazmat response team members, transport operators (drivers, barge captains, railroad engineers, etc.), federal and state and local law enforcement officers, transport company security representatives, academic researchers, and governmental department of transportation representatives. The elicitation results' structures vary depending on the thought-experiment's goal and the methodology employed. In some of the models described in this study, an SME elicitation is conducted at the beginning of the risk assessment to determine which attack scenarios, security areas, or target assets will be analyzed. For the most part, SME elicitations are used as a substitute for quantitative datasets. Unlike safety risk assessments, which often draw on historical data, security risk assessments often do not have robust historical incident data; none of this study's interview participants discussed any publically available threat dataset. Additionally, security risk assessments typically consider an "adaptive adversary," who will shift targets and attack modes to optimize the adversary's goal of a successful attack, often measured in consequences. Consequently, as additional iterations of SME elicitations are conducted, the results may change.

Internal Intelligence Data Using "Black Boxes." Another method of determining threat metrics used by hazmat security risk models is the use of "black box" threat data. The term "black box" is used because it is unclear what data are being used, how they are used, and/or the final result. Some stakeholders are hesitant, for business-proprietary reasons, to share information about perceived threats or how they calculate threat data. Additionally, government agencies use data that is classified security information that cannot be disclosed

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[16] T. T. Treichel, J. P. Hughes, C. P. L. Barkan, R. D. Sims, E. A. Philips, and M. R. Saat, 2006, Safety performance of tank cars in accidents: probability of lading loss, in: RSI-AAR Railroad Tank Car Safety Research and Test Project, Association of American Railroads, Washington, DC.

[17] Harwood D.W, G. Viner, and E. R. Russel, 1993, Procedure for development truck accident and release rates for hazmat routing. Journal of Transportation Engineering, 119, 189-199.

due to public safety concerns. In either case, it is unclear how this group of stakeholders calculates threat.

Outside of the actual calculation or data gathering, the models identified in this project followed a similar process for defining scenarios and potential targets. The first step to obtain threat data is to identify and define the scenario to be analyzed. Within security risk assessments, threat is usually defined along the lines of a target's attractiveness to an attacker and can be a function of the consequences of a successful attack (casualties, economic effects, symbolic or psychological impact, etc.). Of the security methodologies and models reviewed, those that identify potential targeted assets and attack scenarios used SME elicitations, potential-consequence analysis, internal information, or a combination of the three.

After identifying the scenario, its threat score is typically obtained either from an internal intelligence group that does not disclose its methods and/or sources or through relative-scoring against the other scenarios and assets through SME elicitations. Additionally, some models account for proximity to high-population areas (identified through Census or FEMA's HAZUS-MH data), potential or unclassified critical infrastructure, or TSA HTUAs through either emphasizing the targets' geographic locations to the SMEs or scaling the initial threat score. Fedtrak and RCRMS are two examples that embed this information into the methodology.

Outside of these security-focused models, a few safety-based risk models have been adapted to measure security risk, usually through scaling the safety risk score or components (frequency and probability). For instance, IMESAFR multiplies probability and frequency components by a scaling factor that is predetermined based on the DHS communicated public threat level.

Vulnerability

Similar to the threat component, vulnerability datasets are largely structured around SME elicitations. Instead of identifying potential attack scenarios, targets, and the threats associated with those items, however, stakeholders define vulnerability as the likelihood that a defined attack will be successful for a given target. The majority of the models assess vulnerability based on the likelihood the attack scenario will overcome target-specific countermeasures, while two models (Fedtrak and the CCPS' Security Vulnerability Assessment Process) identified in this project also consider the likelihood the attacker will fail on their own volition.

In the case of vulnerability elicitations, some of the countermeasures that SMEs consider are detection equipment positions along hazmat routes (CREATE Model), emergency response rate information (Readiness and Resiliency Assessment Framework), and target or route-specific security activities and actions (RCRMS). Similar to threat data gathered from SME elicitations, vulnerability data is sometimes scaled (THTRA and Fedtrak use the Kent Scale) or scored relative to other vulnerability scenarios discussed.

Two models (Readiness and Resiliency Assessment Framework and RCRMS) use datasets that either involve "black boxes" or their developers were unwilling to disclose their information for the study.

Consequence

The consequence component of the safety and security risk models presented in Section 4 focuses on one or more of four categories for each model: human, economic, environmental, or critical infrastructure.

All but two of the models, the Readiness and Resiliency Assessment Framework and the CREATE Model, have a consequence component that explicitly focuses on impacts to the population exposed to an incident. These models incorporate population-based consequences using various degrees of detail. On the most basic level are models that employ simple population counts for exposed persons. Such models include TRACC, TRAGIS, and the UIUC Tank Car Analysis, among others, who source spatial population data from the U.S. Census Bureau. Several models, such as Fedtrak, RCRMS, and GeoCTA add a level of precision to this population information by employing distinct daytime and nighttime population count data, which are most commonly sourced from FEMA's HAZUS-MH software database.

A number of the models investigated consider population consequences beyond simple counts of potentially exposed persons. For example, TSSRA and IMESAFR calculate casualty estimates in terms of the number of fatalities versus injuries. Casualty estimates are approached with the greatest level of detail, however, in models such as RADTRANS, CTRA, and most of the chemical industry assessment methodologies, by accounting for personal exposures through specific potential pathways (i.e., respiration, ingestion, percutaneous). The high degree of detail in these models' population consequence components tend to be particularly data-intensive and require the user to employ data that must be assumed through expert knowledge or estimated using additional models (e.g., plume dispersion models).

Models that consider the economic consequences of an incident include a range of direct cost impacts, including the costs associated with replacing lost infrastructure, equipment, or products, as well as indirect economic impacts, such as traffic or product delays. Seven of the risk models consider the consequences of losing CIKR, which include assets or materials that are vital to the organization's mission or goal. The loss of a CIKR asset could have substantial consequences across several areas, including, but not limited to, the economy, the stakeholder's ability to function, and public safety. For example, a water treatment plant would consider the local railway as critical to its supply of chlorine, which is typically shipped via rail. Major bridges, tunnels, roadways, and transportation nodes may also be considered CIKR. Government agencies tend to reference the publically available DHS CIKR definitions, but the DHS CIKR list is classified and mainly focused on aggregate impact to the U.S. public. For private stakeholders, CIKR may include DHS CIKR listed and micro-assets, such as the railway referenced in the previous example.

Additionally, economic and environmental consequence data can overlap in certain models as environmental consequences may be calculated in terms of hazmat clean-up costs or the opportunity costs associated with contaminated land; however, not all environmental costs are calculated in economic terms. Instead, some models in this study measure geographic areas or features that are environmentally sensitive. For instance, the Boston Hazmat Route Evaluation measures environmental impact in affected acreage while RCRMS takes into account affected bodies of water and national park lands.

Finally, two of the security risk assessments developed for TSA (THTRA and TSSRA) include a consequence factor for psychological or symbolic losses. By including this factor, TSA was hoping to account for unquantifiable losses that may occur as a result of an attack. The costs associated with rebuilding, replacing or repairing damaged infrastructure may not include the full impact that the accident or incident has on the general public. For instance, consider the loss of an iconic or historic building; while the building may be restored, the event may result in a psychological change in the public that cannot be easily quantified. While the two assessments included discussion on the psychological impact, the most current methodology does allow assessors to omit psychological consequences from the final score.

5.1.3 Interpreting and Applying Results

Results from screening-level and qualitative analyses often are presented in the form of a general category (such as high, medium, or low), based on one or more elements (such as hazard, consequence, frequency, or risk), or in a risk matrix, with consequence and frequency as the two axes. Operations or alternatives that approach the corner with the greatest consequences and frequency are those that warrant the most attention.

For most quantitative models, the results are presented in terms of one of these types:

- Risk indices. This type of result appears to be the most commonly used form and is almost always considered to be a relative risk value. In this method, a risk score is determined for each alternative and then the relative differences between these values is used in the decision making process. Risk scores are often thought of as being unitless. If the risk for one alternative is 10 times that of another, there is no attempt to determine whether the higher-level risk is within an acceptable range and requires no mitigation efforts. Generally, the lower risk option will be chosen in this case, with all other parameters being equal.

  In safety analyses, risk is generally computed at a segment level and aggregated along the length of a route. For security analyses, risk is generally computed at specific locations along a route and the maximum value is taken as the overall risk for the route. This approach is used because an attacker will chose the location of an attack to maximize their intended impacts. Some adjustments may be made for routes that have more high-security risk locations than other routes, but these adjustments would not be linear.
- Individual risk. This presentation of risk is used to indicate the aggregate risk from all sources (or scenarios) at a given location.
- Societal risk. This method of communicating risk takes the risk index for each possible outcome and location and most often uses F-N curves. These curves will usually have the consequences along the *x*-axis and the frequency with which those consequences are expected to occur along the *y*-axis.

As stated previously, it appears that the large majority of hazmat transportation quantitative risk assessments estimate relative risk values rather than absolute risk values. The latter, if computed, could be applied to established ranges for acceptability. When this is done, the three most often used ranges are: (a) acceptable with no additional mitigation needed, (b) acceptable but mitigation is appropriate if it can be accomplished in a cost-effective manner (this might be called 'tolerable risk'), and (c) unacceptable so that additional mitigation is necessary to bring the risk at least into the second range. Absolute values might also facilitate comparison of alternatives across dissimilar choices, such as comparison of routing across different modes.

While uncertainty is a concern expressed by many of those interviewed for this project, it seemed that little effort is made on the industry side to formally quantify it. Margins of error are assumed to exist and the risks of alternates need to be significantly different to support incurring additional costs to achieve the reported safety or security benefits. Depending on the analysts' perspective of the variability in the factors that go into their assessment, they would adjust the error bounds that they would feel comfortable to use in making a distinction between alternatives. In the RCRMS, for example, the risk scores are grouped into 'attractiveness' categories such that any score in an attractiveness band is considered equivalent to any other in that same band.

5.2 Gaps

5.2.1 Gaps in Models for Decisions

Multi-Modal/Intermodal Risk Analyses

Other than those carried out by hazmat shippers, most risk assessments seem to focus on a single mode. There remains a lack of a suitable integrated model to consider multi-modal and intermodal transportation options. For example, there is a current focus of attention directed toward human factors issues as a leading cause of hazmat incidents. Because interchange/transfer operations increase the handling that a shipment may experience, it is important to be able to model these operations when considering different shipment alternatives that may have varying levels and opportunities for these interactions.

Validation of Prior Assessments

From the models reviewed, it appears that when hazmat risk analyses utilize the results of previous analyses, that information is not typically subject to any type of validation. If the previous study's results fill a need in modeling or data, they tend to be used without further scrutiny.

Comparability of Model Results

Most of the models covered in this document use varying methodologies and metrics, rendering their results incomparable to each other. More importantly, the differences make it more difficult to easily understand/interpret results from individual assessments that may differ from those that are more familiar to the user or decision maker.

Uncertainty

Most of those interviewed indicated that uncertainty is acknowledged but usually not quantified or even qualified (TSA and IME are notable exceptions). For some risk assessments, the practitioner will vary the values for one or more parameters that they feel have sufficient levels of uncertainty in order to understand the sensitivity of the assessment's outcome on those parameters. This sensitivity analysis does not help in understanding the true uncertainty of the parameters, but does provide some confidence in how important the parameters are for the decision they are making.

Route Analysis Tools

There is currently a lack of analysis tools for truck-based carriers to use in determining the risks of transporting hazmat by a given route. Conversations with trucking industry representatives indicate that route analyses are rarely done by carriers because hazmat shipments by highway are perceived to be restricted to routes predetermined by governing agencies. Furthermore, there are no significant regulatory incentives to compare potential alternative routes for highway shipments as there are with rail. As such, carriers cannot justify the cost of performing route analyses or developing analytical tools of their own. However, the existence of a widely available model with minimal burden on the user organization, in terms of input data, necessary expertise, and cost, would provide carriers a better understanding of the risks associated with current or planned shipments. Such knowledge would promote better informed shipment and operational decision making, benefitting company and public welfare. It is the goal of the TSA to address this gap through the continued development of the Fedtrak tool, at least in terms of Tier 1 HSSM. A gap may remain, however, for the analysis of other classes of hazmat.

Tools for barge route analysis are similarly unavailable. Barge routes are strictly constrained by river geography. As with the perceived route restrictions in the trucking industry, the inflexibility of waterway paths may have hampered the development of barge risk analysis tools to this point. However, as with trucking, shipment and operational decisions by barge carriers could be bolstered by a better understanding of the risks associated with shipment options. While the TRACC tool addresses situational awareness with regard to current shipments, no tool exists to calculate risk values for the planning or comparison of individual barge shipments.

5.2.2 Gaps in Data for Models

Inadequate Highway Exposure Data and Accident Rates

There is a significant lack of detailed (i.e., disaggregated) exposure data on hazmat transportation shipments of varying materials, packaging types, and operational parameters. Data sources could be improved by adding information that facilitates correlation with hazmat accident data to determine hazmat-specific accident rates. In many cases, the accident rates are desired for some segment of all hazmat transportation and that segmentation is not available. For local or regional intrastate assessments, truck accident rates may be available from the state department of transportation and are sometimes available at the roadway segment level (for roads over which that state has jurisdiction). In other cases, they are aggregated to roadway functional classification. Data on bulk shipments would be the most valuable on an industry-wide basis.

Conditional Probability Data

Available data on the conditional probabilities of release for containers used in highway, rail, and intermodal hazmat transport suffer from having a limited number of sources, from being outdated, or from having information gaps for particular commonly used containers. For example, highway hazmat risk analyses commonly use release rates estimated by Harwood et al. in 1993.[18] This source, for which there is currently no comparable alternative, remains a staple of hazmat risk studies despite not accounting for any of the transportation technology, operations, or infrastructure innovations of the past two decades. An update of the Harwood report could, for example, account for release statistics on all high-priority hazmat containers, including radioactive and explosive material packages. Development of conditional release probabilities for intermodal portable tanks and containers would add value to models such as the UIUC Tank Car Risk Analysis and RCRMS by enabling evaluation of a wider range of common container types.

Available probability information for explosives risk analysis also presents several opportunities for further development. For example, explosives testing data concerning quantities likely to be present in commercial transport, as opposed to military applications, would enhance the applicability of analyses of industrial models, such as IMESAFR, as would conditional probabilities of release due to sympathetic detonation of explosives in close proximity to one another. Development of these data would enable more accurate risk analysis of transportation facilities where explosives are stored, loaded, or unloaded and would contribute to a better understanding of the risks associated with packages of explosives in transit.

Disparate Data Quality across Modes

The degree of data accuracy and precision found in available risk metric data tend to be dissimilar across modes. For example, rail carriers have access to accident rates that are specific to their organizations, track classes, method of operation, and traffic density. Highway accident rates, on the other hand, are available only by roadway functional classification. Another example is the precision with which a shipment can be located during a movement from an origin to a destination along the relatively fixed-path modes of pipeline, rail, and barge, in comparison to highways, where the street network provides a large number of potential paths. This variation in data quality further complicates the comparison of transportation options from mode to mode. Moreover, there is currently no methodology for calibrating or accounting for this disparity when comparing risk analyses for a shipment by different modes. The development of such a method would allow shippers and regulators to make better informed decisions about mode choice.

Security Assessment Credibility and Transparency

Several risk models rely on SMEs or involve classified or proprietary information or processes (black boxes) to identify, calculate, score, or compare risk components. Both processes are most often used to assess threat and vulnerability, which are security-risk components, because necessary datasets either are not publically available, do not contain relevant data to the risk-scenario, or contain information that could harm the business' competitiveness or have an impact on public opinion or behavior. However, private entities may also employ a black box process for business-sensitive safety risk assessments. Both processes lead to gaps in credibility through the introduction of biases and the reduction of transparency, which in turn reduces the ability to reproduce a risk assessment's results.

Black box calculations or datasets, which are not transparent to the public, reduce the credibility of a risk assessment by hiding key processes or inputs into safety and security risk assessments. Black boxes may be employed across security and safety assessments and are used to protect information from external entities. Private risk assessors are reluctant to publically disclose the information or processes they use to access risk for several reasons.

- Incident/accident data may be used against them by affected parties or by third parties that are involved in their business model or strategy.
- A private entity's risk-assessment process may also be considered proprietary business information for competitive reasons or in the case that the private stakeholder considers risk assessments to be a marketable service.
- Public risk assessors may label security-risk data as classified for public safety issues.
- Security-risk data may be withheld to prevent attackers from adapting their attack to other areas. Risk scores may inform resource allocations, so attackers may change their attack strategies and targets according to available information.
- Black boxes may be employed to hide incomplete or skewed data that is being used because the desired data is not available.

Whether the reasons for using a black box or not disclosing data are for market competitiveness, public safety, or that the dataset does not actually exist, the end result is a lack of transparency that hinders the ability of external entities to verify the model through replication.

Typical safety-related datasets for frequency and probability are built on historical data pertaining to incidents. Security risk assessments, on the other hand, may consider previous events, but typically must employ hypothetical scenarios that do not have any historical data. In order to find suitable supporting data, many security risk assessments turn to SME elicitation to

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[18] Harwood D.W, G. Viner, and E. R. Russell, 1993, Procedure for development of truck accident and release rates for hazmat routing. Journal of Transportation Engineering, 119, 189-199.

determine variables such as attack scenarios, potential targets, and relative threat and vulnerability scores. Additionally, SMEs may be used to verify model results or assumptions, but the inclusion of their opinions in the data-creation process introduces the potential for biases. While certain models attempt to mitigate SME biases through multiple elicitations with different SME groups, scaling results, and using three-tier scoring, an elicitation process has not been found to completely eliminate SMEs' preconceptions. Thus, the data collected from an SME elicitation may change based on several factors, including the participants, the number of participants, the number of iterations of the elicitation, how the participants interact with one another, the elicitation process or how it is moderated, etc. As a result, the use of SME elicitations introduces a variable that is difficult to control that makes replication of results difficult and decreases overall credibility.

Lack of Public Vulnerability and Threat Data

Another identified data gap is the lack of publically available datasets for security and safety risk assessments. Several interviewed stakeholders stated that larger or better data is one desired improvement to their model or methodology. One potential solution would be to increase available data on frequency, probability, potential threats, and vulnerability to the same degree that consequence data can be obtained through U.S. Census. Since these data are not currently publically available, private entities that possess this information have a competitive advantage in conducting risk assessments and, therefore, an incentive not to share the data. Moreover, publically shared datasets may reduce the use of SME elicitations and black boxes as attempts to mitigate, patch over, or cover up data deficiencies.

The lack of publically available data has led to an increased importance being placed on models' consequence components, which usually is the most well-defined and available dataset, especially in security risk assessments. For instance, Fedtrak and the CCPS Guidelines take potential consequences into account when identifying targets in their threat assessments. Another explanation for the emphasis on consequence could be the common assumption in the security risk field that an adversary is consequence-maximizing; however, that assumption may be made in an attempt to focus on data that is most readily available and understandable. Some potential attackers, such as those that have issues with particular organization or location, may direct their focus there rather than on other targets with potentially greater consequences. Others may attempt attacks that offer the least resistance to maximize their chances of success and minimizing their likelihood of capture.

A lack of publicly available data leads to imperfect information and can result in ill-informed and skewed risk assessments. Furthermore, data discovery increases the costs of conducting risk assessments, which may result in inefficient risk-mitigation resource allocation and, with regard to hazmat risk consequences, negative effects on public safety. Public disclosure of intelligence reports or target-specific threat and vulnerability assessments will reduce their value by signaling that information to potential attackers.

Validation of Supporting Data

From the research conducted, it appears that where data are available, models that utilize that information perform limited validation on the prior work. If the data fill a need in modeling or data, they are used. This is particularly true for GIS datasets.

5.2.3 Gaps in Model, Data, or Results Availability

The gaps listed in this section relate to those that are related to obtaining access to models or data that exist, but are proprietary or classified. Where gaps refer to the absence of such models or data, they are addressed in Sections 5.2.1 or 5.2.2.

Formal Risk Management Process

For transportation companies and hazmat shippers that consider risk assessments, the key to success is implementation within a structured risk management system, program, or process within which to conduct risk assessments. Companies that implement the CCPS Guidelines or a similar approach are following such a system, but anecdotal evidence suggests there are many companies that do not. From the research conducted, it seems that some companies follow a less structured process with less formal risk assessments, even at the qualitative level.

Data Building Blocks for Assessments

For those entities that build their assessments internally using component pieces and not an integrated software product, there is a desire to have a repository of needed standard data, particularly geographically connected data that can relate potential exposure to affected populations and environmentally sensitive areas. Such a repository can include GIS data for day and night residential and employment population, waterways, parks, and similar items. Transportation networks are already available from the BTS through their National Transportation Atlas Database (NTAD). Models can standardize the methodologies that integrate these elements together, which may make it easier for companies to perform more quantitative analyses. However, having a data repository without accompanying standard implementation guidelines can still result in incomparable results from one implementation to another.

Lack of Awareness of Available Data, Tools, and Methods

Based on the interviews conducted, a knowledge gap about the availability of risk data, models, and methodologies was identified. Stakeholders were not always aware of the full range of available data sources or other hazmat stakeholders' risk frameworks or methods. This knowledge gap can lead to risk decision-making results that are based on incomplete information or do not take advantage of fully developed risk analysis. Additionally, stakeholders may not be using resources in the most efficient manner. An increased awareness of available data and models will prevent new risk assessors from starting from scratch and current stakeholders from using resources to research and implement improvements to their risk models that have already been employed by others. Additionally, this increased awareness would promote cooperation among all stakeholders in developing future improvements.

Lack of Public Disclosure of Datasets

One of the reasons for the knowledge gap between hazmat risk stakeholders is that developers and users are unwilling to disclose information regarding risk calculations or the data that is used in the model. Private stakeholders protect data and information through claims of business proprietary information and the need to maintain competitiveness in the market. For instance, risk models developed through funding from professional associations may only share the model, data, and results with members, which prevents the free-rider problem and incentivizes membership. Furthermore, private users may be averse to disclosing accident rates because the rates may be used against them by competitors or third parties (e.g., insurers, watchdog groups, government). AAR's RCRMS model avoids this data gap by not allowing members access to other members' data and only sharing limited information within the model with the FRA. By limiting the information accessible to users, RCRMS is able to provide a direct benefit to those stakeholders that supply information and fulfill a federal reporting requirement while guaranteeing information will not be divulged to competitors.

Safety risk models developed and used by government stakeholders, such as the Boston Hazmat Route Evaluation and Pipeline Risk Management Manual Risk Assessment Method, often are publically available to promote the model's use and thereby decrease the risk posed to the public by hazmat transportation. In a few cases like the DOE-owned RADTRAN tool, the risk model or tool is available but requires the government to grant the user access. Security risk data, scores, models, or a combination of the three that are used by government agencies are usually considered sensitive information and classified, mostly due to the intelligence data used to calculate the threat component. As described earlier, disclosure of threat scores may cause an adversary to adapt their attack strategy, which could then invalidate the model's assumptions and results. Some government stakeholders, such as TSA, publish their risk methodologies but withhold the data used to calculate risk. Furthermore, the final scores or results for government security-risk methodologies are normally communicated internally and only to external stakeholders on a need to know basis.

Additionally, data is not always shared between all the stakeholders in a risk assessment. Again, stakeholders may have market-based incentives to withhold or skew/adapt data that they share externally. For instance a private carrier may attempt to understate accident information that is reported to the government (to prevent fines or avoid increased oversight), potential clients (to prevent losing customers and revenue), or general public (to prevent increased scrutiny or oversight). Withholding of critical information also occurs between the government and third parties. For instance, certain risk models (e.g., TRACC, THTRA, TSSRA, CTRA, and Fedtrak) use classified CIKR information for identifying targets, high-consequence areas, and potential attack scenarios to be evaluated. While DHS releases definitions for what may be considered a critical infrastructure or key resource, the actual tiered list of CIKR sites is considered security sensitive information and is, therefore, not publically available.

5.3 Recommended Paths Forward

5.3.1 Recommendations for Model Development

- Develop a single risk assessment approach across all modes using a standard architecture that would include a standard (ideal or baseline) model for addressing hazmat transportation risk. Each relevant agency could augment the common approach with their specific area of expertise. Such a model could have varying, yet prescribed, levels of detail for each component, with data availability and cost determining which level that is actually implemented in a particular assessment. This could support both qualitative and quantitative assessments. The common approach could also include methods for measuring the validity and uncertainty in data and results and methods for conveying that information to decision makers along with the results.
- Develop a highway hazmat route risk assessment tool that implements the standard approach described earlier and also considers the FMCSA Hazardous Materials Route Registry and other state and local truck restrictions. This tool, unlike RCRMS, would need the ability to suggest candidate routes for consideration given the significantly

greater extent of the highway network and the lack of operational constraints with which the interlining railroads have to contend.

- Develop a waterway hazmat route risk assessment tool that implements the standard approach described above and also considers dam and lock infrastructure restrictions. This tool could be developed, like the RCRMS, to only analyze prescribed route options.
- Develop an approach for addressing low-probability, high-consequence events into hazmat transportation risk models.

5.3.2 Recommendations for Data Development

- Continued enhancement of the BTS' CFS and the FHWA's Freight Analysis Framework (FAF) may ultimately provide sufficient national-level data on hazmat flows to support improved hazmat-specific highway accident rates. While material-specific rates are desired, rates that include all hazmat would be a marked improvement. Data on multimodal hazmat flows, as an important subset of all commodity flows, should be collected to support risk analysis as part of the CFS and FAF.
- Expand and extend the results of HMCRP project HM-07, *Accident Performance Data of Bulk Packages Used for Hazardous Materials Transportation,* to develop conditional release probabilities for different packaging types, with the emphasis on bulk packages. At a minimum, using the dated Harwood et al. report from 1993 cited earlier to update their analysis would be beneficial.
- Research on commercial-scale explosives would enhance the modeling for fixed facilities and eliminate the use of less-appropriate military explosives characteristics. Transportation risk assessments would also be able to benefit from this more accurate information about these materials when shipped in commerce.
- Similar to the discussion for a standard risk assessment model, there would be benefits to developing a system for calibrating the differences in similar data across modes or other categories. For example, quantifying the differences in underreporting accidents across modes could be used to obtain a more normalized comparison of accident rates. This would involve a research project to develop a methodology to estimate the levels of underreporting.
- The hazmat transportation risk assessment community would benefit from the development of a guidebook that describes different types of elicitation methods and their applicability to the unique issues that are typically addressed in this field. This could include best practices, scenario development, how to present scenarios to SMEs to avoid introducing biases, and appropriate qualitative scaling methods.
- Further research is needed on the benefits that may be realized by sharing security-sensitive threat and vulnerability data with private sector risk assessors with a need to know, as well as the potential pitfalls and security risks that may result. If the outcome suggests that increased sharing is worth pursuing, the subsequent step is to study and identify the best methods and safeguards to use.

5.3.3 Recommendations for Communication and Data/Model Sharing

- Building on the success of the CCPS Guidelines and evolving DHS risk assessment methodologies, an integrated framework document could be developed with more specific checklists to encourage greater adoption of risk management principles and decision making. Such a document would integrate the best practices from both the private and public sectors and facilitate their adoption.
- Develop a single data repository for transportation network data that have the requisite data elements to support hazmat transportation risk assessment. This could also include a catalog of other relevant data sources that is kept evergreen. A less expensive alternative is to expand the catalog to have explicit pointers to all relevant datasets and forgo the repository aspect for the data itself. For example, listings of data sources suitable for use in transportation risk assessment like FEMA's HAZUS-MH daytime and nighttime population data would reduce the effort required by risk assessors looking to model their operations.

APPENDIX A

Literature Review Results

The following section summarizes the major findings from the literature review. It is organized into four primary headings:

- New Modeling Techniques and Approaches
- Data-Driven Risk Assessment
- The Use of Risk Analysis and Route Choice
- Economic Risk Analysis

The documents and articles summarized were found to be the most comprehensive and detailed in each of these areas, but other resources reviewed are listed with brief notations at the end of each section.

A.1. New Modeling Techniques and Approaches

The amount of research and data collected concerning hazardous materials transportation continues to grow every year. As more data exists, newer and more accurate models can be developed to measure the risk associated with transporting hazardous materials. The following articles demonstrate how modeling techniques and approaches can be developed by collecting and analyzing new data.

A.1.1. Cross-Analysis of Hazmat Road Accidents Using Multiple Databases

Martin Trépanier, Marie-Hélène Leroux, and Nathalie de Marcellis-Warin, *Accident Analysis and Prevention,* Vol. 41, Issue 5, 2009; pp. 1192-1198.

Route-based risk researchers often have difficulty in finding strong data pertaining to hazmat accidents; while datasets do exist, not all of them collect the same data or even all the data that is needed to analyze accidents. As a result, the authors set out a methodology and a tool that integrate multiple data sources to analyze hazmat road accidents in Quebec, Canada. The article looks at three databases for Quebec, Canada: Dangerous Goods Accident Information System (DGAIS) from Transport Canada, Road Accident Database from the *Societe de l'assurance – automobile de Quebe – SAAQ,* and Community Database on Work Accidents from the *Commission de la santé et de la securite du travail du Quebec.* DGAIS has information on spills, injuries, death counts, and other parameters related to hazmat, but the information reported is only for instances in which Canadian laws require it. Data of the Road Accident Database is collected by Quebec police officers for each accident involving human or large financial consequences. The Community Database on Work Accidents contains accident information where workers were injured or killed on duty.

Once the data was gathered, the databases were integrated using the Transportation Object-Oriented Modeling (TOOM) approach which allows analysis of data in relation to other transportation sources. The approach is structured around four meta-classes of objects: dynamic objects, kinetic objects, static objects, and system objects. The authors create a master table for each dataset that contains the raw, unmodified data, including dates, time, materials, etc., after which, they use the Hazmat Event Cross-Observer Tool (HECOT), which identifies the same event through different databases and the possible cause of the event, to observe data about single events across several datasets. HECOT focuses on identifying events based on spatial and temporal data contained within the three databases.

Unfortunately, the Database on Work Accidents does not identify the location, so no match could have been called exact, and the authors focused on the first two databases. Even then, it was difficult to make true matches without further investigation using information from Quebec Ministry of Transport. Finally, the temporal and spatial criteria were widened to allow for imprecision of events' location, time, and general data. As a result, 41 true matches were found between the two databases. Those matches accounted for 28.1% of the accidents reported in the DGAIS and 2.9% of the reported accidents in the Road

Accident Database. The authors conclude that there is underreporting of accidents in both databases.

A.1.2. A Behavioural Model for the Level Crossing Collision Risk Assessment

M. Ghazel, *Safety and Security Engineering,* III, 2009; pp. 637-645.

Many accidents occur every year at grade-level rail intersections. At these crossings, trains cross over roads on the same level as vehicular traffic. There is inherent risk associated with these crossings, despite safety measures which include physical barriers and flashing lights and bells that alert drivers to approaching trains. Vehicles often stop in the train crossing zone when a train is not nearby. When a train then approaches, the vehicles are unable to leave the crossing zone and cause a collision.

To address this problem, behavioral models were developed to examine the risk caused by the multiple participants, including the train, the vehicles, and the railway equipment, such as the lights and bells. Because it is believed that people's behavior causes most of these collisions, like when a person drives their vehicle on to the tracks, these behavioral models will allow the risk associated with each participant to be calculated. Attempting to quantify people's behavior to measure risk will allow some subjective criteria to be judged more quantitatively.

Modeling the risk of a collision at a level crossing involves multiple smaller models. One elementary model was created to demonstrate the relationship between the train and the signals, while a separate model was created to show the relationship between vehicular traffic and the signals. A complex model was then developed combining both basic models and to examine a possible accident between a train and vehicular traffic. The model is particularly complex because the trains and vehicular traffic never have any direct interaction. By quantifying individual behaviors, it becomes much easier to evaluate the risk of an accident at a level crossing.

A.1.3. Risk Assessment in Maritime Transportation

C. Guedes Soares, A.P. Teixeira, *Reliability Engineering and System Safety,* 2001; pp. 299-309.

Maritime transportation carries many risks not typically associated with transportation by rail or truck. Transporting cargo across oceans requires more manpower and larger equipment than any other mode. If a ship has an accident in the middle of the ocean, there is a greater potential for fatalities to the crew than with other modes of transportation. This study addresses major causes of ship loss, including fire, explosion, and foundering. Probabilistic approaches can be utilized individually to address each major cause of ship loss, but it is not feasible to prepare for every possible accident on every ship. The risk of each possible incident must be determined so that a shipper can determine which risks it would like to prepare against. For example, relative probabilities of hull failure can be determined based on ocean conditions, including wave frequency. Portions of the ocean with a wave frequency associated with a high relative probability of hull failure can be avoided, if desired.

A.1.4. Comprehensive Risk Assessment for Rail Transportation of Dangerous Goods: A Validated Platform for Decision Support

Adrian V. Gheorghea, *Reliability Engineering & System Safety,* 2005; pp. 247-265.

Most risk assessment models are reactive and only estimate risk after an event has already occurred. Research is needed to help determine causes of incidents that force the release of hazardous materials. By determining why incidents occur, this research will help limit the number of accidents and releases involving hazardous materials. Calculating the consequences of a release of hazardous materials is discussed. Factors such as wind speed, air pressure, and average temperature contribute to the release of airborne particles. Assumptions are also made for incidents involving fires and shock waves. Expected consequences of an incident can influence route choice to avoid hot spots, locations with a large population center or high risk of an incident.

This study analyzes past incidents and categorizes each incident into one of approximately 30 groups. These groups include items such as rail failure, a foreign object on the track, maintenance on the track, and excessive speed. Identifying common causes of the release of hazardous materials can help inform future planning and risk assessments. Data regarding route choice and accident probabilities can be adjusted to be more accurate based on past incidents.

A.1.5. The Weighted Risk Analysis

Shahid Suddle, *Safety Science,* 47, 2009; pp. 668-679.

Suddle discusses how buildings in The Netherlands are being erected near and above hazardous materials transportation routes. Suddle expands on the quantitative risk analysis framework that the Dutch regulations require to assess the safety of such projects to allow other aspects of risk in the decision-making process. He proposes a 'weighted risk analysis' (WRA) methodology that would allow the effect of safety measures to be optimized with regards to environment, quality, political, and economical aspects, thereby expanding the decision criteria from economic and human risks.

Suddle takes the Risk = Frequency × Consequence risk model and introduces weighting with the final overall risk being equal to the sum of the risks of each aspect:

$$Risk_{final} = \sum_{j=1}\left(\propto_j \sum_{i=1} R_{ij} \right)$$

$$where \propto = the\ monetary\ value\ per\ considered\ loss\,(cost\ unit)$$

This risk value is then put into a Cost equation to be minimized:

$$C_{total} = C_0(y) + \sum_{j=1} \frac{Risk_{final}}{(1+r)^j}$$

$$\begin{aligned} where\ C_0(y) &= investment\ in\ the\ safety\ measure\ y, \\ j &= number\ of\ the\ year, \\ r &= real\ rate\ of\ interest \end{aligned}$$

The author states that the monetary value per considered loss, $\propto$, can be found through research; however, varying the values given for each considered loss in the weight can have a strong impact on the final weighted risk value and, thus, over the total decision-making process.

A.1.6. Risk Assessment of Transporting Hazardous Material: Route Analysis and Hazard Management

K. David Pijawka, Steve Foote, and Andy Soesilo, *Transportation Research Record 1020,* 1985.

In this article, the authors delve into the consequence side of hazmat transportation risk by discussing the vulnerability of communities to hazardous material accidents. The authors describe that the lower the vulnerability of a community, whether through preparedness or risk mitigation, the lower the possible consequences.

To emphasize their point and further discuss overall industry risk analysis, the authors use hazmat transportation on major highway routes in Arizona. The first step in the risk analysis is to identify the hazardous materials being shipped, the amount of hazmat cargo, and the routes used to ship the cargo. Next, exposure-miles, the total number of miles traversed annually by vehicles carrying hazmat on a route-by-route basis, is calculated by: (1) applying the load-per-vehicle factors to the weight of hazmat transported by hazard class, which gives the number of trips by class; (2) summing the number of trips by class for an entire route; and (3) multiplying the number of trips by real travel miles along individual routes. Then, the authors calculate the probability of a hazmat accident by multiplying the prevailing accident rate by the number of total number of miles of exposure on each route. The population-at-risk factor is then calculated by multiplying the hazmat accident probability and the population-at-risk, as determined by evacuation distances, for each route.

Alternatively, risk can be assessed through the use of use of the potential hazard rating (PHR), which measures the potential hazard posed by hazmat based on the volume of materials and the evacuation distance by class. Including a PHR in a risk analysis makes it easier to inject a more sensitive measurement of incident severity into any risk equation.

A.1.7. Review of the Department of Homeland Security's Approach to Risk Assessment

Committee to Review the Department of Homeland Security's Approach to Risk Analysis; National Research Council, http://www.nap.edu/catalog/12972.html, 2010.

The committee was tasked by the U.S. Congress to assess risk assessment approaches across the Department of Homeland Security and to offer suggestions on ways to improve upon the department's approaches. The approach for the report was to review six illustrative risk models in use in the department. While the committee does not explicitly discuss hazardous materials transportation, they do make over-arching statements about the approaches that DHS entities use to assess risk. The committee found that DHS' *risk* approach (as a function of threat, vulnerability, and consequence):

> . . . appears appropriate for decomposing risk and organizing information, and it has built models, data streams, and processes for executing risk analyses for some of its various missions. However, with the exception of risk analysis for natural disaster preparedness, the committee did not find any DHS risk analysis capabilities and methods that are yet adequate for supporting DHS decision making, because their validity and reliability are untested.

As a result, the committee recommended that the department's risk assessments for terrorism need to incorporate a peer review process that includes technical experts that are not DHS employees. The document continues along this call for great transparency by recommending that:

> To maximize the transparency of DHS risk analyses for decision-makers, DHS should aim to document its risk analyses as clearly as possible and distribute them with as few constraints as possible. Further, DHS should work toward greater sharing of vulnerability and consequence assessments across infrastructure sectors so that related risk analyses are built on common assessments.

The paper goes on to further express concern about DHS' all-hazards approach because the authors do not feel that terrorism risk and natural hazard risk can be combined and analyzed based on the same metrics. The authors recommend a move from decision-making approaches based on pure quantitative analysis to ones with scientific guidelines with different approaches for different risks.

The committee conducted an in-depth review of the Terrorism Risk Assessment and Management (TRAM) toolkit, which is a software-based approach to assessing risk primarily within the transportation sector. The tool is used by the industry and has six steps: Criticality Assessment, Threat Assessment, Vulnerability Assessment, Response and Recovery Capabilities Assessment, Impact Assessment, and Risk Assessment. The tool uses user-input data, often arrived at through elicitation of subject-matter experts, to determine the values in the first five steps. Currently, TRAM's main use is in regards to terrorism; however, progress is being made to expand this to man-made and natural disasters.

In addition to expanding TRAM's risk scope beyond terrorism, the Committee states that the tool is overly complex despite the subjective and speculative nature of the inputs. Despite their concerns about TRAM's complexity, the authors did claim that the outputs aid in conceptualizing the risk space, ranking different risks, and showing how risk mitigation activities affect those rankings. The only TRAM-specific recommendation made in the report was to have the tool vetted through a peer review process to evaluate its reliability and identify any improvements that could be made.

A.1.8. Additional Resources

The Freight Transport Portfolio: A New Way to Analyze Intermodal Freight Transport as Compared to Single-Mode Road Transport

Bart W Wiegmans. *Transportation Journal,* Lock Haven: Spring 2010. Vol. 49, Iss. 2; pp. 44-53.

- Calculations of expected performance and reliability.
- Discussion of risk of poor performance from rail transportation.
- Little mention of safety or risk assessment from safety viewpoint; mostly financial risk and reliability considered.

Risk Assessment for the Security of Inbound Containers at U.S. Ports: A Failure, Mode, Effects, and Criticality Analysis Approach

Sameer Kumar, Janis Verruso. *Transportation Journal,* Lock Haven: Fall 2008. Vol. 47, Iss. 4; pp. 26-42.

- Discusses developing a risk assessment for cargo at ports; can be extended to hazmat.
- Includes risk of catastrophic event caused by sabotage, a security lapse, equipment malfunction or human error.
- Suggestions for reducing risk as well as to more accurately measure risk.

Analyzing Mitigation of Container Security Risks Using Six Sigma DMAIC Approach in Supply Chain Design

Sameer Kumar, Heidi Jensen, Heather Menge. *Transportation Journal,* Lock Haven: Spring 2008. Vol. 47, Iss. 2; pp. 54-67.

- Discussion of container supply chain safety; how to reduce risk.
- While there is not much mention of measuring risk, it does address reducing risk and improving safety.

Real-Time Crash Risk Reduction on Freeways Using Coordinated and Uncoordinated Ramp Metering Approaches

Mohamed Abdel-Aty, Vikash Gayah. *Journal of Transportation Engineering,* New York: May 2010. Vol. 136, Iss. 5; p. 410.

- Reducing risk of crashes on freeway.
- Measuring risk and reducing crashes through various algorithms.
- Solid analysis of risk determination for highway crashes.

A Tool for Risk Analysis and Protection Design of Railway Infrastructures

Angela Di Febbraro, Federico Papa, Nicola Sacco. Transportation Research Board Annual Meeting, Washington, DC: 2010. Paper #10-0540.

- Presents an "easy-to-use" risk analysis tool, based on a modular architecture, to evaluate risk and provide mitigation indicators.
- Uses real world experiences made by authors on the Italian high-speed rail lines to apply the tool.
- The tool can be tailored to other real-world situations.

Environmental Risk Analysis of Railroad Transportation of Hazardous Materials

M Rapik Saat, Christopher P.L. Barkan, Charles Werth, David Schaeffer, Hongkyu Yoon. Transportation Research Board 89th Annual Meeting, Washington, DC: 2010. Paper #10-2174.

- Research sponsored by Association of American Railroads to estimate environmental risk when transporting LNAPL chemicals via freight rail.
- Uses the Hazardous Materials Transportation Environmental Consequence Model (HMTECM) with a geographic information system (GIS) for probabilistic estimates of exposure to different spill scenarios.
- Risk analysis incorporated the estimated clean-up cost based on HMTECM, route-specific probability distributions of soil type and depth to groundwater, annual traffic, railcar accident rate, and tank car safety features.

- Annual per car-mile and per ton-mile risk was calculated, too, which allowed financial comparisons to be drawn between shipping different chemicals.
- Risk reduction estimates were also investigated based on the use of damage-resistant tankers.

Risk Analysis and Reliability Based Design in Tunnel Fire Safety

M Guarascio, M Lombardi, G Rossi, G Sciarra. Third International Conference on Safety and Security Engineering, Rome, Italy: Jun. 2009; pp. 575-584.

- This article covers transportation risk assessment.
- Authors develop a quantitative risk analysis procedure that focuses on smoke control system effectiveness and the spalling effect and structural reliability of the liners.

Transportation Risk Analysis Tool for Hazardous Substances (TRANS) – A User-Friendly, Semi-Quantitative Multi-Mode HazMat Transport Route Safety Risk Estimation Methodology for Flanders

G L L Reniers, Katleen De Jongh, Bob Gorrens, Dirk Lauwers, Maarten Van Leest, Frank Witlox. *Transportation Research Part D: Transport and Environment,* Dec. 2010. Vol. 15, Iss. 8; p-489-496.

- Describes a methodology for assessing the relative risk levels in moving hazardous materials by various modes.
- TRANS divides routes into small segments using multi-criteria analysis and incident likelihood scores.

A.2. Data-Driven Risk Assessment

Many researchers believe that the most accurate risk assessments are based on data and are not subjective. As such, researchers often attempt to use as much data as possible in their risk assessments. The following papers demonstrate algorithms and calculations using large amounts of data. Larger datasets remove some uncertainty from risk assessments and may more accurately calculate risk.

A.2.1. A Decisional Support System to Quantify Risk Due to the Transportation of Dangerous Substances

A. Romano and G. Romano, *Safety and Security Engineering III,* 2009; pp. 565-573.

More hazardous materials are being manufactured than ever before and the transportation of hazardous materials carries a large amount of risk. These materials must be handled in a safe manner, as they pose a tremendous amount of risk to the surrounding areas. In this paper, researchers have developed a decisional support system to identify risks associated with transportation hazardous materials.

This model integrates a database covering each mode of transportation in the study region with GIS capabilities to illustrate potential risks. The database includes what materials are being transported, the length that they are being transported, the conditional release probabilities of all materials, and population data for surrounding areas. By developing an algorithm that includes how dangerous a material is and how close that material travels near population centers, this model allows the risk to be determined with regards to the number of people potentially affected.

A.2.2. An Expeditious Risk Assessment of the Highway Transportation of Flammable Liquids in Bulk

Theodore Glickman, *Transportation Science.* 1991; pp. 115-123.

There are many regulations concerning the transportation of hazardous materials through New York City. Almost all hazardous materials incidents occur because of an accident or because of container failure. Accidents tend to be more dangerous because of the force involved. Container failure normally only involves a spill of material, which tends to be less lethal than the explosion or ignition of hazardous materials. In this study, differing regulations are analyzed to determine the impact of container and route choice.

Conditional release and accident probabilities must be calculated so that expected outcomes can be determined. This study focused on the use of two different containers, two routes (one considered typical and one considered the "most hazardous"), and two risk scenarios (the average case and the worst case). These scenarios were then analyzed to determine the risk of a release, a release that leads to a fire, and an explosion. An estimated number of fatalities was also determined based on the expected outcome of the above scenarios. By using data to determine risk, a risk model can estimate the potential number of fatalities and other consequences of various transportation scenarios.

A.2.3. A New Approach to Hazardous Materials Transportation Risk Analysis: Decision Modeling to Identify Critical Variables

Renee M. Clark and Mary E. Beserfield-Sacre, *Risk Analysis,* Vol. 29, No. 3. 2009.

The authors design a methodology to assess hazmat transportation risks at the loading and unloading stage through the use of a probability and statistics-based approach. The methodology first simplifies, in part through the use of latent class analysis (LCA), the variables from data collected through the DOT'S HMIRS database, which contains data on hazmat releases. Next, the authors measure the relationships between variables using a log-linear analysis. The authors then develop a Bayesian network decision model. After aggregating container-failure variables with natural subgroups (area type, land use, geographic division, season, shift, material type, container type, release quantity, dollar loss), the authors use the LCA to simplify the five sets of binary variables (contributing action, causing object, failure mode, failure item, and failure area). Through the log-linear analysis, the authors found relationships between: material type and container type, season and material type, and shift and location. Finally, 40,191 accident records were divided into five sets so five-fold cross-validation could be done, resulting in five Bayesian networks. The networks were accurate 70% of the time in regards to "dollar loss" and 87% of the time for "release quantity."

The authors used GeNIe software to determine that "causing object" was the leading explanatory variable based on five networks with regard to medium, small, and zero dollar loss. "Failure item-area" and "contributing action" were, respectively, the second and third leading explanatory variable. With regards to release quantity, contributing action, failure mode, and failure item-area were first, second, and third, respectively, leading explanations.

The authors conclude with two tables that explore the best targets, according to their model, for reducing risks by mitigating the explanatory variables. As a result, their decision model can support decision making at the Office of Hazardous Materials Safety.

A.2.4. Additional Resources

Risk-Based Volume Warrants for Free Right-Turn Lanes on Two-Lane Roadways

Jidong Yang. *Journal of Transportation Engineering*. New York: Apr 2008. Vol. 134, Iss. 4; p. 155.

- Risk assessment of vehicle crashes as cars slow to make a right-hand turn.
- Determining probability of likelihood of crash based on modeled scenarios; can be extended to hazmat.

Crashing, Smashing, Evaluating

Kathi Kube. Trains. Milwaukee: Dec 2010. Vol. 70, Iss. 12; pp. 16-17.

- FRA R&D testing specialized rail cars, designed to transport hazmat.
- Describes FRA testing research.
- Physical testing of pressure cars.

A.3. The Use of Risk Analysis and Route Choice

Individual route choice contributes significantly to the amount of risk associated with transporting a particular shipment. Determining which routes have a greater risk allows a shipper to determine if they are willing to accept higher risk in exchange for lower operating costs. The seemingly shortest and cheapest route might not be best if it travels through a large population center or poses other risks. The following papers illustrate the usefulness of determining routes by balancing risks with costs.

A.3.1. A Framework for Risk Assessment and Decision-Making Strategies in Dangerous Goods Transportation

B. Fabiano*, F. Cuffô, E. Palazzi, R. Pastorin, *Journal of Hazardous Materials.* 2002; pp. 1-15.

While transporting hazardous material by rail involves large quantities of hazardous materials, transport by road is often more dangerous because roads tend to travel through higher populated areas. Data must be collected to describe the population on potential transport routes.

The authors created a model to analyze the impact of route choice in various populations. For example, a route can be determined to have a small, yet vulnerable population. This could influence transportation planners and policy makers to avoid this smaller population and steer hazardous materials towards a larger population with a greater chance of survival. Many of these decisions are entirely subjective and political, but the model offers an objective look at the potential impacts of various route choices.

A.3.2. Road Transportation of Dangerous Goods: Quantitative Risk Assessment and Route Comparison

Philippe Cassini, *Journal of Hazardous Materials,* 61. 1998; pp. 133-138.

The author sets out to compare choices in trucking routes between urban areas and alternatives that include tunnels between 2 and 9 km in length. The key data points are population density along the route, all vehicular traffic along the possible routes, the dangerous goods itself (how it is contained), global annual traffic, weather along the route, the lay-out of the open air routes, and, if applicable, disposition taken for the design and equipment of the tunnels. The program looks at 10 scenarios to evaluate the risk along the route.

The author uses a Fortran-written program to evaluate the risks for open-air travel by developing F/N curves that show yearly frequency against number of fatalities. For tunnels, the author uses a spreadsheet tool to determine the F/N curves.

The author does point out that the research is limited by the low number of scenarios corresponding to a very small number of hazardous materials. Also, there is difficulty in maintaining and forecasting data for future traffic patterns; however, the author points out that it is possible to judge the acceptability of the risks due to the transportation of dangerous goods on the route by comparing the 'F/N' curve with acceptance criteria.

A.3.3. Preliminary Study on the Transport of Hazardous Materials Through Tunnels

Roberto Bubbico, Sergio Di Cave, Barbara Mazzarotta, Barbara Silvetti, *Accident Analysis & Prevention.* 2009; pp. 1200-1205.

The authors conducted a risk analysis to determine the differences in risk for the shipping of hazardous materials via rail and road through tunnels versus open air. They used the American Institute of Chemical Engineers (AIChE)'s 2000 "Guidelines for Chemical Process Quantitative Risk Analysis" and fault tree analysis to determine the risk scores for two potential release scenarios—15 mm hole, 15 minute duration, and whole tanker release via 220 mm hole—of gasoline, LPG, liquefied chlorine and liquefied nitrogen. The risk analysis used TrHazGis software for risk assessment and management.

For rail, tunnels have a lower societal risk than whole route in the open, perhaps due to the lower number of people at risk inside the tunnel (in highway tunnels, the presence of additional vehicular traffic contributes to the risk). For trucking, tunnels increase the societal risk due to the changes in the fault tree of the tunnel scenarios. For instance, LPG may create a jet fire in the open, but in the tunnel there is the possibility of more hazardous outcomes such as BLEVE, vapor cloud explosion (VCE), or fireball. Finally, in the case of an inert gas (nitrogen), the risk associated with rail is extremely low, and for road, the risk is somewhat greater.

A.3.4. Toll Policies for Mitigating Hazardous Materials Transport Risk

Patrice Marcotte, Anne Mercier, Gilles Savard, Vedat Verter, *Transportation Science,* Vol. 43, No 2, May 2009; pp. 228-243.

The paper focuses on governments' attempts to regulate the trucking routes that hazardous materials are shipped through by closing road segments based on minimizing population exposure and transport costs. The authors propose not closing road segments based on regulator decision but instead through the use of tolls for transporting hazmat through certain road segments. By using tolls, the government can set fees that would impact the shippers' cost-benefit analysis and create incentive for the shipper to find alternative, less-populated routes. With a toll-setting policy, the regulator sets a toll where it minimizes population exposure and travel costs, with the use of tolls allowing for the differentiation between carriers. The toll (either positive or negative value) can be set in a way that the regulator and the carriers' optimal routes are the same.

The authors looked at hazmat trucking along the highway system in Western Ontario, Canada, and show how toll-setting policies can achieve higher reductions in the associated transport risks while only slightly increasing the carriers' costs.

A.3.5. Utilization of Accident Databases and Fuzzy Sets to Estimate Frequency of HazMat Transport Accidents

Yaunhua Qiao, Nir Keren, M. Sam Mannan, *Journal of Hazardous Materials.* 2009.

The authors present

> . . . a methodology to estimate the accident frequency for different types of roads by incorporating the effects of a larger number of parameters, including the nature of truck configurations, operating condition, environmental factors, and road condition.

The authors consider the HMIS, which contains information pertaining to hazmat spills and accidents that occur on interstates; state Department of Public Safety (DPS) accident databases, which can contain information about the route and environmental conditions surrounding the accident; and the Commodity Flow Survey, which has information about miles traveled. The methodology has two sets of parameters: route-dependent (lane number, weather, population density) and route-independent (truck configuration, container capacity, driver experience). Their procedure to estimate accident frequency is:

> (1) Number of accidents is derived from the DPS databases as a function of route-dependent parameters. (2) The corresponding vehicle-mile data are obtained from state DOT's or transportation institutes and from the 2002 CFS . . . (3) The basic accident frequency is modified by considering the effects of route-independent parameters. Fuzzy logic is employed to incorporate expert knowledge.

The authors used a highway in Texas to determine the following relationships: increases in population density and in number of lanes lead to an increase in the frequency of accidents, weather conditions (clear or other) affect frequency, increase in both the complexity of vehicle configuration and container capacity resulted in higher frequency.

In the end, the methodology provides information and data that improves upon the frequency term in hazmat trucking risk assessments.

A.3.6. Guidelines for Chemical Transportation Safety, Security, and Risk Management

Center for Chemical Process Safety of the American Institute of Chemical Engineers and John Wiley & Sons, Inc., Hoboken, New Jersey. 2008.

This resource is designed to augment *Guidelines for Chemical Transportation Risk Analysis* published in 1995. It adds a broader perspective and includes "more qualitative and practical techniques for screening, identifying, and managing higher-level risk issues that balance both safety and security." Recognizing the nature of many operations, the book examines risk from an international perspective. The book puts risk analysis into the overall context of safety and security management systems and discusses the key risk assessment concepts of (1) identification and prioritization, (2) risk analysis, (3) risk evaluation, and (4) risk reduction. The authors present a concise differentiation between risk analysis (the process of evaluating likelihood and consequence and estimating risk) and risk assessment (the process of taking risk analysis results and using them to help make decisions).

The authors discuss the scope of a potential assessment, to consider all movements and materials or with some restrictions to material, mode, route, or some smaller subset of all shipments. Four types of initial prioritization options are listed, with each based on (1) hazard, (2) consequence, (3) likelihood, or (4) risk, respectively.

Qualitative and semi-quantitative risk assessments are presented as good practices to focus the more intensive detailed quantitative risk assessments on those operations where they can be most beneficial. A key factor discussed is the importance of company-specific evaluation criteria to guide the decision making process. These criteria need to be consistent with the organizations risk tolerance and established before any analyses are conducted.

The use of benchmarking comparisons in qualitative analyses is presented as a good way to begin and help identify other areas where additional detail or analysis is needed. Qualitative reviews should also consider the nature of any anticipated changes in operations, including new materials, modes, packaging, carrier, quantities, and many others.

Semi-quantitative analyses have a benefit of not requiring risk management experts to conduct; many others are presented and include ease of application and update, ability to address a range of consequences and likelihoods, and efficient use of resources. The book includes a wide range of topic areas and questions to assist in conducting these types of analyses. Ultimately, the results of individual elements are brought together and one approach is to use a risk index. A second approach presented is a risk matrix. Both are very helpful in identifying the key areas for further focus and analysis.

Quantitative risk analysis focuses on basic concepts and methodology, calculation techniques, data requirements and limitations, results and presentation formats, and common pitfalls. Where data and availability are concerned, the authors suggest that simple scenarios are usually better for transportation risk analysis. Data used should be the most applicable, statistically sound data available. For example, specific carrier accident rates are preferred to generic truck accident rates. Generic rates should not be used for specialized conditions, such as for tank truck shipments. The authors caution about using rates derived from different sources for the numerator and denominator. There is also a discussion about endpoint criteria for consequence analysis, including toxic chemical exposure, vapor cloud explosion, and flammability hazards.

Risk presentation includes the use of risk contours, risk transects, and F-N curves as well as a discussion of uncertainty. Transportation security is covered separately from safety but the similarities are clearly highlighted. There is a discussion of the synergies and tradeoffs between the two. Security prioritization and vulnerability assessment are included.

The book includes a treatment of risk reduction strategies that addresses balancing safety and security, factors influencing risk reduction options, pre-shipment risk reduction options, and selecting strategies. The final chapter discusses sustainability of a risk management program that addresses incorporating advances in analysis techniques and best practices.

A.3.7. City of Boston Hazmat Route Evaluation

Battelle, City of Boston Department of Transportation. April 2011.

This report is one of the few route risk analyses publicly available and examines alternatives necessitated to the existing (and grandfathered) routing restrictions after completing of the "Big Dig" project that depressed some of the major roadways through Boston; some of the previously designated routing alternatives no longer existed. This study implements the routing guidelines for non-radioactive hazardous materials specified in 49 CFR 397.71(b) and in accordance with the DOT document *Highway Routing of Hazardous Materials, Guidelines for Applying Criteria to Designate Routes for Transporting Hazardous Materials* (Publication No. FHWA-HI-97-003).

The report discusses the iterative approach for identifying alternate routes for consideration and eliminating those with insufficient roadway width, clearance restrictions, or bridge conditions. Truck accident rates were determined separately by the University of Massachusetts from truck flows provided by the authors and accident data from the City of Boston. The types and quantities of non-radioactive hazardous materials were estimated from PHMSA incident data; inspections conducted in Boston; permits and applications for transporting hazmat in Boston; hazmat shippers and carriers registered within 75 miles from Boston; and Census commodity flow survey data. Generally, Class 3 materials were used as a proxy for all materials in the analysis. Bulk gasoline pool fires were used to determine the potential impact area.

Residential population data from the Census were determined from transportation analysis zone data at the Census tract level and day and night population estimates were derived from other Census data. The authors determined that 30 percent of the nighttime population would be home during the day. Employment population were obtained from city officials and adjusted by broad estimates of the percentage of workers that worked during the day (83%) versus as night (17%). School, hotel, hospital, nursing home, and visitor populations were determined from various GIS analyses.

Ultimately, population density was determined along each potential route. Travel times were determined by city staff that actually drove each of the routes.

The analysis first considered through hazmat routing. A comparative analysis using the ratio of the current route to that of each proposed alternative was used. Risk and distance were used and compared to the guidance to determine if the alternate route should be prescribed. Risk was calculated by multiplying the average population density within one-half mile along the route, the accident rate, and distance.

Uncertainty analysis was used to determine the threshold at which the risk ratio was significant; only alternatives that exceeded this threshold were considered for adoption. Additional sensitivity analyses were also performed, including varying the percentage of residents that stay home during the day and varying the percentage of workers at night. Some qualitative assessments were also considered and discussed.

Finally, the burden to commerce from increased travel times was estimated for different operations. The authors conclude that there is ample justification for monitoring, controlling, or prohibiting through shipments from downtown Boston during the day. They select a specific route as a leading candidate for designation as a through hazmat route. Route risk is population based and the authors state that other factors, such as emergency response capability, location of sensitive environmental features, climate, and burden to commerce cannot "be used to effectively discriminate among the alternative through routes."

A.3.8. Additional Resources

HazMat Transportation by Heavy Vehicles and Road Tunnels: A Simplified Modeling Procedure to Risk Assessment and Mitigation Applied to an Italian Case Study

B. Fabiano, E. Palazzi. *International Journal of Heavy Vehicle Systems***.** Genève, Switzerland: 11 Oct 2010. Vol. 17, Numbers 3-4; pp. 216-236.

- Use an Italian case study to assess the risk associated with transporting hazardous materials by heavy vehicles.
- Analytical model for solving the ventilation design for both plane and sloping tunnels is shown.

Strategic Thinking and Risk Attitudes in Route Choice: Stated Preference Approach

Michael Razo, Song Gao. *Transportation Research Record: Journal of the Transportation Research Board, No. 2156*, Washington, DC: 2010; pp. 28-35.

- Conducts a stated preference study to investigate route choice behavior in networks with risky travel times and real-time information.
- Two maps are used to determine if routes were adapted as new information about the designated route becomes available:
  - Map one measures the basic risk attitude of the subject by offering the choice between a stochastic route and a deterministic route.
  - Map two allows for strategic planning and measures the effect of this opportunity on subject's choice behavior by containing real-time information and an available detour.
- Data gathered is used to estimate several choice models based on travel times and standard deviations as explanatory variables.

Risk Assessment for Transportation of Hazardous Materials Through Tunnels

E G Nathanail, S Zaharis, N Vagiokas**.** *Transportation Research Record: Journal of the Transportation Research Board, No. 2162***,** Washington, DC: 2010; pp. 98-106.

- Presents a methodology to estimate the risk associated with the transportation of hazmat through tunnels and identifies remedial measures to minimize unacceptable risk levels.
- A societal risk assessment is used to determine if alternative routes should be considered and then an overall risk assessment is conducted on the tunnel route and alternative routes.
- If the tunneled route has the lowest risk, risk reduction measures are implemented.

Routing Hazardous Materials around the District of Columbia Area

Shih-Miao Chin, Ho-Ling Hwang, Bruce E Peterson, Lee D Han, Charles Chin. *Journal of Transportation Safety & Security*, 09 Dec. 2009. Vol. 1, Iss. 4; pp. 296-313.

- Lays out a methodology for evaluating hazmat shipment routing options on via freight rail networks various situations similar to D.C.'s shipment ban.
- Methodology is applied to three alternative routes with population and other vulnerable people within a 0.8 km radius buffer zone values being used to evaluate the potential risk from ultra-hazardous materials.
- It is concluded that rerouting results in moderate increases in ton-km and time in transit, but that the overall population at risk will be lowered; however, the population-at-risk burden is shifted from one location to other locations.

A.4. Economic Risk Analysis

Shippers and transportation companies strive to create as much profit as possible, while maintaining a safe workplace and conforming to applicable regulations. Economic risk analysis helps a shipper to maximize profitability while determining the amount of risk they are willing to accept. The following papers explain common techniques when considering economic risk analysis.

A.4.1. A Cost and Expected Consequence Approach to Planning and Managing Railroad Transportation of Hazardous Materials

Manish Verma, *Transportation Research,* Part D 14. 2009; pp. 300-308.

The author looks at the risk and costs associated with the transportation of hazardous materials via rail using a bi-objective optimization model. Verma assesses transporting risk, the primary concern of regulators, by using hazmat-specific expected risk and uses values based on other researcher's efforts to calculate cost to operators.

Verma makes three assumptions: "first, demand is expressed in terms of the number of railcars to be shipped per week; second, operation level details such as congestion is beyond our scope and is ignored; third, the hazmat being shipped possess the same chemical property."

The optimization minimizes the risk associated with hazmat transit and costs to operators such that demand for hazmat and non-hazmat railcars is met and that operating constraints of the train service, classification yard, and transfer yards are not exceeded.

Costs to operators is based on Ahuja et al.[19] research value of \$0.50 to move a railcar one mile and \$50 per intermediate handling. The hourly fixed cost of operating a train is \$500, and the average speed of a train is around 22 mph based on Railroad Performance Measures data from 2008.

The risk is based on the probability that train meets with an accident and the consequence of the accident, which is a function of probability (given that an accident has happened: probability of derailment: 0.2347, probability of derailed car is hazmat: 0.4087, probability of a derailed hazmat car has a hazmat release: 0.3952, and population exposure due to hazmat).

Four hazardous materials are used: ammonia, chlorine, hydrochloric acid, and petroleum. After assessing the probabilities, Verma optimized the data for the Norfolk Southern network and found that hazmat cargo is being shipped along neither the least expensive nor the least risk routes – showing that neither objective (cost or risk) is dominating.

The article lists three key contributions that it makes to the industry: 1) it is the first tactical planning model for railroad transportation of hazmat where transport risk calculation incorporates the sequence of events leading to hazmat release from multiple sources; 2) it is the only work that throws light on yard and line activities, given the incorporation of risk in the decision making framework; 3) it is the only work that suggests a number of non-dominated solutions to generate risk-cost trade-off frontier that could be used to both plan and manage railroad shipments.

A.4.2. Valuation of Road Safety Effects in Cost-Benefit Analysis

Wim Wijnen, Paul Wesemann, Arianne de Blaeij, *Evaluation and Program Planning,* 32. 2009; pp. 326-331.

The VoSL plays an important role in cost-benefit analysis for safety measures and in consequence variable in risk assessments. VoSL is measured via the concept of "willingness to pay," which is the maximum amount people are willing to pay for a given decrease in fatality rate, i.e. if two in 10 people die from an event, the cost paid to lower the rate to one in 10 would represent the "willingness to pay" for one statistical life; therefore, VoSL is the value of a decrease in the fatality rate, not a specific life.

The human capital approach is an alternative method to calculate VoSL. Here, the VoSL is based on the economic loss of the deceased's productive capacity. Additionally, VoSL can be calculated through "quality adjusted life years" (QALYs) which expresses the benefit of saving a life in the number of healthy life years gained. This value "is calculated by a reduction of the number of life years lost due to early death and the number of years someone lives with a disability, weighted for their severity;" however, pure QALYs do not address whether or not an investment is socially profitable. In order to do so, a willingness to pay for a QALY lost or gained needs to be established, and by doing so, the costs in a cost-benefit analysis can include fatalities and injuries.

The "willingness to pay" can be measured through revealed preference (RP)—value risk reductions based on actual behavior—and state preference (SP) methods—uses surveys in which people are asked how much they are willing to pay

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[19] Ahuja, R.K., Jha, K.C., Liu, J., 2007. Solving real-life railroad blocking problems. Interfaces 37, 404-419.

for safety measures. Of the two, RP is seen as being more scientifically rigorous since there could be a difference in real and theoretical behaviors seen in SP methods.

A Canadian study examined 28 VoSL road safety studies and found an average VoSL more than $3.5m (US $, year 2000). Another VoSL road safety study looked at some European countries and the United States. It found an average VoSL of $4.4m (price level 1997). A third study was looked at where the research used regression modeling to calculate the VoSL in 49 countries based on data from 13 and found that the VoSL in Europe was $2.7m (price level in 1995) and $2.2m for North America. Within the EU, member states' transport departments use values between 1.4m Eurodollars and 2.6m Eurodollars, with member governments pegging the VoSL at 1.5m Eurodollars.

Taking The Netherlands, where the CBA accounts for medical costs, production loss, human costs (injury and fatality), property damage, settlement costs and cost of traffic delays, as a case study, the authors conclude that VoSL measurements should include human losses for severe injuries. This is based on the observation that in the Dutch case, the total human costs of serious injuries is higher than the total human cost of fatalities.

A.4.3. Additional Resources

Valuing Risks of Death from Terrorism and Natural Disasters

W Kip Viscusi, *Journal of Risk and Uncertainty,* Jun. 2006. Vol. 38, Iss. 3; pp. 191-213.

- Uses a random utility model to examine stated preferences for valuation of public risk of fatalities from terror and natural disasters.
- Two series of pair-wise risk-risk tradeoff choices are made using traffic-related deaths.
- Nationally representative sample used stated preventing terrorism deaths is almost twice as highly valued as preventing natural disaster-related deaths.
- Might be extended to hazmat.

Economic Evaluation of Routing Strategies for Hazardous Road Shipments

F. Saccomanno and A. Y.-W. Chan, *Transportation Research Record 1020.* 1985. pp. 12-18

- This early article discusses how freight companies must constantly balance their costs with the risks their shipments cause. The cheapest option is often the most dangerous and these shippers must find a way to remain profitable without significantly increasing their risk.
- Potential routes were analyzed on the basis of cost-effectiveness.
- Factors that contribute to a route's risk include visibility, congestion, and pavement conditions.
- The authors found that always choosing a route based on minimum accident likelihood will not be cost-effective.

APPENDIX B

List of Organizations Contacted

Relevant Research Organizations
Carriers
Air Transport Association (ATA)
American Transportation Research Institute (ATRI)
American Trucking Associations (ATA)
Association of American Railroads (AAR)
Association of American Railroads/Rail Research Foundation (AAR/RRF)
Association of American Railroads/Railway Supply Institute (AAR/RSI)
BNSF
CSX
International Vessel Operators Dangerous Goods Association (IVODGA), formerly Vessel Operators Hazardous Materials Association (VOHMA)
National Tank Truck Carriers (NTTC)
Norfolk Southern
R&R Trucking
Sentinel Trucking
SLT Expressway
Union Pacific
Shippers
American Chemistry Council (ACC)
Center for Chemical Process Safety (CCPS)
The Chlorine Institute
Compressed Gas Association (CGA)
Dow Chemical Company
E. I. du Pont de Nemours and Company (DuPont)
Institute of Makers of Explosives (IME)
National Association of Chemical Distributors
The National Industrial Transportation League (NITL)
Olin Corporation
TRANSCAER
Federal Agencies
Bureau of Transportation Statistics (BTS)
Chemical Security Analysis Center (CSAC)
Civilian Radioactive Waste Management Program, Office of Logistics Management
Department of Energy (DOE), Office of Environmental Management
Environmental Protection Agency (EPA)
Federal Aviation Administration (FAA)
Federal Emergency Management Agency (FEMA)
Federal Motor Carrier Safety Administration (FMCSA)
Federal Railroad Administration (FRA)

Federal Agencies
Intelligent Transportation Systems Joint Program Office (ITS JPO)
Maritime Administration (MARAD)
Relevant Research Organizations
National Transportation Safety Board (NTSB)
Nuclear Regulatory Commission (NRC)
Oak Ridge National Laboratory (ORNL), Center for Transportation Analysis (CTA)
Occupational Safety and Health Administration (OSHA), Department of Labor
Office of Research, Development, and Technology (RDT)
Pipeline and Hazardous Materials Safety Administration (PHMSA), Office of Hazardous Materials Safety
Pipeline and Hazardous Materials Safety Administration (PHMSA), Office of Pipeline Safety
Research and Innovative Technology Administration (RITA)
Sandia National Laboratories
Savannah River National Laboratory
Science and Technology Directorate (S&T)
Surface Deployment and Distribution Command (SDDC)
Transportation Security Administration (TSA), Freight Rail Division
Transportation Security Administration (TSA), Highway and Motor Carrier Division
Transportation Security Laboratory (TSL)
U.S. Coast Guard (USCG)
U.S. Transportation Command (USTRANSCOM)
Volpe National Transportation Systems Center (Volpe)
State Agencies
California Emergency Management Agency (CalEMA)
California Highway Patrol (CHP)
Commercial Vehicle Safety Alliance (CVSA)
Illinois Department of Transportation
National Council of State Legislatures (NCSL)
International Organizations
Australia Department of Infrastructure and Transport – Dangerous Goods Policy Unit
Civil Aviation Authority of Singapore
Interuniversity Research Centre on Enterprise Networks, Logistics and Transportation (CIRRELT)
Maritime & Port Authority of Singapore's Hazardous Cargo Section
Singapore Civil Defense Force Hazmat Department
Transport Canada – Surface and Intermodal Security Directorate
Transport Canada, Transport Dangerous Goods Directorate (TDG)
UK Department for Transport – Dangerous Goods Division
UK Department for Transport – Vehicle Certification Agency - Dangerous Goods Office
Consulting and Research Organizations
Illinois Center for Transportation
Johns Hopkins University, Applied Physics Laboratory (JHU APL)
The Kentucky Transportation Center at the University of Kentucky
Midwest Research Institute
North Carolina State University, Department of Civil, Construction, and Environmental Engineering
Rensselaer Polytechnic University, Department of Civil and Environmental Engineering
Standing Committee on Transportation of Hazardous Materials (AT040)
Texas A&M University, National Pipeline Safety & Operations Research Center
Relevant Research Organizations
Texas A&M University, Texas Transportation Institute
Transportation Research Board (TRB)
University of Illinois at Urbana-Champaign, Department of Civil and Environmental Engineering
Vanderbilt University, Department of Civil and Environmental Engineering
Virginia Tech, Center for Truck and Bus Safety
General Hazmat Associations
Council on the Safe Transportation of Hazardous Articles (COSTHA)
Dangerous Goods Advisory Council (DGAC)

Insurers
XL Insurance
Zurich
Railway Supply Institute (RSI)
SLT Secured Systems International
Union Pacific
Response Organizations
International Association of Fire Chiefs (IAFC)
International Chiefs of Police (IAPC)
Consulting Organizations
ABS Consulting
Battelle
Booz Allen Hamilton
Engineering Systems, Inc.
Science Applications International Corporation (SAIC)
Visual Risk Technologies, Inc. (VRT)
Professional Associations
Security Analysis and Risk Management Association (SARMA)
DHS University Centers
National Center for Risk and Economic Analysis of Terrorism Events (CREATE)
National Consortium for the Study of Terrorism and Responses to Terrorism
National Transportation Security Center of Excellence
University Transportation Centers
None of the University Transportation Centers was identified as being involved with hazmat transportation risk assessment.

APPENDIX C

Phone Scripts and Email Templates

HM-10 and HM-12 Combined Initial Voicemail Script

Dr./Mr./Mrs. _____________ ,

My name is _____________ and I'm part of a project team investigating the current state of hazardous materials transportation research and risk assessment. This work is funded by the Transportation Research Board of the National Academies. Because of [*your organization's*] connection to hazmat transportation issues, we were hoping to be able to [*meet / speak*] with you to make sure your input is included.

I'll follow this message up with an email that has more detail about our project and my contact information. I look forward to hearing from you.

HM-10 and HM-12 Combined Email Template

Dr./Mr./Mrs. ____________ ,

As [*mentioned in my voicemail / discussed in our previous conversation*], my project team is investigating the current state and applications of hazardous materials transportation research and risk assessment. This work is funded by the Transportation Research Board of the National Academies (under the Hazardous Materials Cooperative Research Program, http://www.trb.org/HMCRP/) as a means to address critical gaps and promote communication in hazmat transportation safety and security research (project HM-10) and in the tools available to the government and the private sector for conducting risk assessments (project HM-12). As such, my project team is interested in [*meeting / speaking*] with you to discuss the hazmat transportation research and risk assessment activities within [*your organization*]. Specifically, we are interested in learning more about the following:

- General hazmat transportation research…
    - Your organization's recent and current research projects and your motivation for conducting this research
    - Project-specific communications tools, such as websites or status updates, that TRB researchers, or other interested parties could use to follow the status of your projects
    - Hazmat transportation projects your organization plans to pursue in the next 5 years
    - Research needs or problem areas you think are important but that your organization does not currently plan to pursue
- If your organization develops, conducts, or uses hazmat transportation risk assessments…
    - The types of risk assessments, the decision-making processes they support, and how you distinguish between alternatives
    - Details on the parameters, models, data, and approaches for those risk assessments
    - Your thoughts on where improvements could be made in risk assessment methodologies, available information, and data collection
- Recommendations for other organizations or specific points of contact whom we should include

[*OPTIONAL*] Attached to this email you will find a spreadsheet containing a list of the hazmat transportation projects that we have already identified through an online review of your organization's current efforts in this field. This document can be used as an example of the information that we are seeking to compile.

Your participation will be used to help shape the future of TRB-sponsored research and provide insight into how different organizations are applying risk assessment to hazmat transportation. I look forward to [*meeting / speaking*] with you and discussing these topics in greater detail.

[*If a time is not already set up*] **Please advise as to your availability over the next couple of weeks to provide input into this research. Include others in your organization as you feel appropriate.**

Thank you for your time and consideration.

Sincerely

APPENDIX D

Interview Questionnaire

HM-10 and HM-12 Combined Questionnaire

Note that the items in blue do not necessarily need to be asked and are intended to facilitate the discussion with the interviewee(s).

#	Question	Comment/Response
	— General Hazmat Transportation Research Questions (A1 – B2) Omitted —	
	Risk Assessment – General	
C1	What does risk assessment mean to you?	[Do they only focus on safety OR security risk assessment? Perhaps they only assess consequence or conditional risk (ignoring the threat component.]
C2	Do you conduct research to improve hazmat transportation risk assessments either for your own organization or for the community in general?	[Ask 'Risk Assessment Researchers' questions (D1-D2)]
C3	Do you conduct hazmat transportation risk assessments for your own organization or for clients?	[Ask 'Risk Assessment Practitioners questions' (E1-E13)]
C4	Are you a consumer of risk assessments performed by others?	[Ask 'Risk Assessment Users questions' (F1-F4)]
	Risk Assessment Researchers	
D1	[Assuming the A-section questions have been answered, ensure that risk assessment-specific research projects are identified; if not, follow up with a focus on hazmat transportation risk assessment.]	
D2	What are the main constraints and analytic assumptions made in your risk-related research, and do you see any weaknesses in your approach?	
	Risk Assessment Practitioners	
E1	What types of risk assessments do you perform?	[Capture differentiation between safety and security here; see C1 comments.]
E2	Who performs these risk assessments?	[Established roles or job positions for this?]

#	Question	Comment/Response
E3	What are your decision-making processes that consider risk assessments? Who are the users? How do they distinguish between different alternatives? *Current uses:* a. Mode choice b. Route choice c. Packaging selection d. Application of security countermeasures anti- e. Carrier selection f. Manufacturing location for serving certain customers g. Alternate product selection enforcement h. Operational changes (incl. training and procedures) i. Emergency response resource planning j. Research prioritization k. Inspection and enforcement prioritization *Users:* a. transportation managers b. route planners c. emergency responders d. law enforcement and terrorism officials e. regulators f. transportation officials g. distribution managers h. insurers i. senior management	[If providing results to others, do they just provide data or do they make recommendations? Does the methodology support considering unquantifiable parameters or cost-benefit output?]
E4	Did you establish your risk assessment models internally or did you adopt external or industry standard models?	
E5	What are the key data elements that are input or built into your models?	[What are the main elements in (T×V×C) or (F×P×C)?]
E6	Where do you acquire the data used in your risk assessments? Are these data sufficient (i.e., relevant, accurate, complete, timely) for your specific purposes?	
E7	How often do you update your risk assessments? Do you only update the data or do you revisit the models as well?	
E8	What assumptions do you make when performing these risk assessments? *Examples:* a. Uniform distribution of accidents, threats, or release probabilities b. Applicability to all entities, vehicle types, etc. c. Availability of emergency response personnel with training and equipment	

#	Question	Comment/Response
E9	What consequences does your methodology consider *Examples:* a. Human health: acute and chronic; potential exposure vs. expected fatalities b. Environmental: waterways (rivers, streams, reservoirs, lakes) and sensitive land areas (parks, forests, wetlands) c. Critical infrastructure/key resources: bridges, tunnels, intermodal facilities, monuments, landmarks, stadiums d. Economic: economically important areas	
E10	What modes of transportation do you assess? Could your risk assessment methods be applied to other modes or intermodal transport?	[highway, rail, marine, air, pipeline; ability to address intermodal?]
E12	Are there any biases built into data or methods that you use? Are they intentional? *Example biases:* a. More detailed accident rates or other data for one mode or aspect b. Very conservative, such as choosing to overestimate consequences	
E13	Does your methodology address uncertainty (e.g., inherent errors in data, missing or unquantifiable data, sensitivity analysis, determination of confidence intervals)	
	Risk Assessment Users	
F1	What types of risk assessments do you perform?	[Capture differentiation between safety and security here; see C1 comments.]

#	Question	Comment/Response
F2	What are your decision-making processes that consider risk assessments? Who are the users? How do they distinguish between different alternatives? *Current uses:* a. Mode choice b. Route choice c. Packaging selection d. Application of security countermeasures e. Carrier selection f. Manufacturing location for serving certain customers g. Alternate product selection h. Operational changes (incl. training and procedures) i. Emergency response resource planning j. Research prioritization k. Inspection and enforcement prioritization	
F3	Where do you get current risk assessments from? How often do you get updated risk assessments?	
F4	Why do you use that source instead of others or your own work?	
	All	
G1	Do you communicate the results of your risk assessments internally or externally?	[To first responders, sales representatives, enforcement, in developing proposed regulations, etc.?]
G2	What improvements in risk assessment methodologies, available information, or data collection would be most helpful to your organization? *Examples of limitations:* a. Applicability to a single mode b. Cannot support integration of safety and security c. Applicability only to large shipments or locations of frequent operations d. Large uncertainty makes clear choices among alternatives difficult e. Historical data do not reflect changing conditions/trends f. Applicable to generic hazard class(es) and not specific materials	[cover improving perceived limitations or gaps]
G3	What are the main barriers you see for using or performing risk assessments?	[e.g., legal ramifications from doing a benefit-cost analysis]
G4	Are there any specific organizations or people that you recommend we contact?	

APPENDIX E

Online Survey Invitation

Our project team is researching the state of the practice for hazardous materials transportation risk assessment for the Transportation Research Board (TRB) Hazardous Materials Cooperative Research Program (HMCRP) and has directly interviewed many organizations.

This survey is being conducted to allow other users, practitioners, and researchers of hazardous materials transportation risk assessments to provide input. Your responses will be used to help determine the current state of the practice and help identify gaps and needs regarding risk assessments. A complete description of the project from the TRB website is available at http://goo.gl/G6JW7.

The one-page survey is available at: http://goo.gl/8hsm1. Forwarding to other colleagues is welcome. We appreciate your contribution to our research!

Sincerely,

APPENDIX F

On-Line Survey

HazMat Risk Assessment - State of the Practice

Our project team is researching the state of the practice for hazardous materials transportation risk assessment for the Transportation Research Board (TRB) Hazardous Materials Cooperative Research Program (HMCRP) and has directly interviewed many organizations. This survey is being conducted to allow other users, practitioners, and researchers of hazardous materials transportation risk assessments to provide input. Your responses will be used to help determine the current state of the practice and help identify gaps and needs regarding risk assessments. A complete description of the project from the TRB website is available at http://goo.gl/G6JW7.

* Required

1. What is your organization type: public, shipper, carrier, consultant, academic, association (industry, shipper, carrier)? *
2. What does risk assessment mean to you? Do you include safety, security, or both when you think of risk assessment? *
3. Which best characterizes your organization's hazmat transportation risk assessment activities? More than one may apply. *

   (a) Conduct Research on Data or Methodologies
   (b) Conduct Assessments
   (c) Use Assessment Results

4. If (a) in question 3 applies to your organization, briefly describe the research.
5. If (b) or (c) in Question 3 applies to your organization, briefly describe your risk assessment activities, including the users, the decision-making processes that consider risk assessments, and how the users distinguish between different alternatives.
6. Describe any constraints, analytic assumptions, or biases in your research or risk assessments. *
7. What are the key data elements that are input or built into your models (consider frequency, probability, threat, vulnerability, and consequence, as appropriate, in your response)? Where do you acquire the data? Are these data sufficient (i.e., relevant, accurate, complete, timely) for your specific purposes? *
8. What are the main barriers you see for using or performing risk assessments? *
9. Do you communicate the results of your risk assessments internally or externally? How? To whom? *
10. What improvements in risk assessment methodologies, available information, or data collection would be most helpful to your organization? *
11. Please provide your name and company/organization. This information will remain confidential. *
12. Please provide a phone number or e-mail address so that we can reach you if we have any follow-up questions.

Acronyms and Abbreviations

AAR – Association of American Railroads
ABS – ABS Consulting
ADR – European Agreement concerning the International Carriage of Dangerous Goods by Road
AIChE – American Institute of Chemical Engineers
ANSI – American National Standards Institute
ASME – American Society of Mechanical Engineers
ATA – Air Transportation Association
ATA – American Trucking Association
ATCCRP – Advanced Tank Car Collaborative Research Program
ATF – Bureau of Alcohol, Tobacco, Firearms and Explosives
ATRI – American Transportation Research Institute
BASIC – Behavior Analysis and Safety Improvement Category
BLEVE – boiling liquid expanding vapor explosion
BTS – Bureau of Transportation Statistics
C – consequence
Cal EMA – California Emergency Management Agency
CANUTEC – Canadian Transport Emergency Centre
CCPS – Center for Chemical Process Safety
CDC – Centers for Disease Control
CFS – Commodity Flow Survey
CGA – Compressed Gas Association
CIKR – critical infrastructure/key resources
CIRA – Chemical Infrastructure Risk Assessment
CIRRELT – Interuniversity Research Centre on Enterprise Networks, Logistics and Transportation
CONTAM – Contaminant Multizone Modeling Software
COSTHA – Council on the Safe Transportation of Hazardous Articles
CPR – conditional probability of release
CREATE – National Center for Risk and Economic Analysis of Terrorism Events
CSA – Compliance, Safety, Accountability
CSAC – Chemical Security Analysis Center
CTA – Oak Ridge National Laboratory Center for Transportation Analysis
CTPS – Central Transportation Planning Staff
CTRA – Chemical Terrorism Risk Assessment
CVSA – Commercial Vehicle Safety Alliance
DGAC – Dangerous Goods Advisory Council
DGAIS – Dangerous Goods Accident Information System
DHS – Department of Homeland Security

DOD – Department of Defense
DOE – Department of Energy
DOT – Department of Transportation
DPS – Department of Public Safety
EA – environmental assessments
EIS – environmental impact statements
EPA – Environmental Protection Agency
ERAP – emergency response action plan
ESI – Engineering Systems, Inc.
F – frequency
FAA – Federal Aviation Administration
FAF – Freight Analysis Framework
FDA – Food and Drug Administration
FEMA – Federal Emergency Management Agency
FMCSA – Federal Motor Carrier Safety Administration
FRA – Federal Railroad Administration
FRMAC – Federal Radiological Monitoring and Assessment Center
GIS – geographic information system
GPS – Global Positioning System
HECOT – Hazmat Event Cross-Observer Tool
HIP – Hazardous Materials Intelligence Portal
HMC – Highway Motor Carriers Division
HMCRP – Hazardous Materials Cooperative Research Program
HMIRS – Hazardous Materials Incident Reporting System
HMIS – Hazardous Materials Information System
HMTECM – Hazardous Materials Transportation Environmental Consequence Model
HPAC – Health Prediction and Assessment Capability
HSSM – Highway Security Sensitive Materials
HTUA – high-threat urban area
IAFC – International Association of Fire Chiefs
IAPC – International Chiefs of Police
IBC – intermodal bulk container
IME – Institute of Makers of Explosives
IMESAFR – Institute of Makers of Explosives Safety Analysis for Risk
ISO – International Standards Organization
ITRD – International Transport Documentation Database
ITS JPO – Intelligent Transportation Systems Joint Program Office
IVODGA – International Vessel Operations Dangerous Goods Association
JHU APL – Johns Hopkins University Applied Physics Laboratory
KTC – Kentucky Transportation Center
LCA – latent class analysis
LEPC – local emergency planning committee
MARAD – Maritime Administration
MSRAM – Maritime Security Risk Analysis Model
NASA – National Aeronautics and Space Administration
NCSL – National Council of State Legislatures
NDE – nondestructive examination
NITL – The National Industrial Transportation League
NNSA – National Nuclear Security Administration
NRC – National Research Council
NRC – National Response Center
NRC – Nuclear Regulatory Commission

NTAD – National Transportation Atlas Database
NTIS – National Technical Information Service
NTSB – National Transportation Safety Board
NTTC – National Tank Truck Carriers, Inc.
OHMS – PHMSA Office of Hazardous Materials Safety
OMB – Office of Management and Budget
OPS – PHMSA Office of Pipeline Safety
ORNL CTA – Oak Ridge National Laboratory Center for Transportation Analysis
OSC – Office of Security Capabilities
P – probability
PHMSA – Pipeline and Hazardous Materials Safety Administration
PHR – potential hazard rating
PRA – probabilistic risk assessment
PTC – positive train control
QALY – quality adjusted life years
RCRAM – Rail Corridor Risk Assessment Model
RCRMS – Rail Corridor Risk Management System
RIP – Research in Progress
RITA – Research and Innovative Technology Administration
RP – revealed preference
RRAS – Readiness and Resilience Assessment System
RRF – Railroad Research Foundation
RSI – Railway Supply Institute
S&T – Science and Technology Directorate
SAFER – Safety Assessment for Explosives Risk
SAIC – Science Applications International Corporation
SARMA – Security Analysis and Risk Management Association
SCC – Sector Coordinator Council
SCIPUFF – Self Consistent Integral Puff
SDDC – Surface Deployment and Distribution Command
SME – subject matter expert
SMS – Safety Measurement System
SP – state preference
SRS – Savannah River Site
SSI – sensitive security information
STB – Surface Transportation Board
TCL – Target Capabilities List
TDG – Transport Canada Transport Dangerous Goods Directorate
THTRA – Trucking and Hazardous Materials Trucking Risk Assessment
TIH – toxic inhalation hazard
TLCat – Transportation Libraries Catalog
TOOM – Transportation Object-Oriented Modeling
TRAGIS – Transportation Routing Analysis Geographic Information System
TRAM – Terrorism Risk Assessment and Management
TRANS – Transportation Risk Analysis Tool for Hazardous Substances
TRB – Transportation Research Board of the National Academies
TRIS – Transportation Research Information Service
TSA – Transportation Security Administration
TSNM – Transportation Security Network Management
TSSRA – Transportation Sector Security Risk Assessment
TVSA – transportation vulnerability security assessment
UIUC – University of Illinois at Urbana-Champaign

UK – University of Kentucky
USCG – U.S. Coast Guard
USDA – U.S. Department of Agriculture
USTRANSCOM – United States Transportation Command
VCE – vapor cloud explosion
VOHMA – Vessel Operators Hazardous Materials Association
Volpe – John A. Volpe National Transportation Systems Center
VoSL – Value of a Statistical Life
VRT – Visual Risk Technologies, Inc.
WRA – weighted risk analysis

Abbreviations and acronyms used without definitions in TRB publications:

A4A	Airlines for America
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
MAP-21	Moving Ahead for Progress in the 21st Century Act (2012)
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