National University Rail Center - NURail
US DOT OST-R Tier 1 University Transportation Center

NURail Project ID: NURail2013-UIUC-E03

Development and Teaching of a Graduate Course in Multimodal Transportation Safety and Risk

By

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DISCLAIMER

Funding for this research was provided by the NURail Center, University of Illinois at Urbana - Champaign under Grant No. DTRT12-G-UTC18 of the U.S. Department of Transportation, Office of the Assistant Secretary for Research & Technology (OST-R), University Transportation Centers Program. The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the information presented herein. This document is disseminated under the sponsorship of the U.S. Department of Transportation's University Transportation Centers Program, in the interest of information exchange. The U.S. Government assumes no liability for the contents or use thereof.

TECHNICAL SUMMARY

Title

Development and Teaching of a Graduate Course in Multimodal Transportation Safety and Risk

Introduction

One of the U.S. Department of Transportation (DOT)'s strategic goals is to enhance public health and safety by working toward the elimination of transportation-related deaths and injuries. Near term targets include reducing highway fatalities, rail-related accidents and incidents, and the number of serious hazardous materials transportation incidents. Attaining the goal requires engineers to understand the causal factors and risks in accidents, and determine the most effective ways of mitigating the consequences of transportation accidents in all modes.

This project involved the development of teaching materials and the actual teaching of a course that provides an introduction to transportation risk concepts, risk management framework and risk assessment methodologies to address safety and security of freight and hazardous materials transport by railways, roads, waterways and pipelines.

Description of Activities

The key effort in this project was identifying and reviewing relevant publications and other resources to develop the class lectures and independent projects. The course was an advanced, graduate-level class as part of the Transportation Engineering curriculum in the Department of Civil and Environmental Engineering (CEE) at the University of Illinois at Urbana-Champaign (UIUC).

Outcomes

Eleven students were enrolled when the class was offered in the Fall 2013 semester at UIUC. The syllabus and lectures are appended to this report. Part of the lectures were used by a NURail-affiliated partner, Rutgers University, in their transportation logistics class. The course implemented an active-learning process including:

- Pre-Reading Assignment
- Pre-Class Quiz
- Traditional Lecture
- In-Class Group Discussion
- Risk Analysis Bootcamp - two-week group project to complete a route-specific risk analysis

- State-of-the-Practice Paper Review (SOP)
- Individual Term Project & Final Presentation

Conclusions/Recommendations

The course as a whole or part of the lectures can be incorporated in courses at other institutions.

Publications/Examples

See course syllabus and lectures attached.

Primary Contact

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University of Illinois at Urbana-Champaign
Department of Civil and Environmental Engineering

CEE 498 TSR - Transportation Safety and Risk

SYLLABUS

Instructors: Dr. M. Rapik Saat, Ph.D. (mohdsaat@illinois.edu)

Semester: Fall 2013

Credit: 3 hours

Weekly Meeting Schedule: 5-6:20pm M/W (2312 Newmark) or Online (for online students)

Course Description:

One of the U.S. Department of Transportation (DOT)'s strategic goals is to enhance public health and safety by working toward the elimination of transportation-related deaths and injuries. Near term targets include reducing highway fatalities, rail-related accidents and incidents, and the number of serious hazardous materials transportation incidents. Attaining the goal requires engineers to understand the causal factors and risks in accidents, and determine the most effective ways of mitigating the consequences of transportation accidents in all modes.

This course provides an introduction to transportation risk concepts, risk management framework and risk assessment methodologies to address safety and security of freight and hazardous materials transport by railways, roads, waterways and pipelines. Students learn about the tools needed to perform comprehensive mode-specific and multimodal transportation risk analyses. Each student is expected to work on a specific transportation safety problem of his/her interest, and identify, assess and mitigate the risk.

This is an advanced, graduate-level class as part of the Transportation Engineering curriculum in the Department of Civil and Environmental Engineering (CEE) at the University of Illinois at Urbana-Champaign (UIUC). This course could also be used as one of the core courses for the newly developed Societal Risk Management (SRM) cross-disciplinary program in the department. This course is being developed as part of the US DOT National University Rail Center (NURail) that UIUC is leading to support the aforementioned U.S. DOT safety strategic goal.

Objectives:

Introduce transportation risk concepts, risk management framework and risk assessment methodologies to address safety and security of freight and hazardous materials transport by railways, roads, waterways, pipelines and air.

CEE 498 TSR - Transportation Safety and Risk

SYLLABUS

List of Principal Topics

- Transportation risk management system
- Structuring decision problem
- Basic GIS & transportation spatial data
- Risk assessment techniques
- Risk communications
- Rail transportation risk
- Road transportation risk
- Highway Safety Manual (HSM)
- Pipelines transportation risk
- Inland waterway (barge) transportation risk
- Maritime transportation risk
- Aviation transportation risk
- Risk reduction strategies
- Hazardous materials consequence models
- Transportation security considerations
- Passenger and transit safety issues
- Other advanced topics in transportation risk analysis

Reading Materials:

Selected industry publications and journal articles related to the course topics

Grading Weights:

- Term project: 60 % (abstract 5%, mid-term draft presentation 15%, final presentation 40%)
- Homework and group assignments: 30%
- Class participation: 10%

CEE Honor Code

To foster and promote integrity among students, the CEE Honor Code was developed with input from several CEE undergraduate organizations, the CEE Graduate Student Advisory Committee, and the CEE Graduate Affairs Committee. You (the student) commit to honor the code each time you sign an exam, and implicitly whenever you sign homework or other class assignments.

The CEE Honor Code pledge is the following:

I pledge to uphold the highest levels of professional and personal integrity in all of my actions, including 1) never assisting or receiving unfair assistance during exams, 2) never assisting or receiving assistance on class assignments beyond that specified by an instructor, and 3) always fully contributing to group activities that are part of a course activity.

INTRODUCTION

CEE498 TSR -Transportation Safety and Risk

Dr. Rapik Saat, Ph.D.

Rail Transportation and Engineering Center – RailTEC

Department of Civil & Environmental Engineering

University of Illinois at Urbana-Champaign, U.S.A.

RAILTEC
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

Course Introduction

- Introduction to transportation risk analysis, focusing on freight and hazardous materials transportation
- Covers:
  - Transportation risk management framework
  - Transportation risk assessment concepts
  - Transportation risk assessment methodologies
  - Multimodal transportation quantitative risk analysis (QRA)

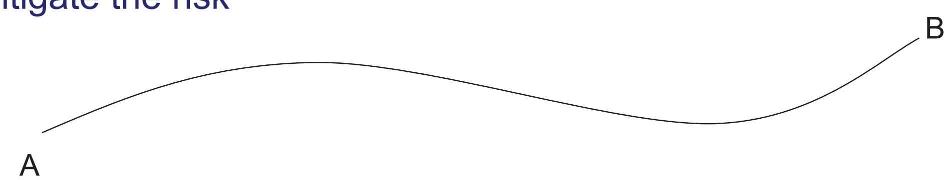
Learning Outcomes

At the end of this course students will be able to:

1. Understand basic concepts in transportation risk
2. Structure transportation risk problems by identifying potential hazards, initiating events, likelihood and accident consequences
3. Identify data needs to perform transportation risk analysis
4. Perform a comprehensive transportation route risk analysis

General Expectation

- If there is a demand to transport a product from point A to B:
  - Identify potential single or multiple transportation mode(s)
  - Which alternative is better (risk, cost, etc.)?
  - What data we need/have?
  - How to quantify the risk?
  - How can we reduce the risk?
- Each student is expected to work on a specific transportation safety problem of his/her interest, and identify, assess and mitigate the risk



Grading

- Term project: 60%
  - Abstract 5% (due date TBA)
  - Mid-term draft final presentation (15%) (dates TBA)
  - Final presentation 40% (a half-day mini-symposium on Saturday 12/7 or Thursday 12/12)
- Homework and group assignments 30%
- Class participation 10%

ILLINOIS - RAILTEC

Active Learning Process

- Reading Assignment
- Pre-Class Quiz
- Traditional Lecture
- In-Class Group Discussion
- Risk Analysis Bootcamp
  - *Two-week group project to complete a route-specific risk analysis*
- State-of-the-Practice Paper Review (SOP)
  - *See next slide*
- Individual Term Project & Final Presentation

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State-of-the-Practice Paper Review

- Groups of two each to be proponent or critique of a selected journal paper in a session
- Proponent will prepare a short Pre-Class Quiz for everyone
  - Five to ten True-or-False questions
  - All to complete reading and Pre-Class Quiz before class
- 20-min presentation by the proponent
- 20-min presentation by the critique
- Q&A

Optional Independent Study

- One-hour credit
- Prepare a journal-quality paper based on term project
- Draft due on final presentation day
- Review and submittal of paper and other materials (e.g. cover letter) during final week

ArcGIS Tutorial

- Basic introduction to ArcGIS
- Review ArcGIS tools for transportation risk
- Installed software from campus webstore (free): http://webstore.illinois.edu/
- Bring laptop* to next class
- GIS Self-Learning Module on Compass2g

**You are encouraged to bring a laptop in every class to assist in completing in-class discussion*

Make-Up Classes

- Due to travel to conferences and meetings
- Attend make-up classes or watch recorded lectures
- Make-up classes (Thursday 3:30-5pm):
  - 8/29, 9/5, 9/19, 9/26, 10/3
- No class (*this list might change*):
  - 9/30, 10/7, 10/9, 12/2, 12/4, 12/9, 12/11
- Final Presentation Half-Day Symposium
  - Saturday 12/7 or Thursday 12/12 (Reading Day)

CEE 498HRP Compass2g Site

- Compass2g site for this class will be set up for:
  - Announcements
  - Syllabus
  - Course plan & schedules
  - Lecture notes
  - Reading assignments
  - Pre-class quizzes

Contact Information

- Room : 1243 NCEL
- Office : 217-333-6974
- Mobile: 217-721-4448
- Skype: rapiksaat
- E-Mail: mohdsaat@illinois.edu
- Office hours: By appoinment
- http://cee.illinois.edu/faculty/rapiksaat

Acknowledgements

The development of this course is partially supported by the following organizations. The opinions expressed here do not necessarily represent the views of these organizations.

National University Rail (NURail) Center
U.S. DOT RITA University Transportation Center

RAILTEC
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

An AIChE Technology Alliance
CCPS
Center for Chemical Process Safety

Hazardous Materials Cooperative Research Program
TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

UIUC Railroad Courses

FALL 2013

- CEE 408 - Railroad Transportation Engineering
- CEE 409 - Railroad Track Engineering
- CEE 498HSR - High-Speed Rail Engineering
- CEE 498TSR – Transportation Safety and Risk

SPRING 2014

- CEE 410 - Railway Signaling and Control
- CEE 411 - Railroad Project Design and Construction
- CEE 498HRP - High-Speed Rail Planning
- CEE 598ATE - Advanced Track Engineering

Later Semesters

- CEE 498HRM - High-Speed Rail Construction Management (Fall 14)
- CEE 498HRO - High-Speed Rail Operations and Maintenance (Spring 15)
- CEE 598SRC - Shared Rail Corridor Engineering & Operation (TBD)
- CEE 598ART - Advances in Railway Technology (TBD)

UIUC Railroad Calendar - Fall 2013

- **William W. Hay Railroad Seminars**
  - Presentations by rail industry professionals, faculty and students
  - Approximately every other Friday at noon (free pizza!)
    2311 Yeh Center, NCEL
    To begin in September date TBD
  - *(Recommended for all, mandatory for 4 credit grad students unless they have a conflict)*

  American Railway Engineering and Maintenance of Way Association
  Annual Conference: 30 Sept – 2 Oct, Indianapolis, IN
- **Field Trip - Monticello Railway Museum - Railroad Trackwork**
  Saturday 14 September
- **15th Annual Railroad Environmental Conference**
  Tuesday & Wednesday 5 - 6 November - Illini Union

OVERVIEW OF THE LAC-MEGANTIC DERAILMENT

CEE498 TSR -Transportation Safety and Risk

Dr. Rapik Saat, Ph.D.

Rail Transportation and Engineering Center – RailTEC

Department of Civil & Environmental Engineering

University of Illinois at Urbana-Champaign, U.S.A.

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Overview of the Accident

- On July 6, 2013 (Saturday), at approximately 1:14 am, an unattended 73-car freight train carrying crude oil derailed in Lac-Mégantic, Quebec, Canada
- The resultant fire and explosions from the accident caused the death of 47 people and the destruction of half of Lac-Mégantic's downtown area
- More than 2,000 people were evacuated
- It is the worst crude oil rail accident in North American history and the deadliest rail accident in Canada in the past 150 years

Explosion originated by the derailment of the 73 tank car crude oil train.

Aerial view of Lac-Megantic's Downtown after the accident .

Location of the Accident

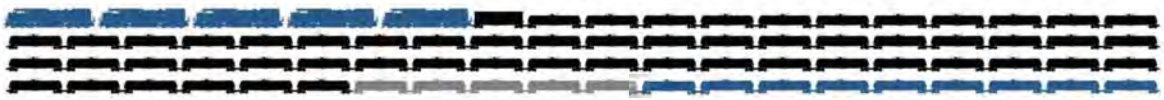
The accident occurred in Lac-Mégantic, Quebec (Canada), home to about 6,000 people

The Train

- The 1.4 km freight train was operated by the United States-based Montreal, Maine and Atlantic Railway (MMA)

- The train departed from New Town, ND where it was loaded with crude oil originated from the Bakken shale formation
- It ran on Canadian Pacific Railway tracks until it was handed over to the MMA near Montreal in Côte Saint-Luc.
- Its final destination was the Irving Oil Refinery in Saint John, New Brunswick
- The train comprised:
  - 5 diesel locomotives
  - 1 buffer car
  - 72 DOT-111 tank cars
- Each tank car was filled approximately with 30,000 gallons of crude oil. In total the train was transporting about 51,429 barrels.

Schematic of the 73 tank car derailed train



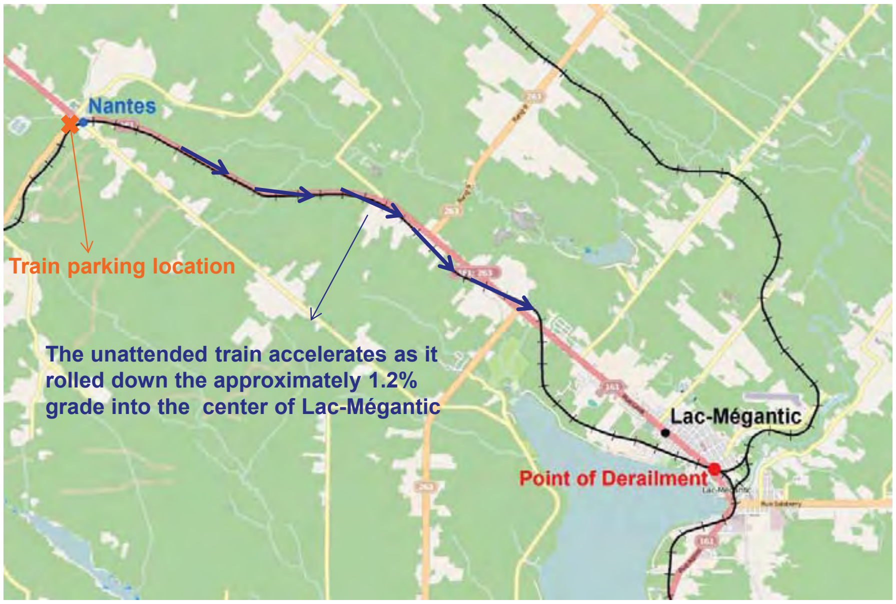
Source: http://news.nationalpost.com/2013/07/12/graphic-the-lac-megantic-runaway-train-disaster//

Detailed Sequence of Events

- Thursday July 5, 2013
  - Morning: The MMA freight train departs the CPR yard in Côte Saint-Luc, Quebec
  - Afternoon: The train changes crews at the MMA yard in Farnham. From this point on, the crew of the train consists only in a driver engineer
  - At 23:25 the train stops at Nantes, 7 miles west of Lac-Mégantic for another crew change
    - The train is parked in the main line as the adjacent siding was occupied by another freight train
    - The lead engine #5017 is left running to keep air pressure supplied to the train's air brakes.
    - The manual hand brakes on the 5 locomotives and 10 of the 73 freight cars are activated
  - The engineer departs by taxi for a local hotel to spend the night

Source: news.nationalpost.com/2013/07/07/graphic-timeline-of-key-events-in-quebec-train-disaster/

Train Stop Location



Detailed Sequence of Events (cont.)

- Thursday July 5, 2013
  - At 23:32 a citizen reports a fire on the lead locomotive to the Nantes Fires department as well as the Sûreté du Québec's Lac-Mégantic
  - At 11:47 two fire engines and 17 firefighters arrive on the scene
    - The lead locomotive is shut down to stop fuel circulation into the fire, following firefighters protocol
    - The fire department extinguishes the fire and notifies MMA's rail traffic controller in Farnham
- Friday July 6, 2013
  - At 00:13 two MMA track maintenance employees arrive at the scene
    - Everyone leaves the scene as MMA track maintenance employees confirm to the Farnham rail traffic controller and to the firefighters that the train is safe

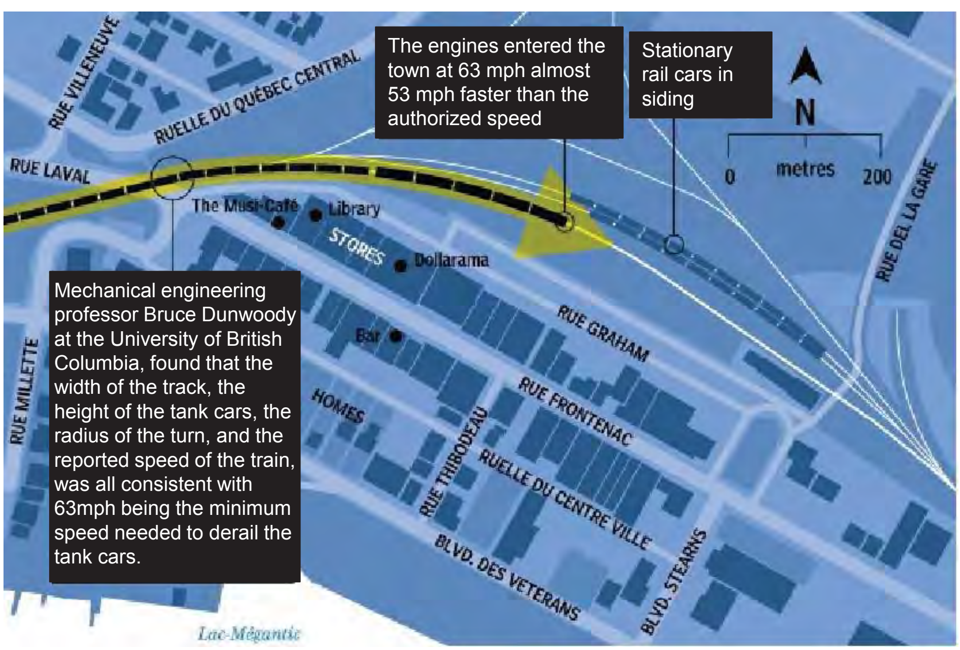
Source: news.nationalpost.com/2013/07/07/graphic-timeline-of-key-events-in-quebec-train-disaster/

Detailed Sequence of Events (cont.)

- Friday July 6, 2013
  - Approximately at 00:56 the unattended freight train begins to roll downhill toward Lac-Mégantic
    - There were no signals or track circuits, so the rail traffic controller would have no indication of a runaway train
  - At 1:14 the train which is going over 60 mph approaches a 10 mph curve in the downtown area
    - 64 cars derailed on the curve (the buffer car + 63 tank cars)
    - The locomotives were found intact about 0.5 miles away from the accident

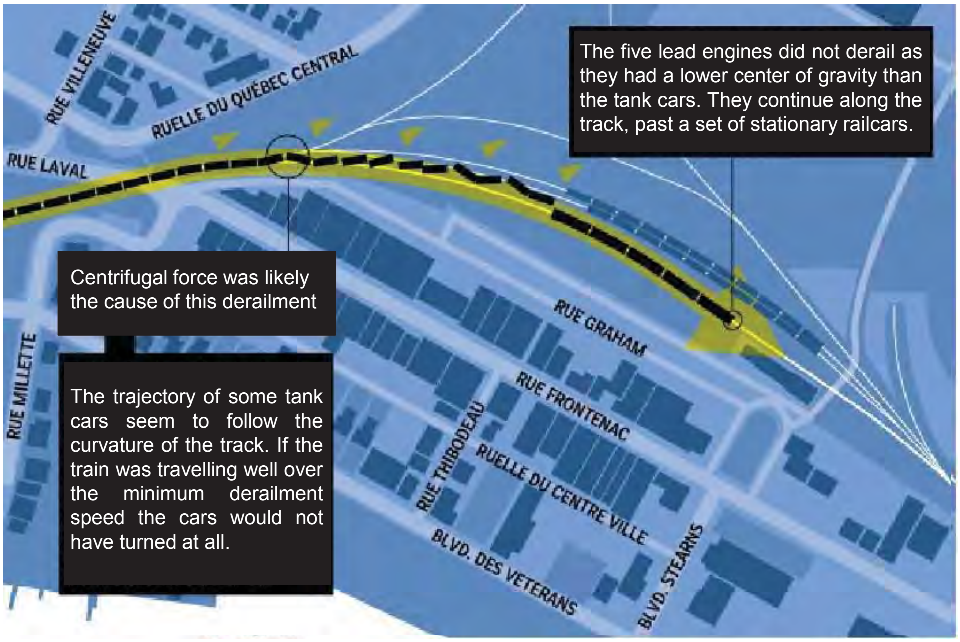
Source: news.nationalpost.com/2013/07/07/graphic-timeline-of-key-events-in-quebec-train-disaster/

The Accident



Source: http://news.nationalpost.com/2013/07/12/graphic-the-lac-megantic-runaway-train-disaster/

The Accident



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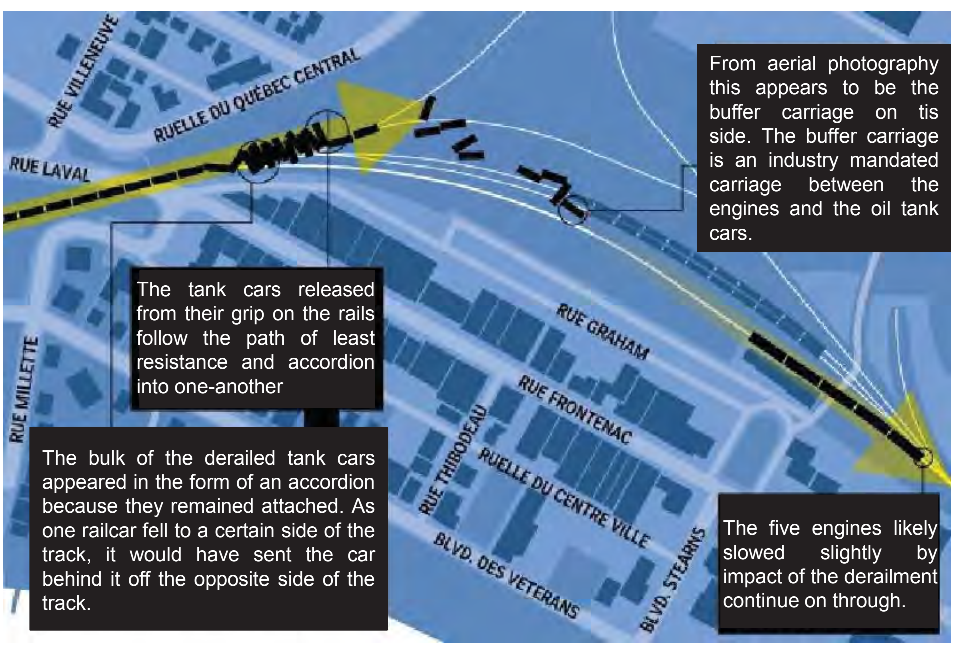
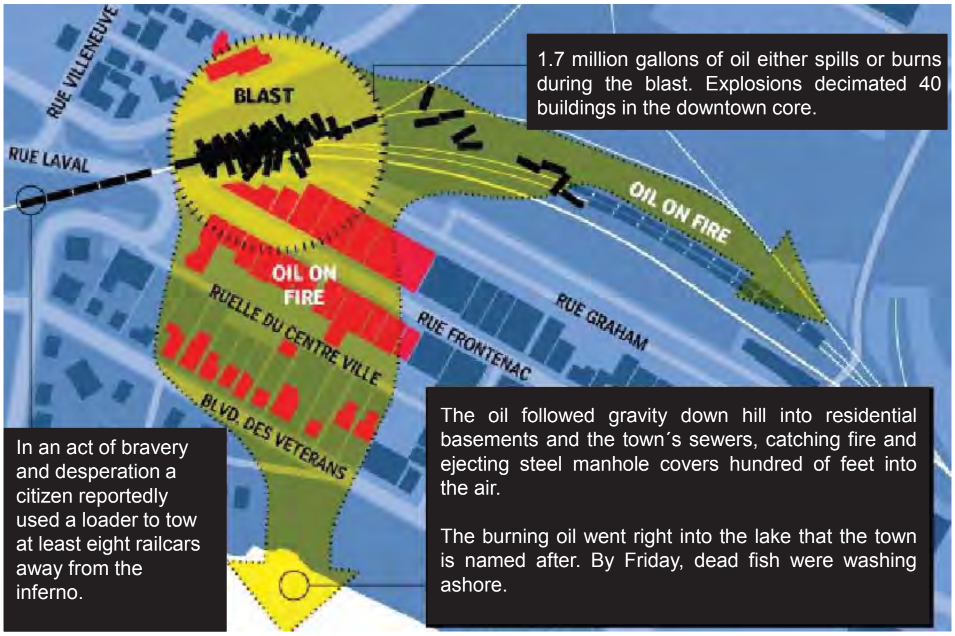


Source: http://news.nationalpost.com/2013/07/12/graphic-the-lac-megantic-runaway-train-disaster/

The Accident



Source: http://news.nationalpost.com/2013/07/12/graphic-the-lac-megantic-runaway-train-disaster/

Accident Consequences

- The resultant fire and explosions from the accident caused the death of 47 people
- More than 2,000 people were evacuated:
  - 800 remained evacuated after three days
  - 200 remained evacuated after six days
- At least 30 buildings were destroyed in the downtown area

Apparent Blast Radius

Source: news.nationalpost.com/2013/07/07/graphic-timeline-of-key-events-in-quebec-train-disaster/ and en.wikipedia.org/wiki/File:Lac_megantic_affected_area.png

Accident Consequences





Source: http://www.radio-canada.ca/regions/estrie/2013/07/06/001-explosion-lac-megantic-train.shtml/

Lac-Megantic's Downtown after the accident

Source: http://www.radio-canada.ca/regions/estrie/2013/07/06/001-explosion-lac-megantic-train.shtml/

Lac-Megantic's Downtown: Before and After

1. The railroad
2. The Musi-Café
3. The library
4. The former site of a Dollarama store
5. A commercial building

6. An old chapel that housed a bar
7. A bank of Montreal
8. A stationery store
9. A gift shop called "l'Ambrequin"
10. A residential area

Source: news.nationalpost.com/2013/07/08/before-and-after-photos-show-how-train-explosion-flattened-lac-megantics-bustling-downtown-core/

Environmental Impact

- Some sites in Lac Mégantic's downtown will take up to five years to be decontaminated

- The Chaudière River was contaminated with 26,000 gallons
- The spill travelled down the river and reached Saint Georges, which is 50 miles away

Source: www.lapresse.ca/le-soleil/affaires/actualite-economique/201307/15/01-4671028-lac-megantic-le-service-postal-reprend-son-cours-normal.php

Investigation

- The Transportation Safety Board of Canada (TSB) started an investigation under reference R13D0054. A team of 20 experts was deployed in the area to gather evidence.
- TSB investigation is still underway. Mainly focus:
  - The cause of the fire and its role on the later accident
  - The packaging of dangerous goods (e.g., class 111 tank cars)
  - The cause of the release of the air brake system and the apparent inefficiency of the manual brakes
  - The exact composition of the train's cargo since crude oil does not usually blow up
- As a result of the accident TSB has already issued two urgent Safety Advisory Letters to Transport Canada (TC) in relation with:
  - The securement of trains carrying dangerous goods
  - The securement of equipment and trains left unattended

Source:Transportation Safety Board of Canada: http://www.bst-tsb.gc.ca/eng/index.asp

Industry Response

- On July 23 Transport Canada (TC) issued immediate directives that:
  - Require at least two persons operate trains carrying hazardous materials
  - Prohibit dangerous material trains to be left on the mainline unattended
  - Require to apply both automatic brake and independent brake at their maximum force on trains unattended for less than an hour
  - Require to set hand brakes on trains unattended for more than an hour

Source:Transportation Safety Board of Canada: http://www.bst-tsb.gc.ca/eng/index.asp

Thank You!

Special appreciation to Manuel Martin
NURail Summer 2013 Undergraduate Research Assistant
for preparing this accident overview

Reminder

- ArcGIS tutorial on Wednesday
  - Bring laptop installed with ArcGIS
- Complete reading assignment (ISO-31000) and pre-class quiz before make-up class Thursday or before watching the recorded lecture by 11:59pm Friday

Bibliography and Additional Resources

– Wikipedia. Lac-Mégantic_derailment: en.wikipedia.org/wiki/Lac-M%C3%A9gantic_derailment
– Transportation Safety Board of Canada: www.tsb.gc.ca/eng/enquetes-investigations/rail/2013/R13D0054/R13D0054.asp
– National Post website: news.nationalpost.com/2013/07/12/graphic-the-lac-megantic-runaway-train-disaster
– "Press Release: Derailment in Lac-Megantic, Quebec". Montreal, Maine and Atlantic Railway. July 6, 2013. Retrieved July 6, 2013. http://mmarail.com/sections/news/files/MMA_7.6.2013_Press.Release.pdf
– Moving Crude Oil by Rail. Association of American Railroads. May 2013.

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University of Illinois at Urbana-Champaign
Department of Civil and Environmental Engineering

CEE 498 TSR – Transportation Safety and Risk

Consequence Estimation Tutorial:
Population potentially affected by a hazmat release event

Author: Jesus Aguilar Serrano
Graduate Research Assistant

Objective:

Estimate the consequences of a hazardous material release event in terms of population potentially affected along a route from Chicago to Springfield through Champaign.

Data used:

≠ rail_lines.shp
≠ USCensus_2010.shp
≠ place.shp

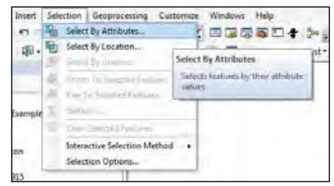
Methodology:

1) Get the data from different sources. In this example, all data is provided by Compass2g but it has been obtained from governmental agencies as the National Transportation Atlas Database (NTAD) or the Census Bureau.
2) Open a blank map and load all the data.


Click on this button to load the data.

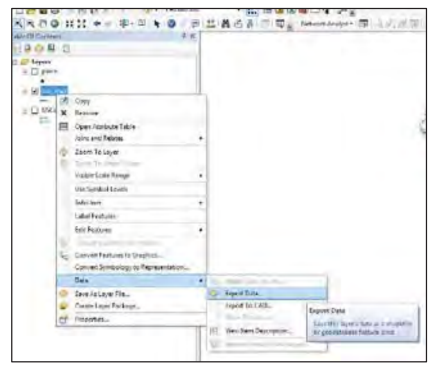
After loading the three layers, turn off census and points.

3) Using *Selection by attributes*, select the network of interest. In this tutorial, Main lines in Illinois are selected.



Right-click on *rail_lines* and click on *Export Data*

Export data to a new shapefile named IL_*M_Lines.shp*

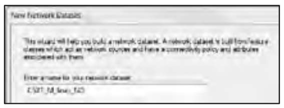


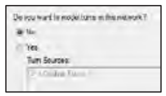
4) Create New Network:

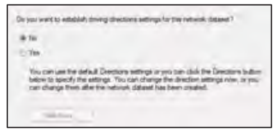
Activate *Network Analyst* extension by clicking in *Customize -> Extension -> Network Analyst*.

Going to *Catalog*, right-click on our network (IL_*M_Lines.shp*) and click on *New Network Dataset…*

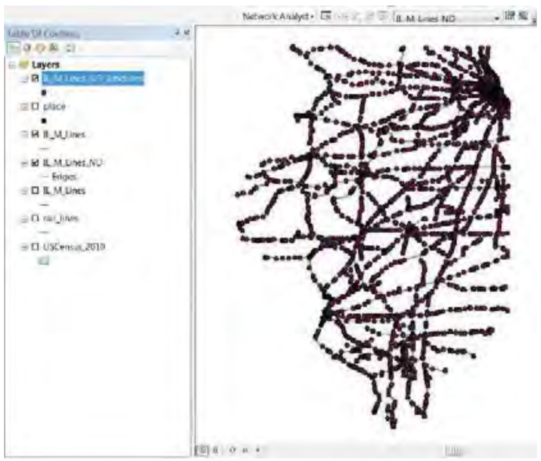
Leave all default values except for name (in case you want to change it), turns (select no), and directions (select no), and click finish.



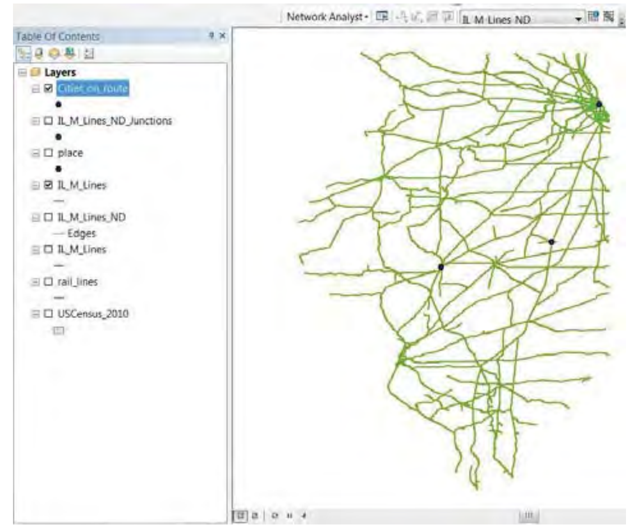




Build the network and add the information to the map.



5) Select the origin and destination cities using the attribute table of *places.shp* and export them to a new layer using *Export Data.* In this case, the route goes from Chicago to Springfield through Champaign.

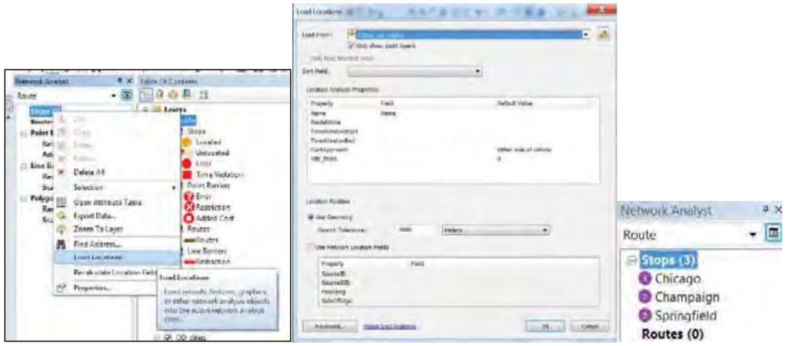


6) Calculate the route using *Network Analyst:*

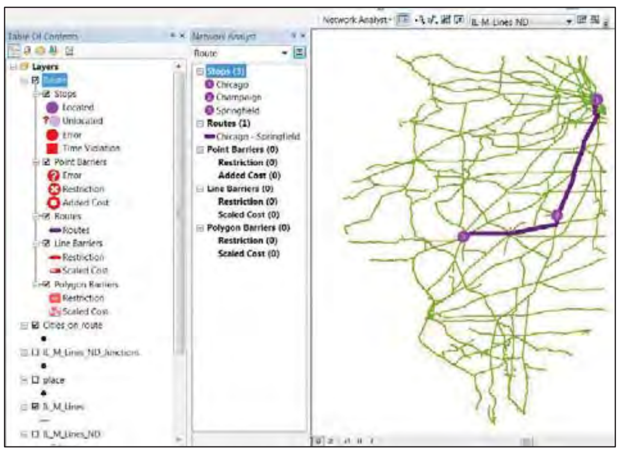
Click on *New Route and open the Network Analyst Window* clicking on

(If the toolbar is not visible, you can right click on *Customize -> Toolbars -> Network Analyst*)

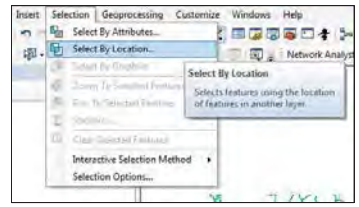
Right click on *Stops(0) -> Load Locations… -> Load from: Cities_on_route -> OK*

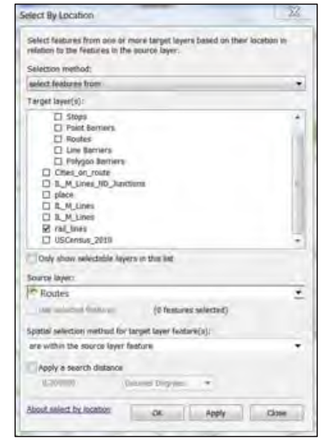


Click on [icon] to solve the route.

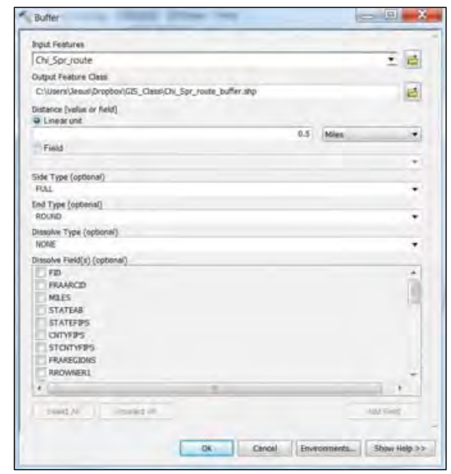


7) In this case, the route obtained is OK. In case the route obtained was not the route we want to analyze for any given reason, we would repeat the process adding more stops along the route or editing the route manually.
8) Using the route obtained from *Network Analyst*, select from *rail_lines* the route using *Select by Location…*

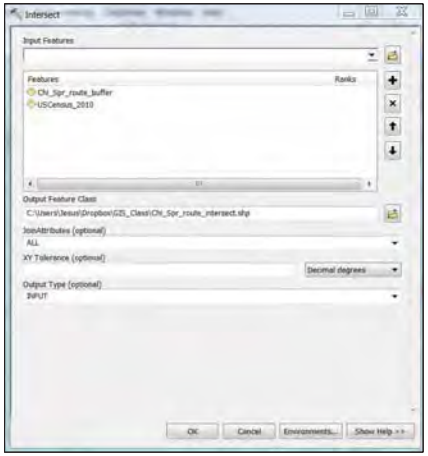




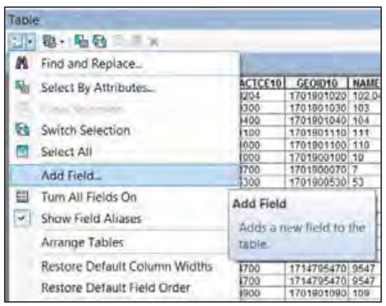
9) Export the selection to a new layer named *Chi_Spr_route.shp* using *Export Data*.
10) Create a buffer layer named Chi_Spr_*route_buffer.shp* with 0.5 miles around the route.



11) Intersect the *USCensus_2010* and Chi_Spr_*route_buffer* layers. The new layer will be named as *Chi_Spr_route_intersect.shp*

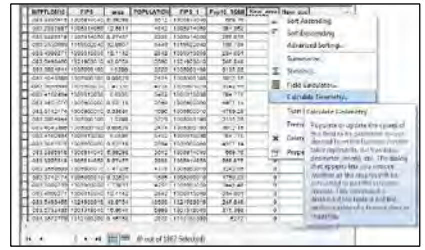


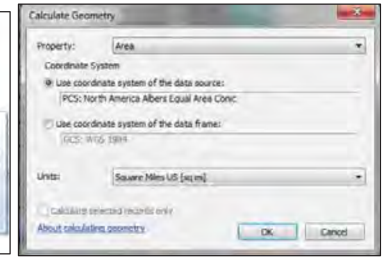
12) Go to *Catalog* and right-click on Chi_*Spr_route_intersect -> Attribute table -> Add Field…*



13) Introduce two new fields: *New_area* and *New_pop.* Both are *Double* type. Click *OK.*

14) Scroll to the right and right-click on *New_area -> Calculate Geometry…*





<u>Note that may be needed to make a projection to be able to calculate the area.</u>

15) Right-click on *New_pop -> Field Calculator.* Type the equation showed in the following picture and click *OK*

16) Right-click on *New_pop -> Summarize…* the population and the area according to buffer id

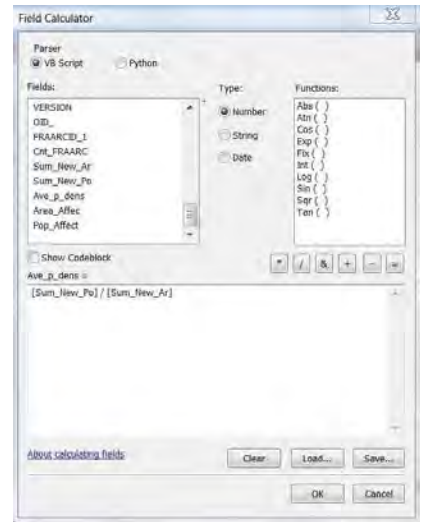
17) Select *FRAARCID* to summarize the population and the area, and save the table named Chi_*Spr_Table.dbf*

18) Right-click on Chi_*Spr_route* and click on *Join…* then fill out the *Join* menu like in the picture bellow.

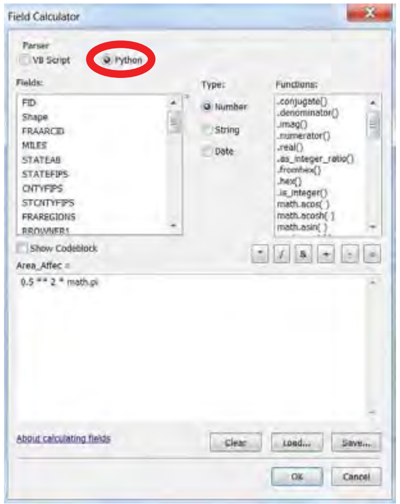
19) Using *Export Data,* we export Chi_*Spr_route* to save the new attribute table. The new layer is named *Chi_Spr_route_info.shp* and contains the information about our analysis.

20) Introduce three new fields: *Ave_pop_density, Area_Affected* and *Pop_Affected.* Both are *Double* type. Click *OK*

21) Right-click on *Ave_pop_density -> Field Calculator.* Type the equation showed in the following picture and click *OK*

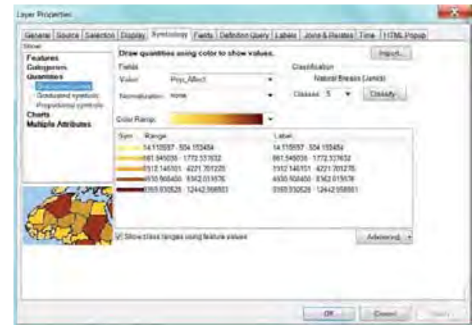


22) Right-click on *Area_Affected -> Field Calculator.* Type the equation showed in the following picture and click *OK*



23) Right-click on *Pop_Affected -> Field Calculator*. Type the equation showed in the following picture and click *OK*

24) Using *Symbology* we can represent the population distribution along the route.

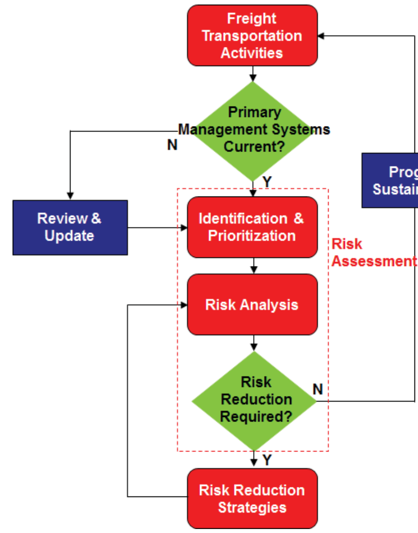


25) The final deliverable would be the layer named *Chi_Spr_route_info.shp,* which contains the population affected by segment along our route.

26) The end…

TRANSPORTATION RISK MANAGEMENT

CEE498 TSR -Transportation Safety and Risk



Dr. Rapik Saat, Ph.D.

Rail Transportation and Engineering Center – RailTEC

Department of Civil & Environmental Engineering

University of Illinois at Urbana-Champaign, U.S.A.

Learning Outcomes

At the end of this lecture students will be able to:

1. Understand risk definition
2. Understand risk management concepts
3. Understand the steps involved in transportation risk management process
4. Understand important transportation risk terms

Managing Risk

- We all manage risk consciously or unconsciously, but rarely systematically
- Managing risk is all about maximizing opportunity and minimizing threats
- The risk management process provides a framework to facilitate more effective decision making

What is Risk?

- ISO 31000 provides principles and generic guidelines on risk management
- **Risk** = effect of **uncertainty** on ***objectives***
  - Potential different aspects (e.g. safety, health, environmental, financial) and levels (e.g. strategic, organization-wide, project, product, process) of objectives
  - The effect on the objectives could be positive or negative
  - Risk is often expressed in terms of a combination of the ***likelihood*** of an event and the associated ***consequences***

What is Risk? (cont.)

- Risk is the potential for an unwanted outcome resulting from an incident as determined by its likelihood [or probability] and the associated consequences

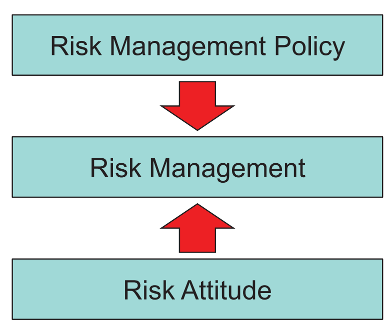
HMCRP HM-16 Project

- Risk = *f*(probability P, consequence C)
  - Risk = P × C
- The word "*risk*" derives from the early Italian *risicare,* which means "to dare". In this sense, risk is a choice rather than a fate.

Bernstein (1996) - Against the Gods

Risk Management is Driven by Policy and Risk Attitude

- *Risk management* involves coordinated activities to direct and control an organization with regard to risk
- *Risk management policy* is statement of the overall intentions and direction of an organization related to risk management
- *Risk attitude* is organization's value and priority to assess and eventually pursue, retain, take or turn away from risk



Risk Management Principles

- Risk management creates and protects value
- Risk management is an integral part of all organizational processes
- Risk management is **part of decision making**
- Risk management explicitly addresses uncertainty
- Risk management is systematic, structured and timely
- Risk management is **based on the best available information**
- Risk management is tailored
- Risk management takes human and cultural factors into account
- Risk management is **transparent and inclusive**
- Risk management is dynamic, iterative and responsive to change
- Risk management facilitates continual improvement of the organization

Risk Management Framework

- Set of components that provide the foundations and organizational arrangements for designing, implementing, monitoring, reviewing and continually improving risk management
  - The foundations include the policy, objectives, mandate and commitment to manage risk
  - The organizational arrangements include plans, relationships, accountabilities, resources, processes and activities

Risk Management Plan

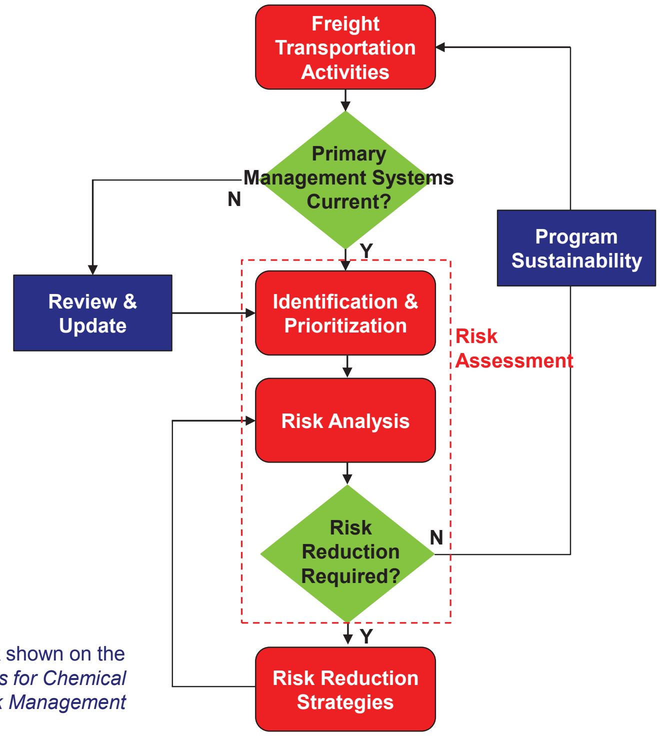
- Scheme within the risk management framework specifying the approach, the management components and resources to be applied to the management of risk
  - Management components typically include:
    - procedures,
    - practices,
    - assignment of responsibilities,
    - sequence and timing of activities

Risk Management Process

- Systematic application of management policies, procedures and practices to the activities of communicating, consulting, establishing the context, identifying, analyzing, evaluating, treating, monitoring and reviewing risk

Transportation Risk Management Process

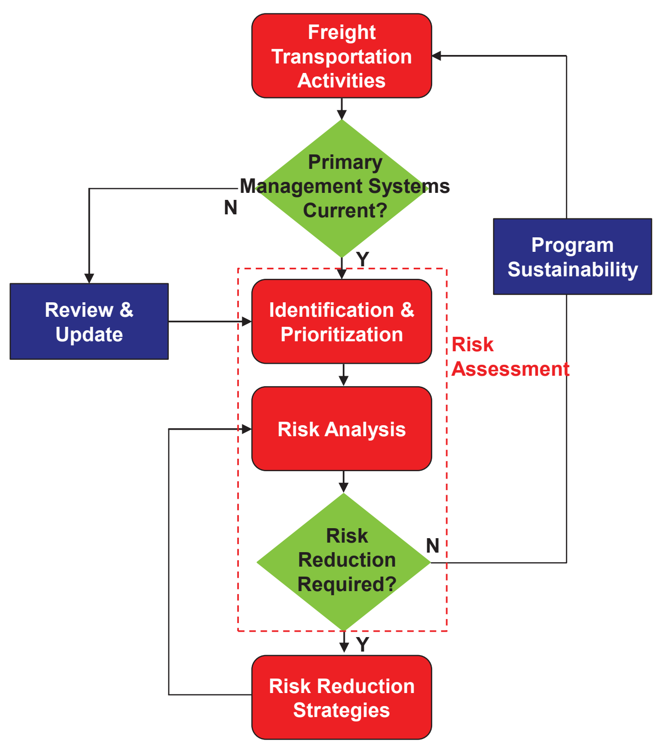
- A *process/method* for identifying, assessing and reducing transportation risks
- Fundamental questions:
  - What can go wrong?
  - How likely is it?
  - What are the consequences?
  - How to effectively use resources to reduce risks?



Note: Transportation Risk Management (TRM) framework shown on the right is modified from *CCPS (2008) – Guidelines for Chemical Transportation Safety, Security and Risk Management*

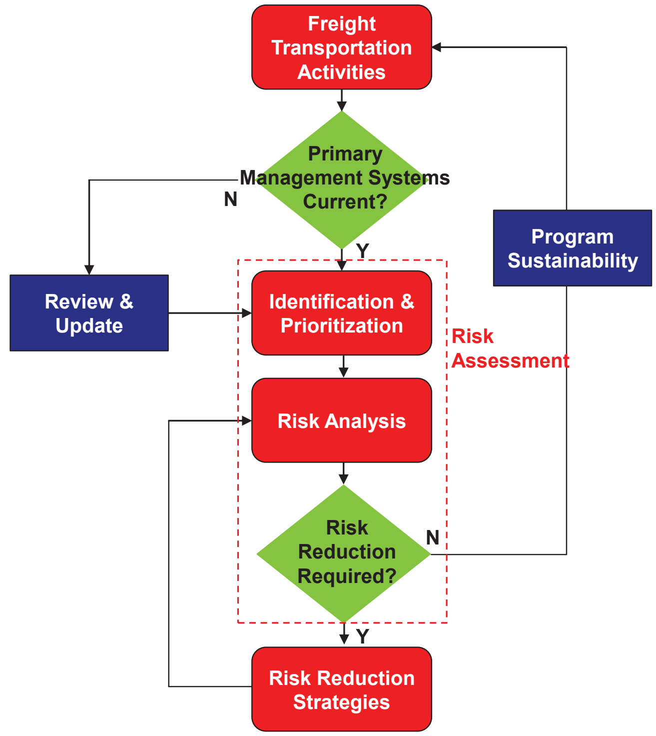
Primary Management Systems

- A set of compliance *activities* to address:
  - Regulations
  - Standards and guidelines
  - Operational management
  - Emergency response and preparedness
  - Incident reporting and investigation
  - Management of change
  - Program auditing
- Requires periodical review and update



Risk Assessment

- Overall process of
  - Risk identification,
  - Risk analysis, and
  - Risk evaluation



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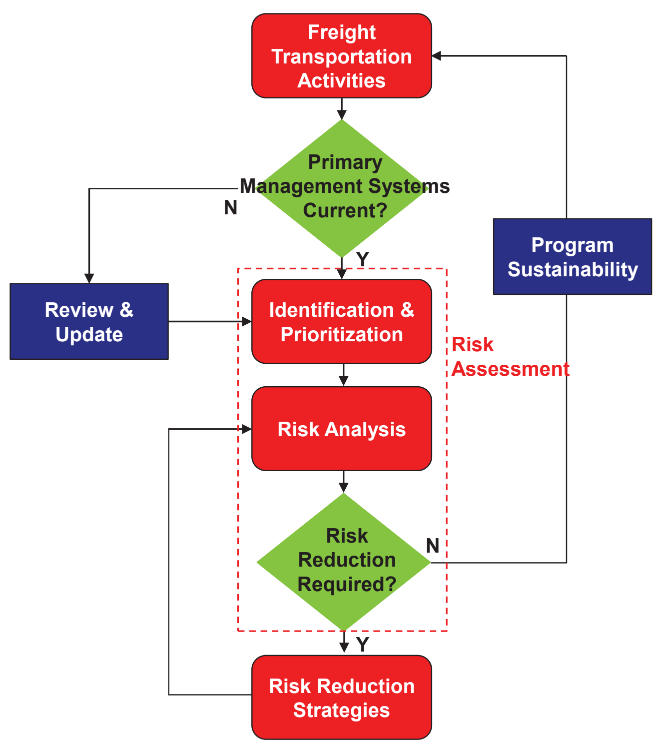
Identification & Prioritization

- Risk identification is a process of finding, recognizing and describing risks (e.g. sources, areas of impacts, causes, consequences)
- Specific steps involve:
  - Cataloging transportation activity details e.g. mode, product, container types
  - Identifying sensitive areas and potential points of failure along the transit route
  - Understanding interactions with other stakeholders in the supply chain
- The key objective is to identify specific transportation activities that will require further evaluation and risk assessment



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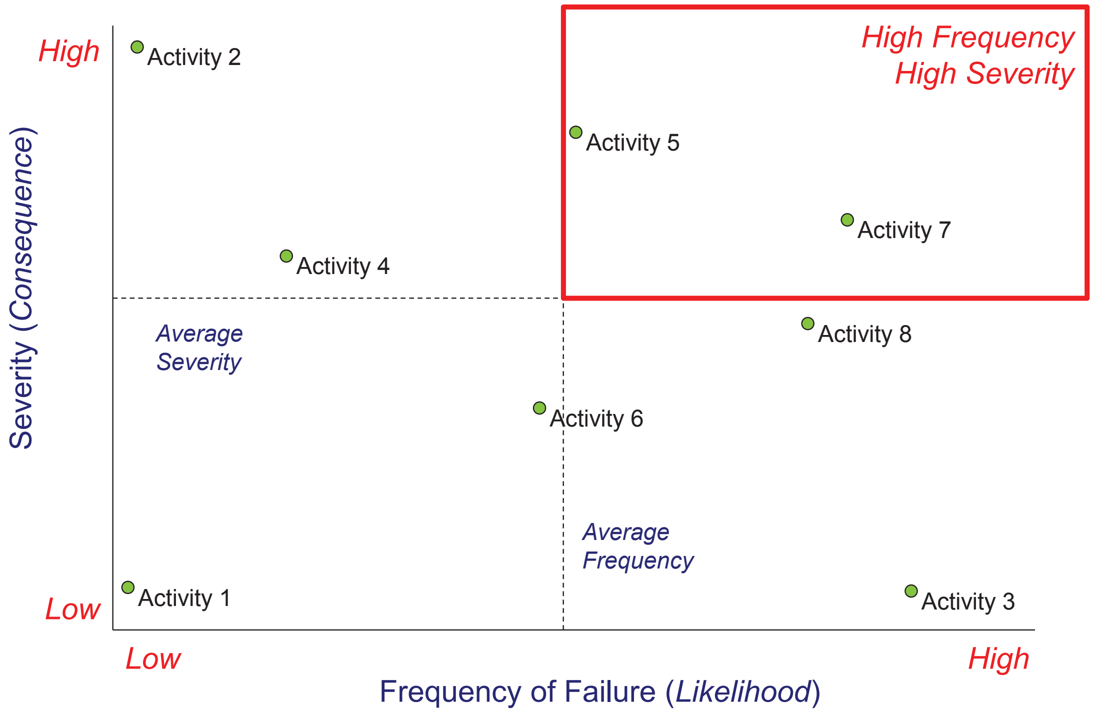
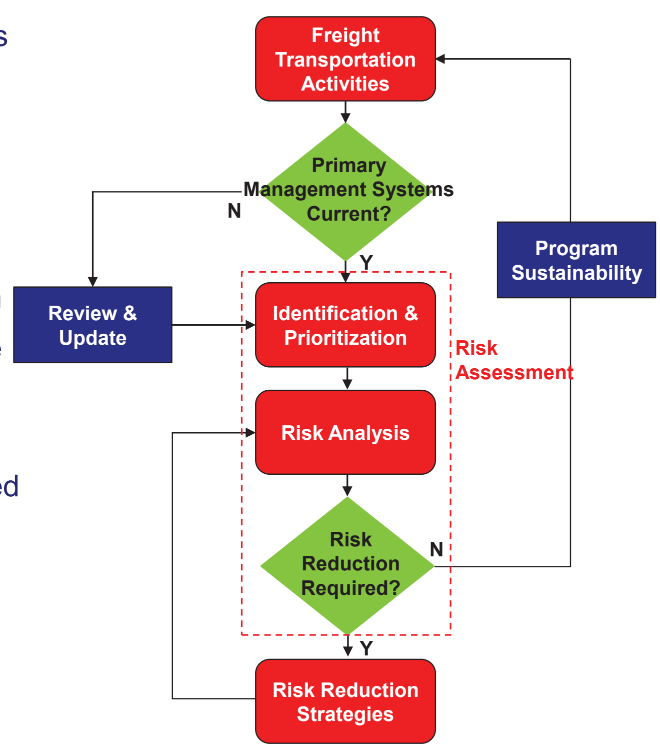
Identification & Prioritization



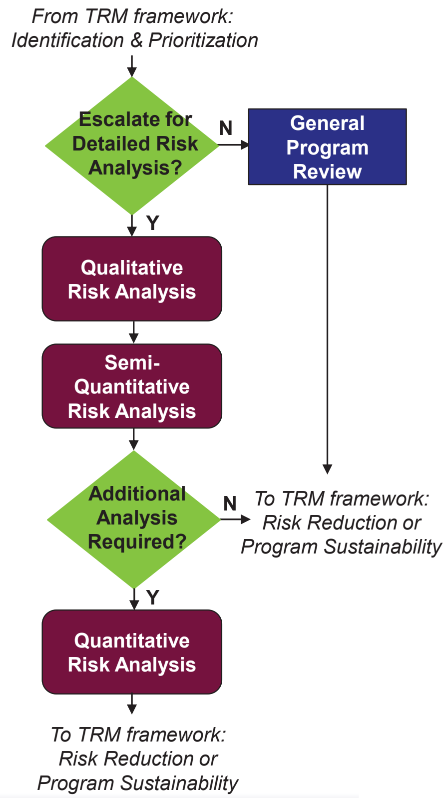
Risk Analysis

- Consideration of causes and sources of risk, and their consequences and likelihood
- This course will be focusing on Risk Analysis
  - Basic risk concepts
  - Structuring risk decision problem
  - Qualitative and semi-quantitative risk analysis
  - Quantitative risk analysis
- Type and scope of analysis are based on the needs and complexity of specific issues



Risk Analysis Protocol

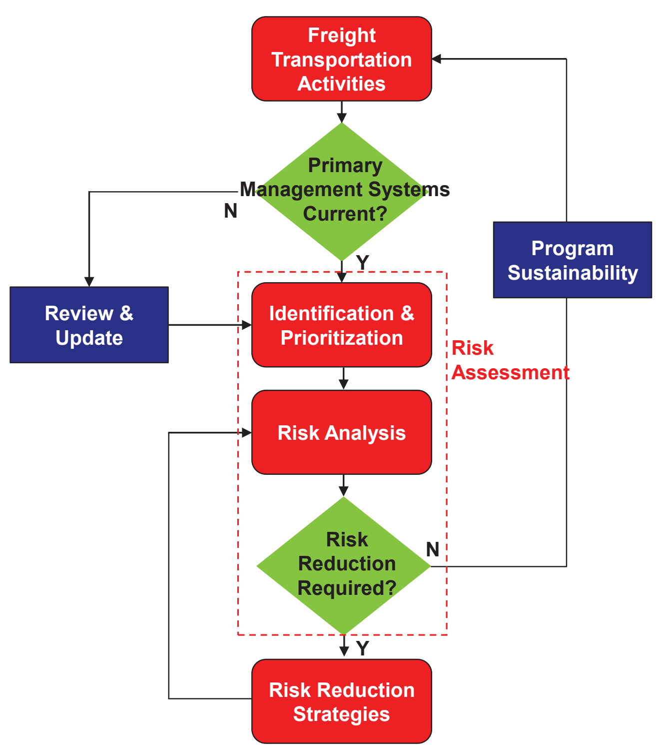
- A process to specify the risk analysis scope
- Other scope:
  - The entire supply chain
  - A segment of the transportation network
  - A single product or a mixed shipment
  - A subset of all the materials shipped
  - One single mode or multimodal



Note: Risk Analysis Protocol shown on the right is modified from *CCPS (2008) – Guidelines for Chemical Transportation Safety, Security and Risk Management*

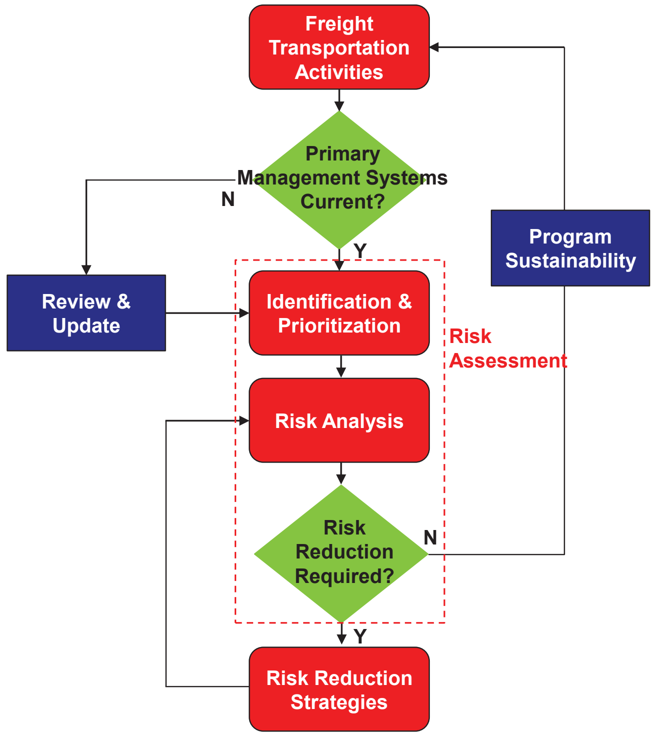
Risk Evaluation: Risk Reduction Required?

- Making decisions about which risks need to be reduced
  - Based on the outcomes of risk analysis
- Comparing risk level with established risk criteria or any industry benchmark
- Consideration of not to treat risk, but maintain existing controls
- Consideration of risk tolerance
- Consideration of further analysis



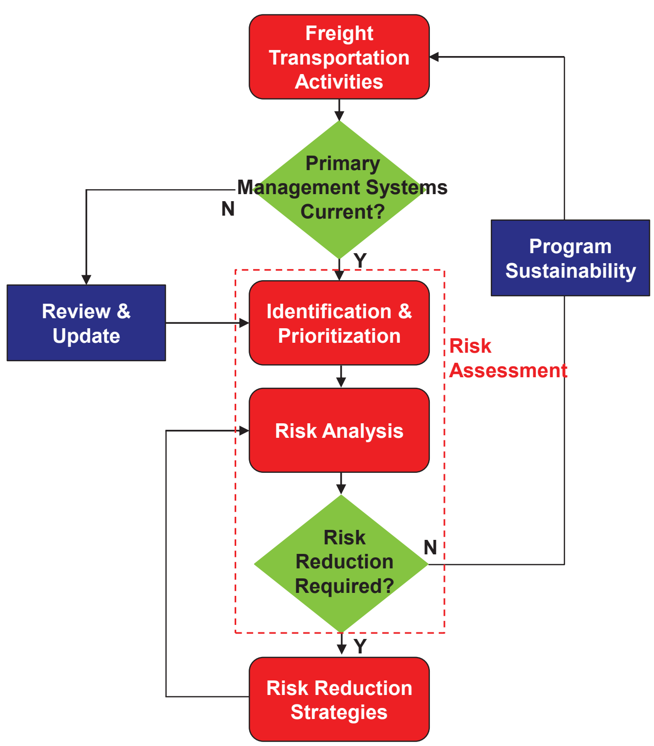
Risk Reduction Strategies

- Evaluating or implementing options to reduce risk, as needed
- May include:
  - avoiding the risk by deciding not to start or continue with the activity that gives rise to the risk
  - *taking or increasing the risk in order to pursue an opportunity*
  - removing the risk source
  - changing the likelihood
  - changing the consequences
  - sharing the risk with another party or parties (including contracts and risk financing)
  - retaining the risk by informed decision



Program Sustainability

- A process to ensure the risk management process remains current
  - Ongoing commitment to managing risk
  - Continuous improvement
  - Adjusting to emerging trends
  - Keeping current on evolving transportation risk analysis practices
  - Continuing communications with external and internal stakeholders



Other Key Risk Terms

- Event: occurrence or change of a particular set of circumstances
- Release incident
- Hazard
- Likelihood
- Consequence

Initiating Event: Accidents

- Example types of accident-initiated events

Road	Rail	Waterway	Air	Pipeline
Collision Overturning Grade Crossing Cargo Shifting	Collision Derailment Grade Crossing	Collision Grounding Ramming Capsizing Allision	Crash Cargo Shifting	External Impact

- Potential causes:
  - Infrastructure defects (e.g. road/rail track)
  - Equipment defects
  - Human factors
  - Navigational failures
  - Control system failures
  - External events

Initiating Event: Non-Accidents

- Potential causes:
  - Improper securement
  - Corrosion
  - Metallurgical failure
  - Overpressure
  - Equipment component failures (e.g. valves, rupture disks, fittings)
  - Overfilling or underfilling
  - Relief device activation due to surges
  - Contamination
  - Temperature changes
  - Control system failures

Release Incident

- The loss of containment of material
- Hazard: inherent property or characteristics of a material, systems, or process that has the potential for causing injury and/or damage to people, property and/or the environment

Likelihood

- The measure of the probability or frequency of an event
- Chance of something happening
- Key likelihood estimates:
  - Initiating event rate
  - Conditional probability of release
  - Release size probability distribution
  - Consequence exposure probability distribution

Consequence

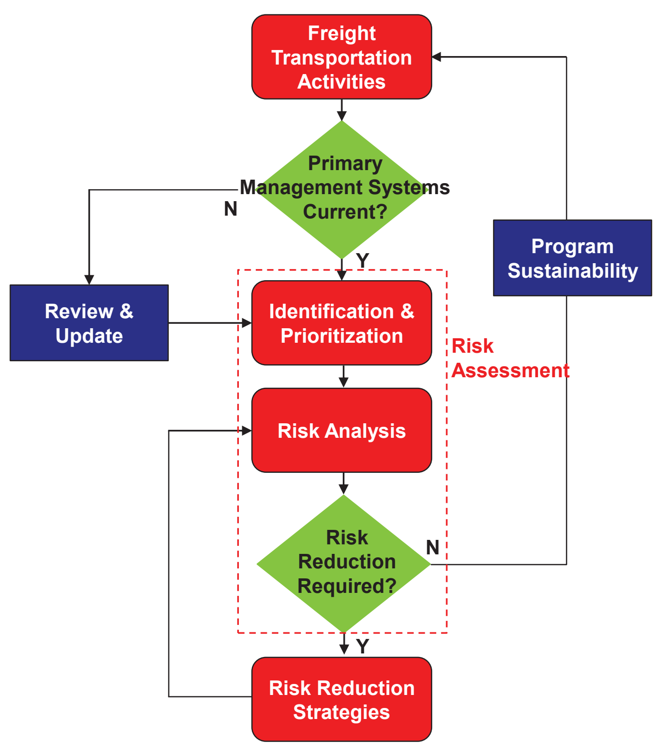
- The direct results or impacts of an event
- Outcome of an event affecting objectives
- Examples:
  - Fatalities
  - Injuries
  - Property damage
  - Environmental impacts
  - Business interruption
  - Evacuation
  - Distribution system disruption
  - Negative publicity
  - Excess regulations

Key Takeaways

- Risk of an event is correlated with the likelihood and consequence of the event
- Risk management is a process for identifying, assessing and reducing risks
- Key steps in Transportation Risk Management framework include:
  - Primary Management Systems
  - Risk Assessment
    - Identification & Prioritization
    - Risk Analysis
    - Risk Reduction Strategies
  - Program Sustainability

In-Class Group Discussion

- In a group of 3-4, select a transportation activity, and perform risk identification exercise
  - Identify key risk factors
    - Initiating event and causing factors
    - Other secondary event(s) and causing factors
    - Potential consequences
    - Factors affecting levels of consequences



Thank You!

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Additional Resources

- ISO 31000. Risk Management – Principles and Guidelines, International Standard Organization, ISO 31000:2009(E).

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RISK ASSESSMENT

CEE498 TSR -Transportation Safety and Risk

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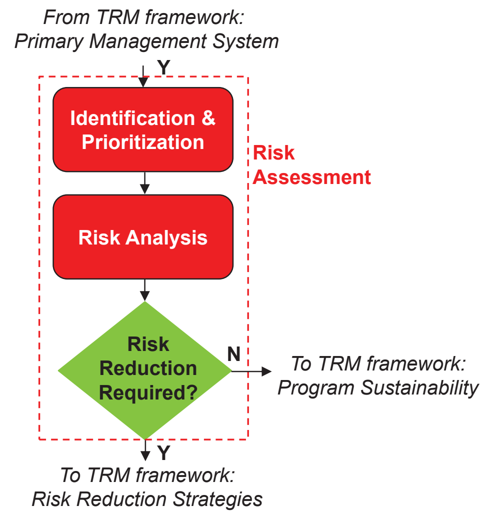

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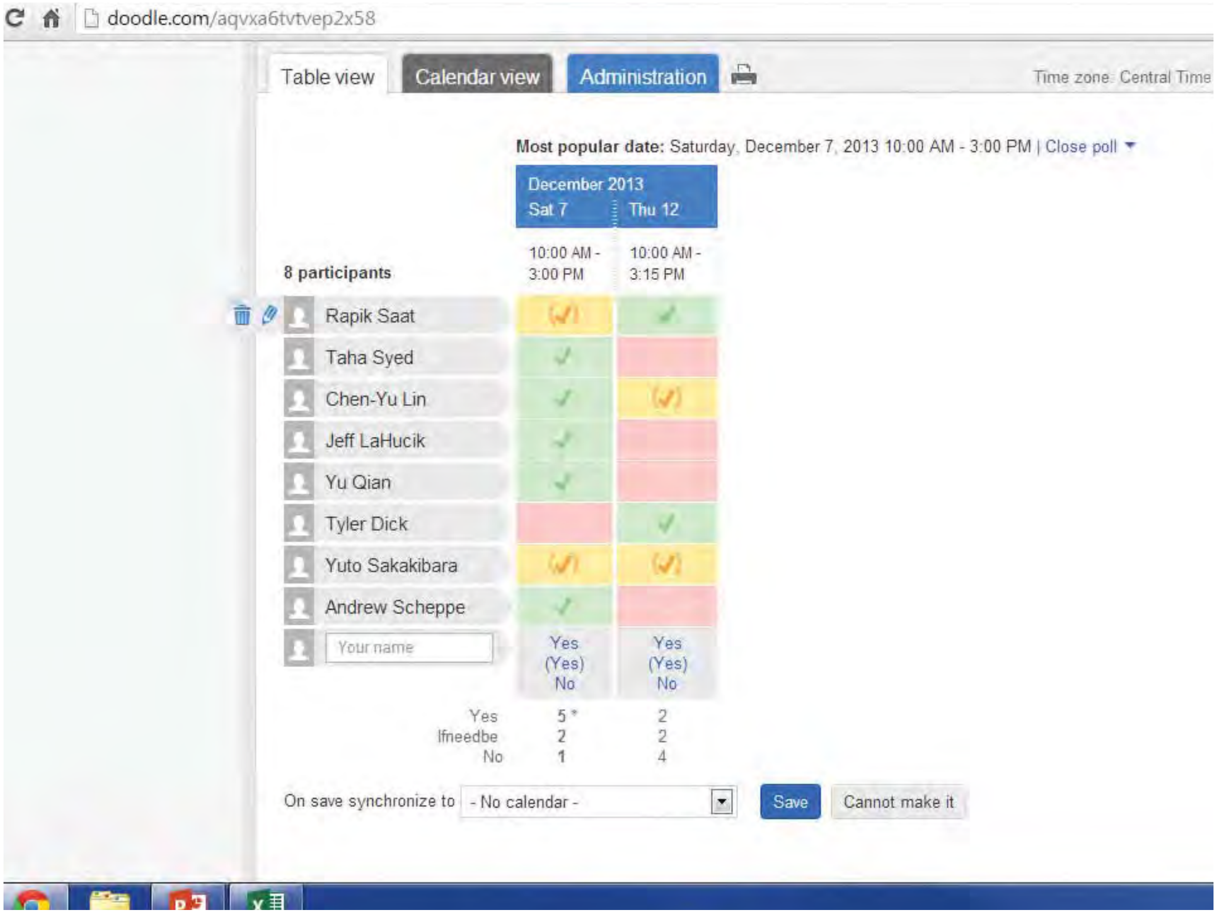
Administrative

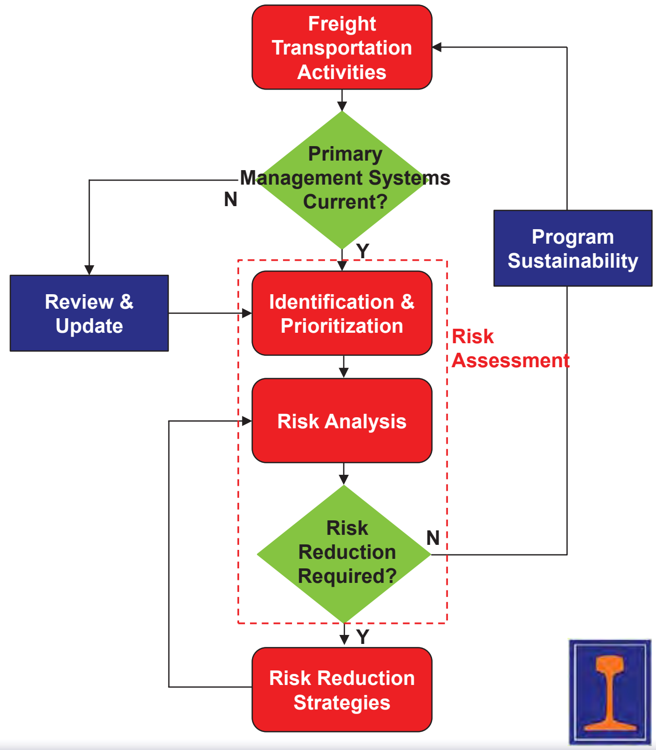
- Final presentation date:
  - Saturday 12/7, 10am-3pm
- State-of-the-Practice Discussion
  - Wednesday 9/11
  - *Suddle 2009 - The weighted risk analysis*
  - Proponent: Xiaonan Zhou, Jeff LaHucik
  - Opponent: Syed Taha, Hsiao-Hsuan Liu



State-of-the-Practice Paper Review

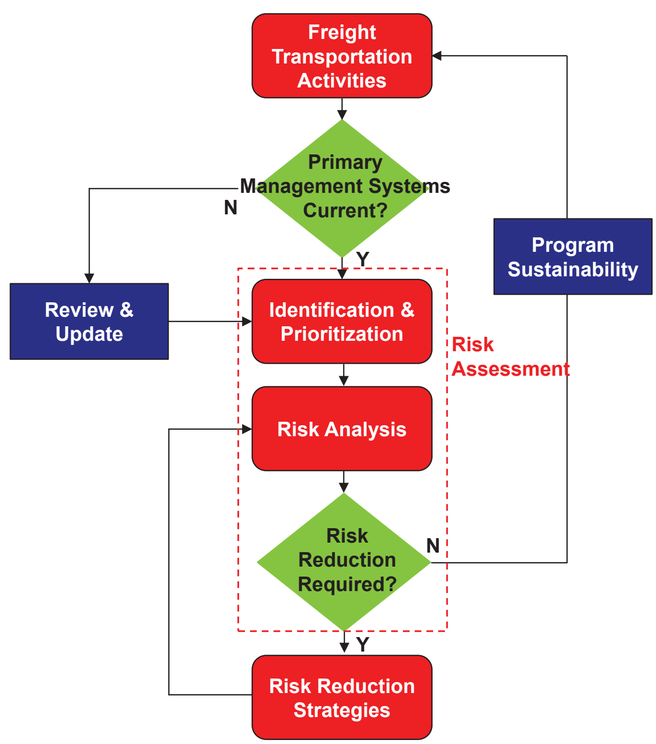
- Groups of two each to be proponent or critique of a selected journal paper in a session
- Proponent will prepare a short Pre-Class Quiz for everyone (*email by Tuesday 5pm*)
  - Five to ten True-or-False questions
  - All to complete reading and Pre-Class Quiz before class
- 20-min presentation by the proponent
- 20-min presentation by the critique (*e.g. alternative approach from other sources*)
- Q&A

Review



Review: In-Class Group Discussion

- In a group of 3-4, select a transportation activity, and perform risk identification exercise
  - Identify key risk factors
    - Initiating event and causing factors
    - Other secondary event(s) and causing factors
    - Potential consequences
    - Factors affecting levels of consequences



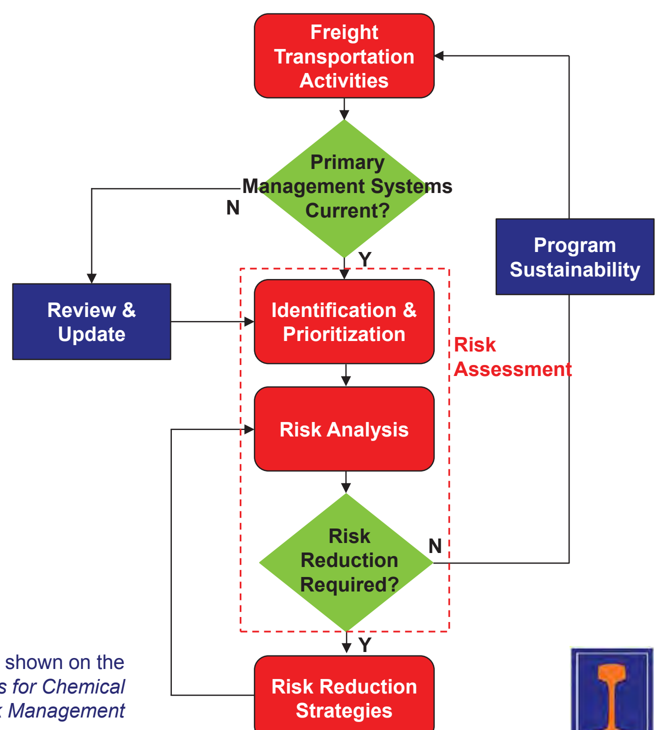
Learning Outcomes

At the end of this lecture students will be able to:

1. Be familiar with ISO 31010
2. Understand risk assessment concepts, process and techniques
3. Differentiate qualitative, semi-quantitative and quantitative risk analysis
4. Aware of other risk assessment techniques

Transportation Risk Management Process Revisited

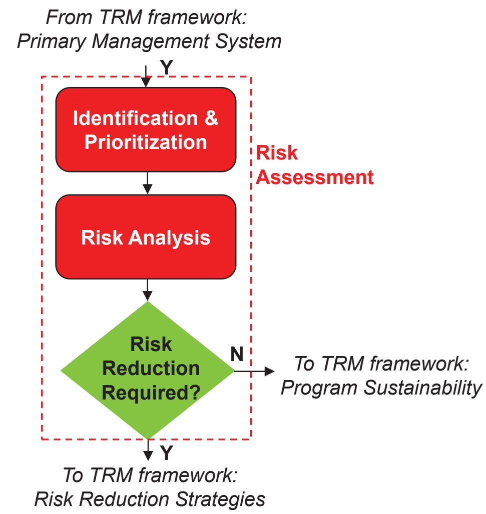
- A *process* for identifying, assessing and reducing transportation risks
- A *method* for prioritizing transportation risk management needs and evaluating risk reduction strategies



Note: Transportation Risk Management (TRM) framework shown on the right is modified from *CCPS (2008) – Guidelines for Chemical Transportation Safety, Security and Risk Management*

Risk Assessment Revisited

- Risk assessment is a structured process involving:
  - risk identification
  - risk analysis,
  - risk evaluation
- Fundamental questions to answer:
  - What can happen and why?
  - What are the consequences?
  - What is the probability of their future occurrence?
  - What are potential mitigating factors?
  - Is the risk level tolerable or require further treatment?



Risk Assessment Purpose and Benefits

- Purpose: provides evidence-based information and analysis to make informed decisions on how to treat particular risks
- Principal benefits:
  - understanding the risk and its potential impact upon objectives
  - **providing information for decision makers**
  - contributing to the understanding of risks, in order to assist in selection of treatment options
  - identifying the important contributors to risks and weak links in systems and organizations
  - comparing of risks in alternative systems, technologies or approaches
  - **communicating risks and uncertainties**
  - assisting with establishing priorities
  - contributing towards incident prevention based upon post-incident investigation
  - selecting different forms of risk treatment;
  - **meeting regulatory requirements**
  - providing information that will help evaluate whether the risk should be accepted when compared with pre-defined criteria
  - assessing risks for end-of-life disposal

Risk Assessment & Risk Management Policy

- The context and objectives of the organization
- The extent and type of risks that are tolerable, and how unacceptable risks are to be treated
- How risk assessment integrates into organizational processes
- Methods and techniques to be used for risk assessment, and their contribution to the risk management process
- Accountability, responsibility and authority for performing risk assessment
- Resources available to carry out risk assessment
- How the risk assessment will be reported and reviewed

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Communication with Stakeholders is Key for Successful Risk Assessment

- Developing a communication plan
- Defining the context (external, internal, process) appropriately
- Ensuring that the interests of stakeholders are understood and considered
- Bringing together different areas of expertise for identifying and analyzing risk
- Ensuring that different views are appropriately considered in evaluating risks
- Ensuring that risks are adequately identified
- Securing endorsement and support for a treatment plan

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Establishing Risk Assessment External Context

- External context involving considerations of:
  - cultural, political, legal, regulatory, financial, economic and competitive environment factors, whether international, national, regional or local;
  - key drivers and trends having impact on the objectives of the organization;
  - perceptions and values of external stakeholders

Establishing Risk Assessment Internal Context

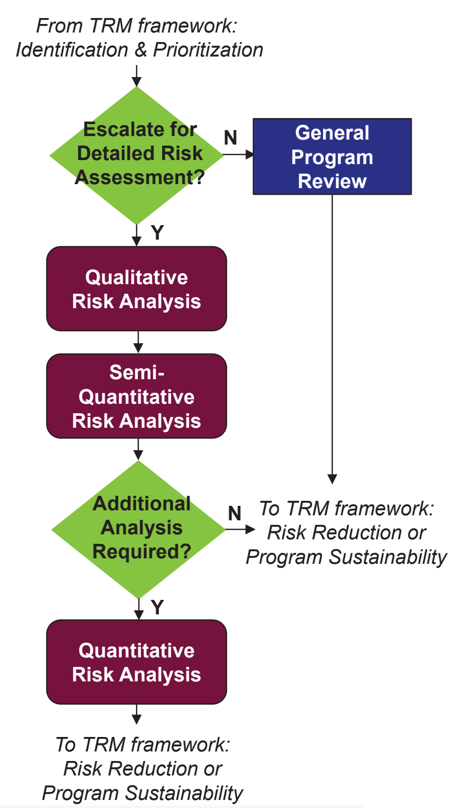
- Internal context involve considerations of:
  - **capabilities of the organization in terms of resources and knowledge**,
  - information flows and decision-making processes,
  - internal stakeholders,
  - objectives and the strategies that are in place to achieve them,
  - perceptions, values and culture,
  - **policies and processes**,
  - **standards and reference models adopted by the organization**,
  - structures (e.g. governance, roles and accountabilities).

Establishing Risk Assessment Process Context

- Process context involve considerations of:
  - defining accountabilities and responsibilities,
  - **defining the extent of the risk management activities to be carried out, including specific inclusions and exclusions**,
  - defining the extent of the project, process, function or activity in terms of time and location,
  - defining the relationships between a particular project or activity and other projects or activities of the organization,
  - **defining the risk assessment methodologies**,
  - **defining the risk criteria**,
  - defining how risk management performance is evaluated,
  - **identifying and specifying the decisions and actions that have to be made,**
  - identifying scoping or framing studies needed, their extent, objectives and the resources required for such studies.

Risk Assessment Protocol Revisited

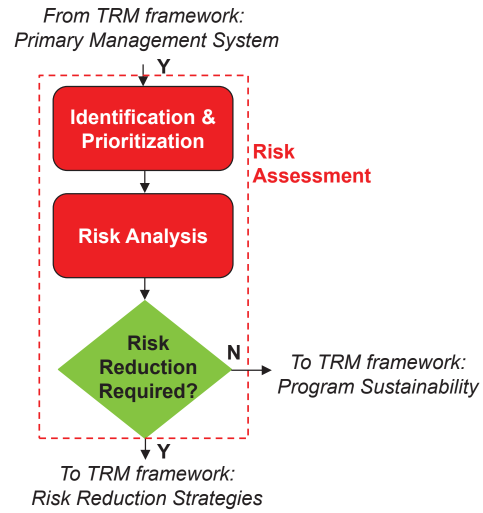
- A *process* to specify the risk assessment scope
- Other scope:
  - The entire supply chain
  - A segment of the transportation network
  - A single product or a mixed shipment
  - A subset of all the materials shipped
  - One single mode or multimodal



Note: Risk Assessment Protocol shown on the right is modified from *CCPS (2008) – Guidelines for Chemical Transportation Safety, Security and Risk Management*

Risk Identification Revisited

- Risk identification is a process of finding, recognizing and describing risks (e.g. sources, areas of impacts, causes, consequences)
- Methods can include:
  - evidence based methods, examples of which are check-lists and reviews of historical data;
  - systematic team approaches where a team of experts follow a systematic process to identify risks by means of a structured set of prompts or questions;
  - inductive reasoning techniques such as HAZOP.



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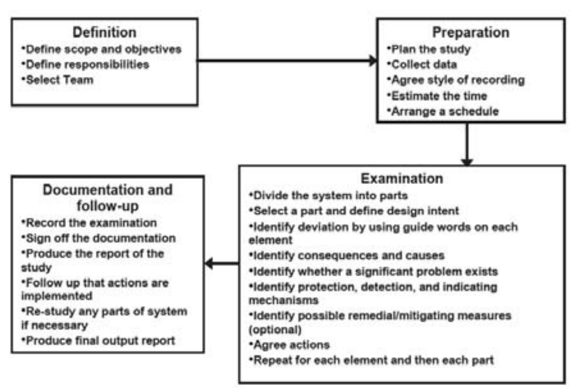
Hazard and Operability Analysis (HAZOP)

- HAZOP is a structured and systematic brainstorming technique for system examination and risk management
- A technique for identifying potential hazards in a system
- Based on a theory that assumes risk events are caused by deviations from design or operating intentions
- Identification of such deviations is facilitated by using sets of "guide words"
- This approach is a unique feature of the HAZOP methodology that helps stimulate the imagination of team members when exploring potential deviations

- **No or not** - no detergent added
- **More** - too much detergent volume added (difficult to rinse)
- **More** – supplied detergent solution concentration is too high
- **Less** - too little detergent volume added (soil isn't effectively removed)
- **Less** – supplied detergent solution concentration is too low
- **Part of** - critical detergent component omitted (ex: surfactant)
- **Reverse** - detergent is contaminated with a harmful hazard
- **Other than** - wrong detergent used
- **Early** - detergent added too early (ex: if you need to pre-rinse bulk soil to drain before washing with detergent)
- **Late** - detergent added too late in the cleaning cycle

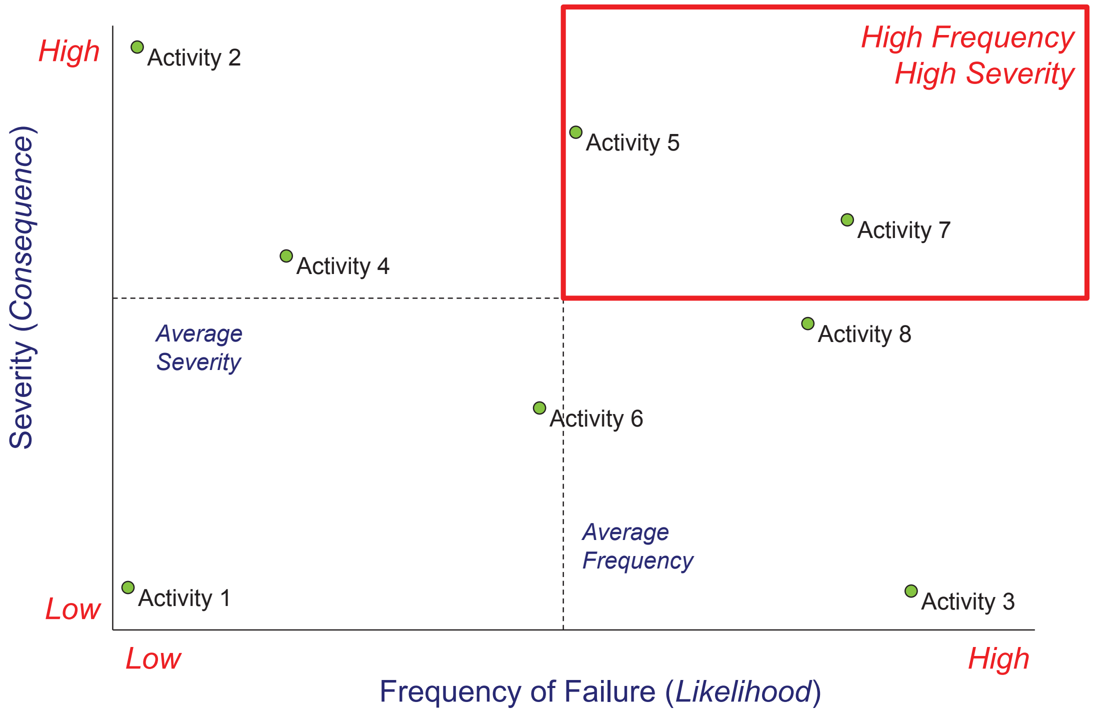
Example Guide Words



General Methodology

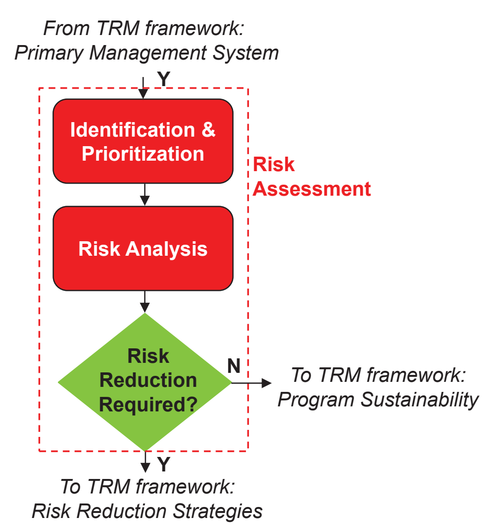
Source: HAZOP Training Guide.
Manufacturing Technology Committee - Risk Management Working Group, Product Quality Research Institute:
http://www.oshrisk.org/assets/docs/Tools/3%20Conduct%20Risk%20Assessments/HAZOP_Training_Guide.pdf

Risk Prioritization Revisited



Risk Analysis Revisited

- Consideration of causes and sources of risk, and their consequences and likelihood
- Methods can be
  - Qualitative,
  - Semi-quantitative, or
  - Quantitative risk analysis



Qualitative Transportation Risk Analysis

- Defines likelihood, consequence and level of risk by significant levels such as “high”, “medium” or “low”
- Establishing benchmark comparisons
  – Compare and improve operating practices to align or exceed the desired industry best practices and regulatory standards
- Identifying and elevating issues of concern
  – Develop and respond to a checklist of general review of transportation issues
- Understand the impact of anticipated changes
  – Identify concerns with a change in operating practices

Example Qualitative Transportation Risk Analysis Results

Product	Mode	Qualitative Risk Ranking	Action
Chlorine	Rail	High	Escalate
Coal	Barge	Low	Screen out
Chlorine	Truck	High	Escalate
Aqueous HCl	Intermodal	Medium	Benchmark

Semi-Quantitative Transportation Risk Analysis

- Some degree of quantification is required to characterize different levels of likelihood, consequence and/or risk
- Use numerical rating scales for consequence and probability and combine them to produce a level of risk
- Example techniques
  - Risk Index
  - Risk Matrix

Semi-Quantitative Transportation Risk Analysis Methodology – Risk Index

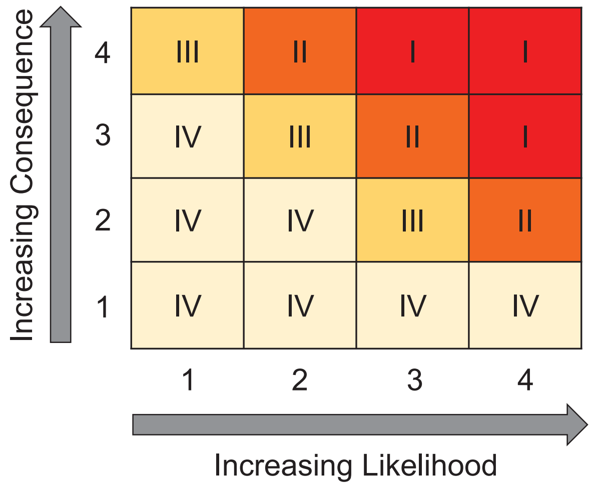
- A single number or a tabulation of numbers correlated to the risk level

Product	Mode	Qualitative Risk Ranking	Action
Chlorine	Rail	High	Escalate
Coal	Barge	Low	Screen out
Chlorine	Truck	High	Escalate
Aqueous HCl	Intermodal	Medium	Benchmark

	A ∩	B ∩	C ∩	D	A×B×C×D
Product - Mode	Frequency of Shipments	Historical Incidents	Hazard Rating	Population Along Route	RISK INDEX
Chlorine – Rail	6	2	10	5	600
Coal - Barge	5	2	1	1	10
Chlorine - Truck	6	5	10	6	1,800
Aqueous HCl - Intermodal	4	6	4	5	480

Semi-Quantitative Transportation Risk Analysis Methodology – Risk Matrix

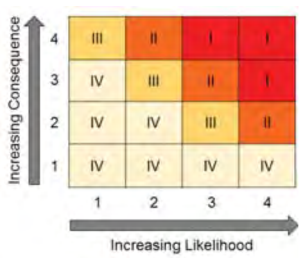
- A graphical tool to classify the level of risk based on the levels of likelihood and consequence



Semi-Quantitative Transportation Risk Analysis Methodology – Example Risk Matrix Definitions

Likelihood Level	Description
1 (Extremely Unlikely)	Not realistically expected to occur
2 (Very Unlikely)	Not Expected to occur (but credible)
3 (Unlikely)	Unlikely to occur but has occurred for similar operations
4 (Likely)	May occur at least once in the lifetime of the operation

Consequence Level	Description
1 (Minor)	No or limited minor injuries; Property damage: <$500,000
2 (Low)	Potential multiple minor injuries or limited serious injuries; Property damage: $500,000 - $1M
3 (High)	Potential multiple serious injuries or limited fatalities; Property damage: $1M - $10M
4 (Very High)	Potential multiple fatalities; Property damage: > $10M



Risk Level	Description
I	Risk must be mitigated
II	Risk mitigations should be considered
III	Operational practices benchmarked
IV	No mitigation required

Note: Example is modified from CCPS (2008) – *Guidelines for Chemical Transportation Safety, Security and Risk Management*

In-Class Group Discussion

- In the same group from the Risk Management lecture, develop a semi-quantitative risk model to address the selected transportation activity (focus on the overall likelihood and consequence of one hazard event)
- Based on your specific transportation activity, describe the conditions where the likelihood and consequence impact is high or low

Likelihood Level	Description
1 (Extremely Unlikely)	Not realistically expected to occur
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4 (Very High)	Potential multiple fatalities; Property damage: > $10M

Increasing Consequence \ Increasing Likelihood	1	2	3	4
4	III	II	I	I
3	IV	III	II	I
2	IV	IV	III	II
1	IV	IV	IV	IV

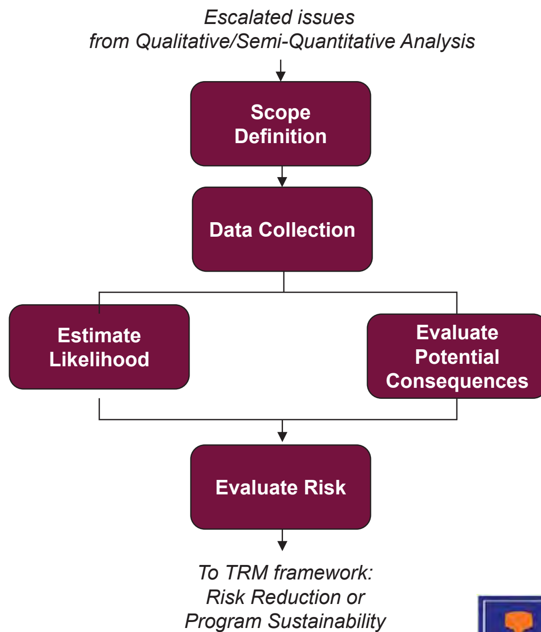
Risk Level	Description
I	Risk must be mitigated
II	Risk mitigations should be considered
III	Operational practices benchmarked
IV	No mitigation required

Quantitative Transportation Risk Analysis

- Quantitative risk analysis estimates practical values, based on the best information available, for the likelihood and the consequence of a hazard event

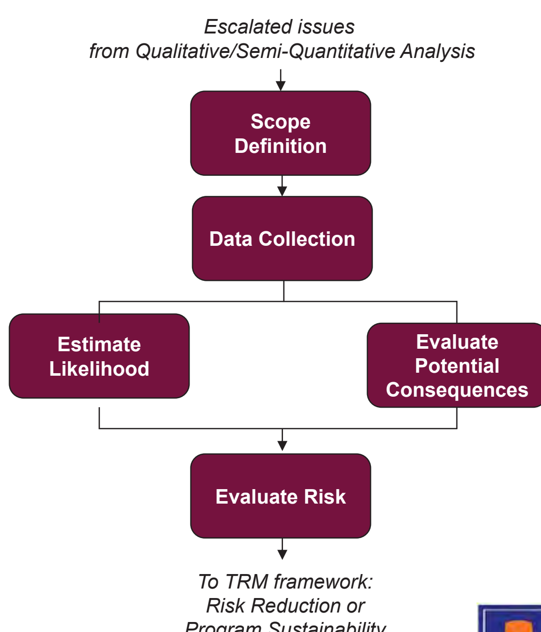
Transportation Quantitative Risk Analysis Protocol

1. Scope definition
   - Single mode or multimodal
   - Route characteristics
   - Vehicle/container types
   - Consequence impacts
2. Data collection and evaluation
   - Literature review, public data, confidential data
3. Likelihood estimation
4. Consequence evaluation
5. Risk evaluation



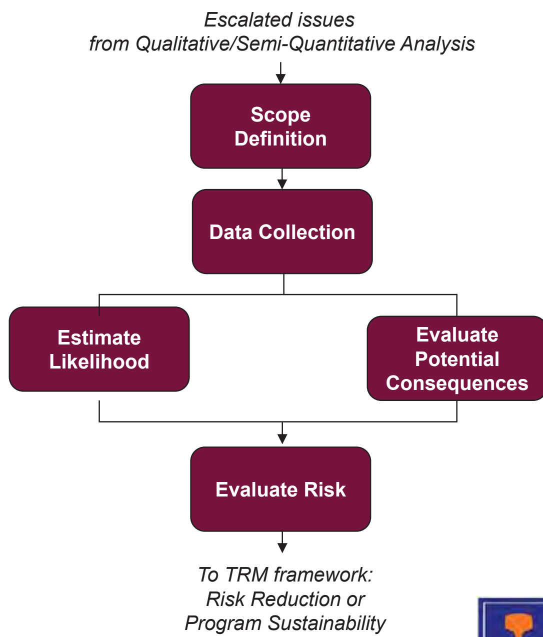
Likelihood Estimation

- Key transportation risk likelihood estimates:
  - Initiating event rate
  - Conditional probability of release
  - Release size probability distribution
  - Consequence exposure probability distribution
- Typical approaches:
  - Historical data
  - Probability forecasts using predictive or simulation techniques
  - Expert opinion



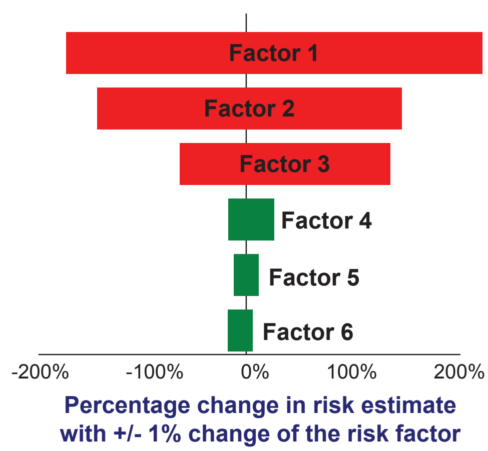
Consequence Analysis

- Consequence analysis determines the nature and type of impact which could occur assuming that a particular event situation or circumstance has occurred
- Example: fatalities, injuries, property damage, environmental impacts, business interruption, evacuation, distribution system disruption, negative publicity, excess regulations
- Consequence analysis can vary from a simple description of outcomes to detailed quantitative modeling or vulnerability analysis



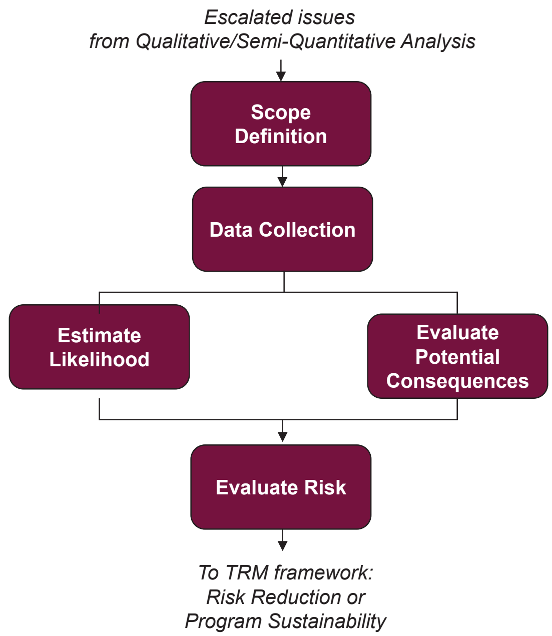
Uncertainties and Sensitivities

- There are often considerable uncertainties associated with the analysis of risk
- Uncertainty analysis involves the determination of the variation or imprecision in the results
- Sensitivity analysis involves the determination of the size and significance of the magnitude of risk to changes in individual input parameters
  - It is used to identify those data which need to be accurate, and those which are less sensitive and hence have less effect upon overall accuracy



Risk Evaluation

- Making decisions about which risks need to be reduced
  - Based on the outcomes of risk analysis
- Comparing risk level with established risk criteria or any industry benchmark
- Consideration of not to treat risk, but maintain existing controls
- Consideration of risk tolerance
- Consideration of further analysis



Risk Assessment Documentation

- Objectives and scope
- Description of relevant parts of the system and their functions
- A summary of the external and internal context of the organization and how it relates to the situation, system or circumstances being assessed
- Risk criteria applied and their justification
- Limitations, assumptions and justification of hypotheses
- Assessment methodology
- Risk identification results
- Data, assumptions and their sources and validation
- Risk analysis results and their evaluation
- Sensitivity and uncertainty analysis
- Critical assumptions and other factors which need to be monitored;
- Discussion of results
- Conclusions and recommendations
- References

Risk Assessment Tools: ISO 30010 Appendix A

Tools and techniques	Risk assessment process					See Annex
	Risk Identification	Risk analysis			Risk evaluation	
		Consequence	Probability	Level of risk		
Brainstorming	SA[1]	NA[2]	NA	NA	NA	B 01
Structured or semi-structured interviews	SA	NA	NA	NA	NA	B 02
Delphi	SA	NA	NA	NA	NA	B 03
Check-lists	SA	NA	NA	NA	NA	B 04
Primary hazard analysis	SA	NA	NA	NA	NA	B 05
Hazard and operability studies (HAZOP)	SA	SA	A[3]	A	A	B 06
Hazard Analysis and Critical Control Points (HACCP)	SA	SA	NA	NA	SA	B 07
Environmental risk assessment	SA	SA	SA	SA	SA	B 08
Structure « What if? » (SWIFT)	SA	SA	SA	SA	SA	B 09
Scenario analysis	SA	SA	A	A	A	B 10
Business impact analysis	A	SA	A	A	A	B 11
Root cause analysis	NA	SA	SA	SA	SA	B 12
Failure mode effect analysis	SA	SA	SA	SA	SA	B 13
Fault tree analysis	A	NA	SA	A	A	B 14
Event tree analysis	A	SA	A	A	NA	B 15
Cause and consequence analysis	A	SA	SA	A	A	B 16
Cause-and-effect analysis	SA	SA	NA	NA	NA	B 17
Layer protection analysis (LOPA)	A	SA	A	A	NA	B 18
Decision tree	NA	SA	SA	A	A	B 19
Human reliability analysis	SA	SA	SA	SA	A	B 20
Bow tie analysis	NA	A	SA	SA	A	B 21
Reliability centred maintenance	SA	SA	SA	SA	SA	B 22
Sneak circuit analysis	A	NA	NA	NA	NA	B 23
Markov analysis	A	SA	NA	NA	NA	B 24
Monte Carlo simulation	NA	NA	NA	NA	SA	B 25
Bayesian statistics and Bayes Nets	NA	SA	NA	NA	SA	B 26
FN curves	A	SA	SA	A	SA	B 27
Risk indices	A	SA	SA	A	SA	B 28
Consequence/probability matrix	SA	SA	SA	SA	A	B 29
Cost/benefit analysis	A	SA	A	A	A	B 30
Multi-criteria decision analysis (MCDA)	A	SA	A	SA	A	B 31

1) Strongly applicable.
2) Not applicable.
3) Applicable.

Key Takeaways

- Risk assessment provides evidence-based information and analysis to make informed decisions on how to treat particular risks
- Risk assessment involves risk identification, risk analysis and risk evaluation
- Risk analysis methods can be qualitative, semi-quantitative, or quantitative

In-Class Group Discussion

- Identify data requirements and potential data sources or data collection processes to perform quantitative risk analysis to address the selected transportation activity from the previous in-class group discussion
  - Likelihood estimates to consider?
  - Consequence estimates to consider?
  - Existing data sources?
  - New data collection or survey?

Additional Resources

- ISO 31010. Risk Management – Risk Assessment Techniques, International Standard Organization, ISO 31000:2009.
- Center for Chemical Process Safety (CCPS). *Guidelines for Chemical Transportation Safety, Security, and Risk Management*. American Institute of Chemical Engineers, Second Edition, Hoboken, NJ, 2008.
- HAZOP Training Guide. Manufacturing Technology Committee - Risk Management Working Group, Product Quality Research Institute: http://www.oshrisk.org/assets/docs/Tools/3%20Conduct%20Risk%20Assessments/HAZOP_Training_Guide.pdf

STRUCTURING RISK DECISION PROBLEM

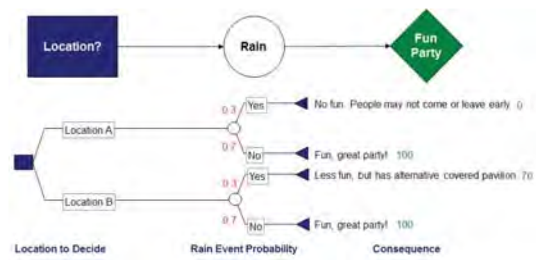
CEE498 TSR -Transportation Safety and Risk

Dr. Rapik Saat, Ph.D.

Rail Transportation and Engineering Center – RailTEC

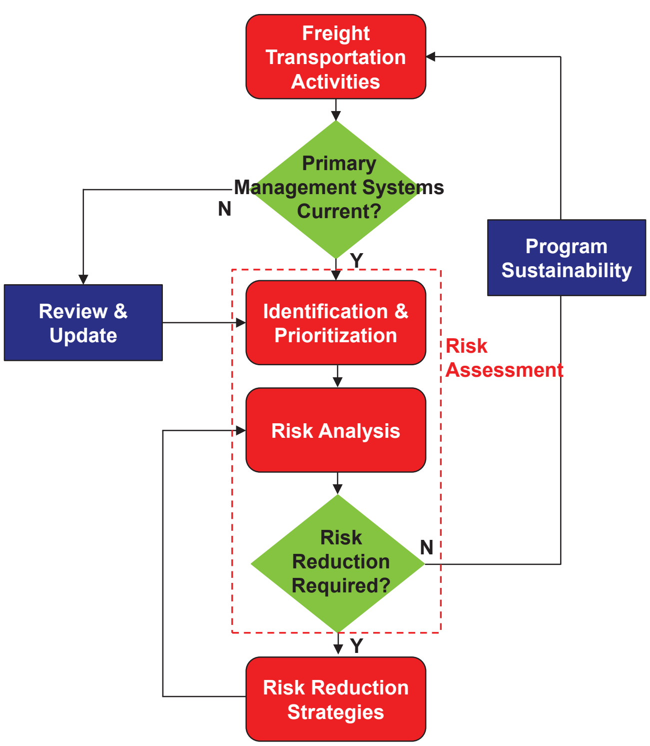
Department of Civil & Environmental Engineering

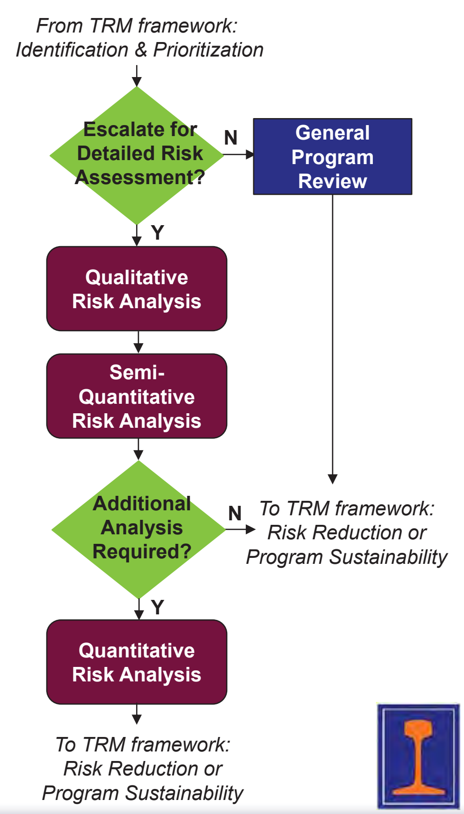
University of Illinois at Urbana-Champaign, U.S.A.



RAILTEC UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

Review





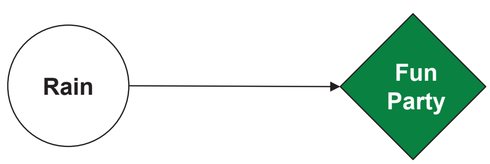
Learning Outcomes

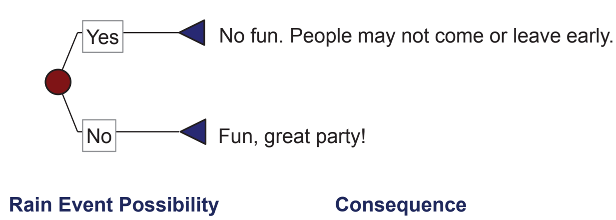
At the end of this lecture students will be able to:

1. Understand influence diagram and event or decision tree
2. Structure a transportation risk scenario by developing influence diagram and event tree

Structuring Risky Scenario: Planning and Outdoor Party

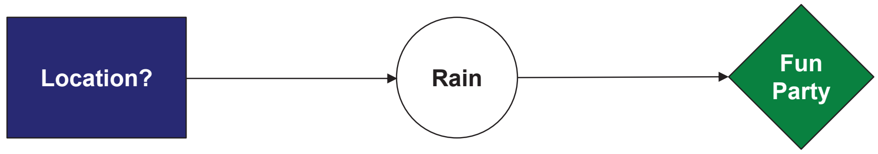
- What's the objective or key value to achieve? *Fun party*
- What could go wrong? What are you worried about? *Rain*

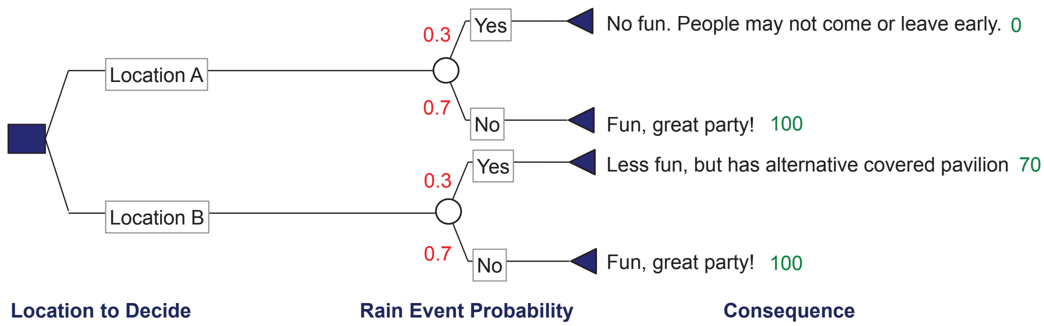




Structuring Risky *Decision*: Planning and Outdoor Party

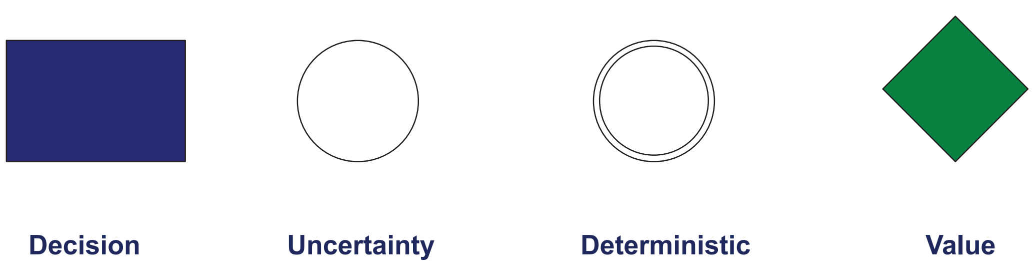
- What's the objective or key value to achieve? *Fun party*
- What could go wrong? What are you worried about? *Rain*



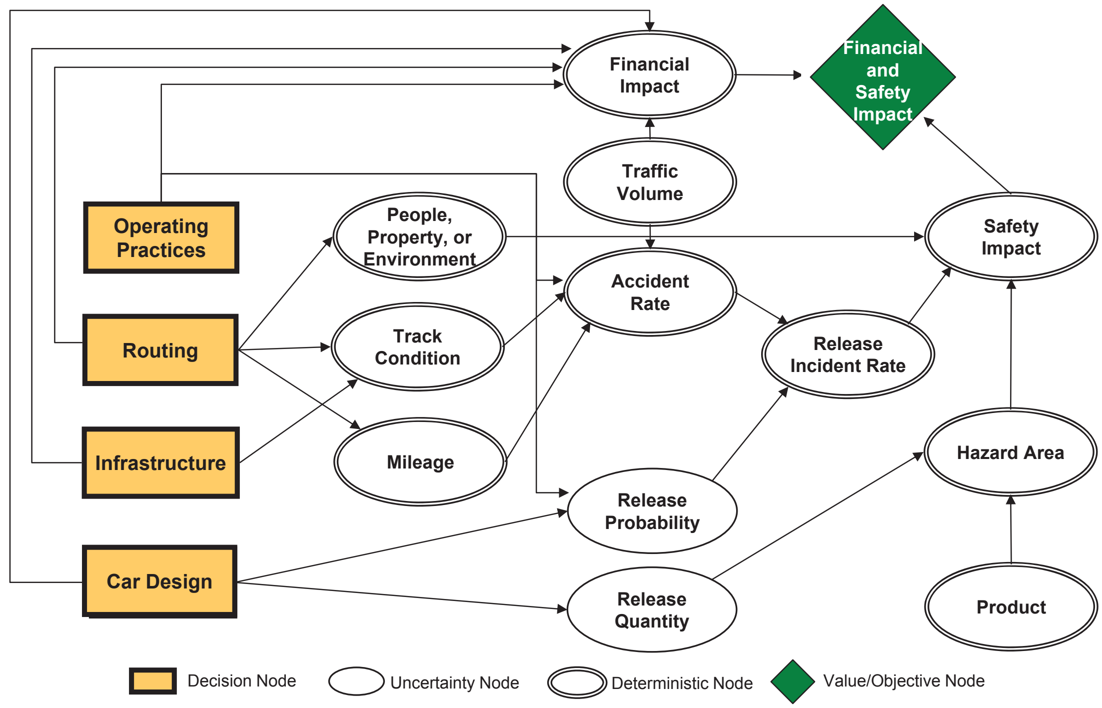


Influence Diagram & Event Tree

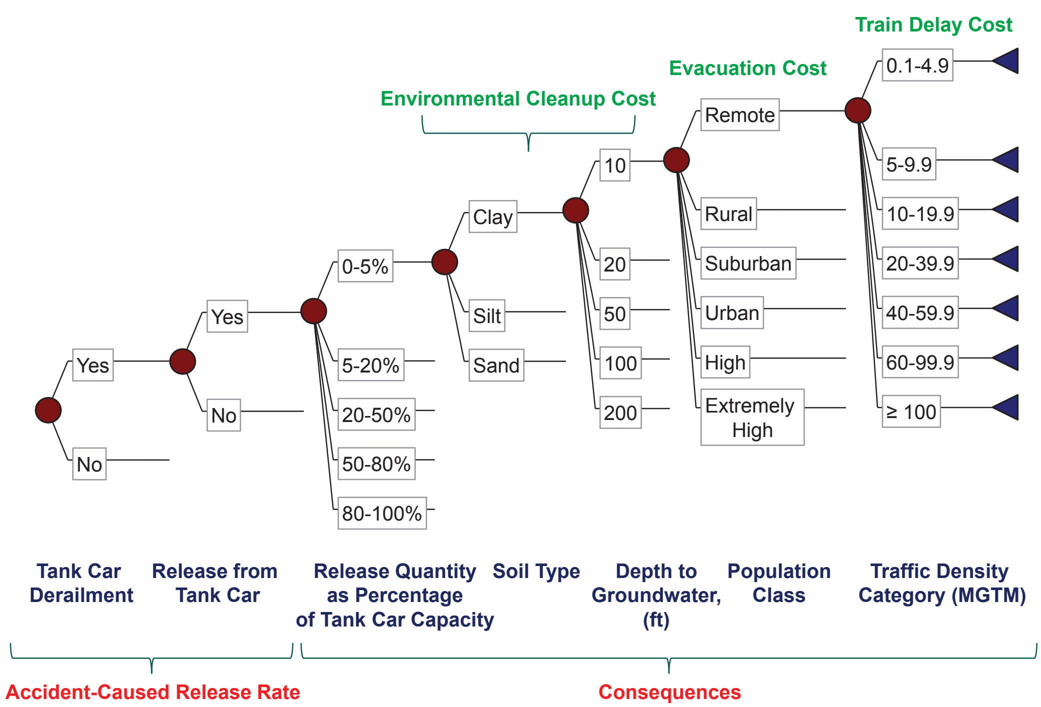
- Influence diagram to show relations between different factors
- Event tree depicts different possibilities of each factor



Influence diagram showing relationships of factors affecting hazardous materials transportation safety



Framework for Railroad Environmental Risk Assessment



Key Takeaway

- Influence diagram and event tree are useful to summarize risky scenarios or decision problems

Group Discussion Revisited – Semi-Quantitative Risk Analysis

- In the same group from the Risk Management lecture, describe specific strategies using a semi-quantitative risk analysis approach to address the selected transportation activity (focus on the overall likelihood and consequence of <u>one</u> hazard event)
- Based on your specific transportation activity, describe the conditions where the likelihood and consequence impact is high or low

Likelihood Level	Description
1 (Extremely Unlikely)	Not realistically expected to occur
2 (Very Unlikely)	Not Expected to occur (but credible)
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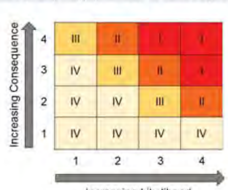

Risk Level	Description
I	Risk must be mitigated
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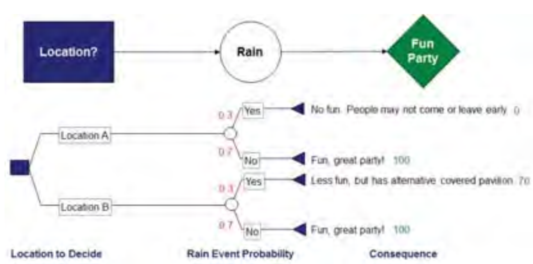
III	Operational practices benchmarked
IV	No mitigation required

Group Discussion Revisited – Quantitative Risk Analysis

- Identify data requirements and potential data sources or data collection processes to perform quantitative risk analysis to address the selected transportation activity from the previous in-class group discussion
  - Likelihood estimates to consider?
  - Consequence estimates to consider?
  - Existing data sources?
  - New data collection or survey?

Group Discussion Extension

- In the same group from the lecture, develop an influence diagram and event tree for the selected transportation activity
  - Identify one decision
  - Prioritize and show key risk factors



Additional Resources

- Howard, R.A. and A. Abbas. *The Foundations of Decision Analysis*. 2004.
- Clemen, R.T. and T. Reilly. *Making Hard Decisions*. 2001.

Introduction to Decision Analysis

DA Fundamentals: Decision Analysis = Decision Engineering

http://www.youtube.com/watch?v=gUQJt5sQv2U

OVERVIEW OF HAZARDOUS MATERIALS TRANSPORTATION

CEE498 TSR -Transportation Safety and Risk

Dr. Rapik Saat, Ph.D.

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Department of Civil & Environmental Engineering

University of Illinois at Urbana-Champaign, U.S.A.

RAILTEC
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

Analytical Rogue:
Superficial Values or Feel Good Prioritization

- Well-meaning committees judge value with some sort of scoring system, often with each committee member voting or dividing up points on various factors such as probability of success, commercial potential, strategic fit, etc.
  - Technically these systems often subsume a logical model by applying direct "judgment" of the committee members, when there good reasons to believe that the members are not equipped to make this "visceral calculation."
  - Scores are added when logically they should be combined in other ways; for example, probability of success should be multiplied by the value given success.
  - Finally the scoring systems often cover up a political process of "I'll vote for your project if you'll vote for mine."
- The scoring approach usually evolves into an exercise in manipulating the weights to get your favorite projects funded, rather than providing real insight into which course of action should be taken.
  - The more controversy in a situation, the more pressure there is for manipulation.
  - These scores too often do not have the objective power to change people's minds about what is in their best interest.
- One client put it this way "these methods add sophistication without adding knowledge."

Semi-Quantitative Transportation Risk Analysis Methodology – Risk Index

- A single number or a tabulation of numbers correlated to the risk level

Product	Mode	Qualitative Risk Ranking	Action
Chlorine	Rail	High	Escalate
Coal	Barge	Low	Screen out
Chlorine	Truck	High	Escalate
Aqueous HCl	Intermodal	Medium	Benchmark

A ∩ B ∩ C ∩ D A×B×C×D

Product - Mode	Frequency of Shipments	Historical Incidents	Hazard Rating	Population Along Route	RISK INDEX
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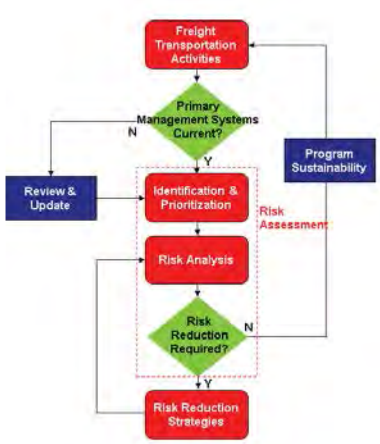
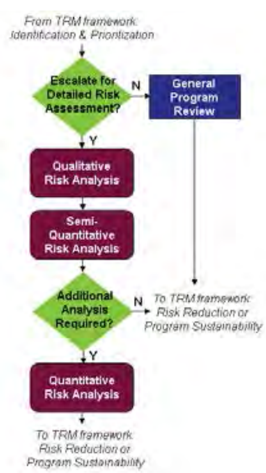
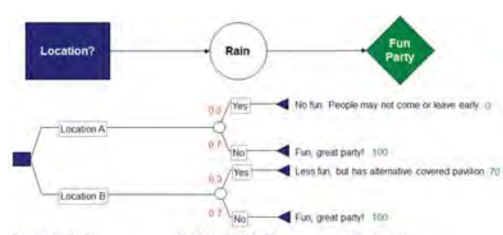
Aqueous HCl - Intermodal	4	6	4	5	480

Review







Learning Outcomes

At the end of this lecture students will be able to:

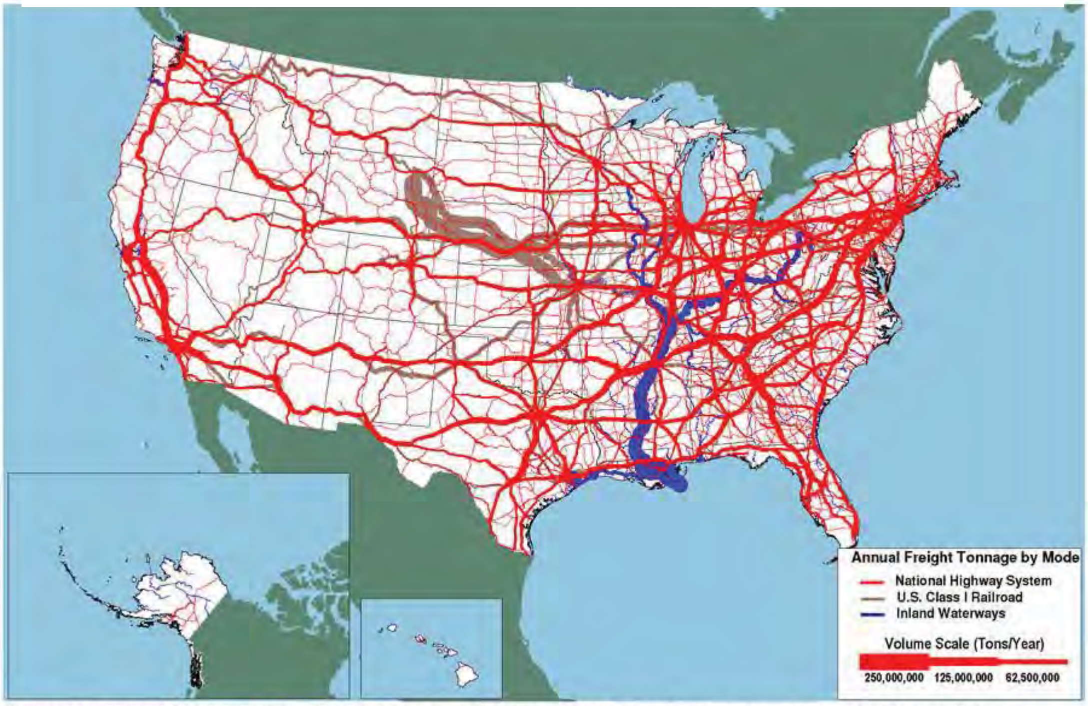
1. Recognize the extent of freight transportation infrastructure in the U.S.
2. Identify the major types of hazardous commodities that are moved and how various transport modes are utilized in this regard
3. Recognize US federal hazardous materials transportation regulations
4. Recognize the economic considerations that affect the transport of hazardous materials
5. Describe the supply chain for hazardous materials

U.S. Freight Transportation Infrastructure

- Roads
  - Over 4 million miles of public roads
  - 164,000 miles of roads comprising the National Highway System, including over 47,000 miles of Interstates
- Rail
  - Over 250,000 miles of track, including yards, sidings and parallel lines
  - Nearly 95,000 miles of Class I railroad track
- Waterway
  - Over 13,000 miles of inland waterways, including rivers and Great Lakes
  - Nearly 300 major commercial ports
- Pipeline
  - Roughly 1.7 million miles of oil and gas pipelines
- Air
  - Over 13,000 airports

Sources: FHWA Freight Facts and Figures 2011, North American Transportation Statistics Database

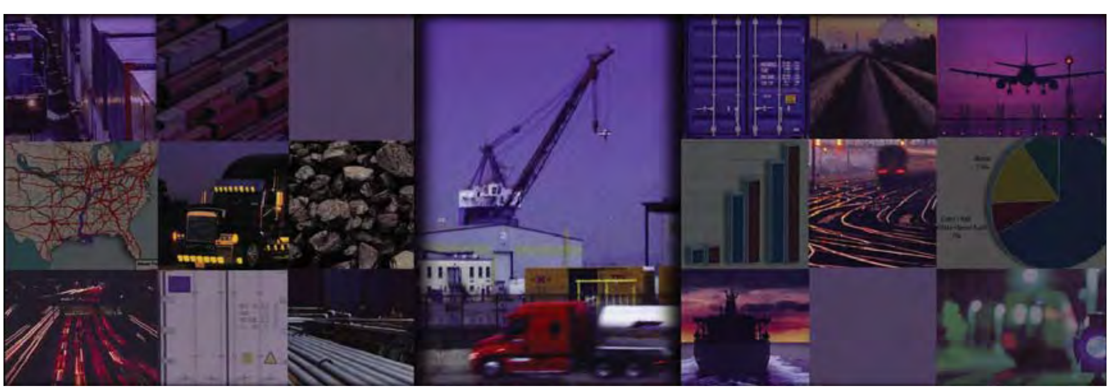
U.S. Freight Tonnage by Mode: 2007



Sources: Highways: U.S. Department of Transportation, Federal Highway Administration, Freight Analysis Framework, Version 3.1, 2010. Rail: Based on Surface Transportation Board, Annual Carload Waybill Sample and rail freight flow assignments done by Oak Ridge National Laboratory. Inland Waterways: U.S. Army Corps of Engineers (USACE), Annual Vessel Operating Activity and Lock Performance Monitoring System data, as processed for USACE by the Tennessee Valley Authority; and USACE, Institute for Water Resources, Waterborne Foreign Trade Data, Water flow asssignments done by Oak Ridge National Laboratory.

U.S. Freight Transportation Vehicles & Equipment

- Nearly 11 million commercial freight trucks
- 24,000 freight locomotives and over 1.3 million rail cars
- 40,000 freight vessels – 9,000 self-propelled and 31,000 barges
- Over 18,000 commercial aircraft



Sources: FHWA Freight Facts and Figures 2011, North American Transportation Statistics Database

Slide 9

ILLINOIS - RAILTEC

What Is A Hazardous Material?

- A substance or material that poses an unreasonable risk to health, safety, or property when it's transported, used incorrectly, or not properly stored or contained

Source: U.S. DOT Pipelines and Hazardous Materials Safety Administration (PHMSA)

Slide 10

ILLINOIS - RAILTEC

PHMSA Hazmat Classification System

Class 1: Explosives
- 1.1 Mass explosion hazard
- 1.2 Blast/projection hazard
- 1.3 Predominately a fire hazard
- 1.4 No significant blast hazard
- 1.5 Very insensitive explosives; blasting agents
- 1.6 Extremely insensitive detonating substances

Class 2: Gases
- 2.1 Flammable
- 2.2 Non-Flammable
- 2.3 Poisonous

Class 3: Flammable Liquids

Class 4: Flammable Solids
- 4.1 Flammable solids
- 4.2 Spontaneously combustible
- 4.3 Dangerous when wet

Class 5: Oxidizing Agents & Organic Peroxides
- 5.1 Oxidizing agents
- 5.2 Organic peroxides

Class 6: Toxic & Infectious Substances
- 6.1 Poisonous materials
- 6.2 Etiologic (infectious) materials

Class 7: Radioactive Substances

Class 8: Corrosive Substances

Class 9: Miscellaneous

Hazardous Materials and Societal Needs

- More than 70,000 chemicals are used regularly around the world
- They are used to produce almost everything we use
- Some of these hazardous materials are finished products while others are used as ingredients in producing these products

Sample Products Made From Hazardous Materials

- Building insulation
- Automobile parts
- Compact fluorescent bulbs
- Coolant systems
- Plastic packaging
- Solar panels
- Batteries
- Diesel additives
- Detergents
- Paper
- Air filters
- Oil spill absorbents, booms and skimmers
- Drugs and vaccines
- Medical devices
- Fertilizers
- Safe drinking water
- Athletic gear
- Computer parts

Source: American Chemistry Council

Hazardous Materials Transportation Modes

Truck

Rail

Waterway

Air

Pipeline

Intermodal

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Various Types of Hazmat Packaging

Drums

Boxes

Cylinders

Special Containers

Tanks

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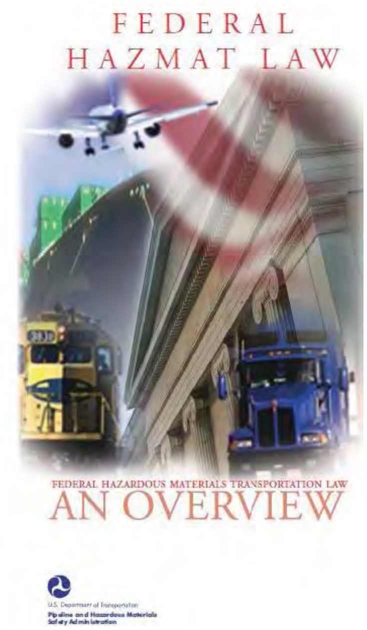
US DOT Hazardous Materials Regulations (HMR)

49 CFR 171 through 180

- 171 General information, regulations, and definitions
- 172 Hazardous materials table, special provisions, hazmat communications, emergency response, training
- 173 Shippers and packaging
- 174 Carriage by rail
- 175 Carriage by aircraft
- 176 Carriage by vessel
- 177 Carriage by public highway
- 178 Specs for packaging
- 179 Specs for tank cars
- 180 Continuing qualification and maintenance of packagings



Source: http://hazmat.dot.gov

US DOT Hazardous Materials Regulations (HMR)

The HMR are designed to achieve four goals:

Classify
- To ensure hazardous materials are packaged and handled safely and securely during transportation, hazardous materials are categorized into hazard classes and packing groups based upon the transportation risks.

Contain
- To minimize the consequences of an incident should one occur, the HMR require shippers to properly package the materials commensurate with the risks they pose in transportation.

Communicate
- To provide effective communication to transportation workers and emergency responders regarding the hazards of the materials being transported, the HMR require hazard communications through use of shipping papers, package marking and labeling, and vehicle placarding. Additionally, the HMR require shippers to provide emergency response information applicable to the specific hazards of the material being transported.

Comply
- To improve awareness of and adherence to relevant laws and regulations, PHMSA evaluates risk, enforces safety standards, educates stakeholders, investigates incidents and failures, conducts research, and supports the emergency response community.

Source: US DOT Pipeline and Hazardous Material Safety Administration, Transportation of Hazardous Materials, 2009-2010.

Hazardous Material Shipment Characteristics - 2007

- Over 2.2 billion tons of hazardous materials are transported, valued at over $1.4 trillion
- This corresponds to 323 trillion ton-miles of hazmat cargo moved annually
- The average trip distance of these shipments is 96 miles
- Hazmat transportation represents roughly 18% of total tons transported by freight industry and accounts for nearly 10% of the ton-miles

Source: 2007 Commodity Flow Survey

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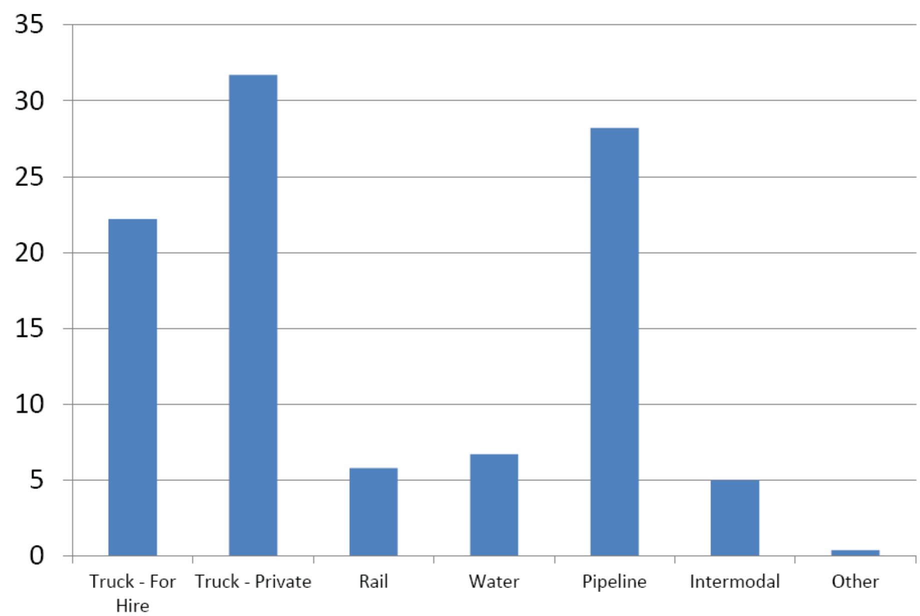
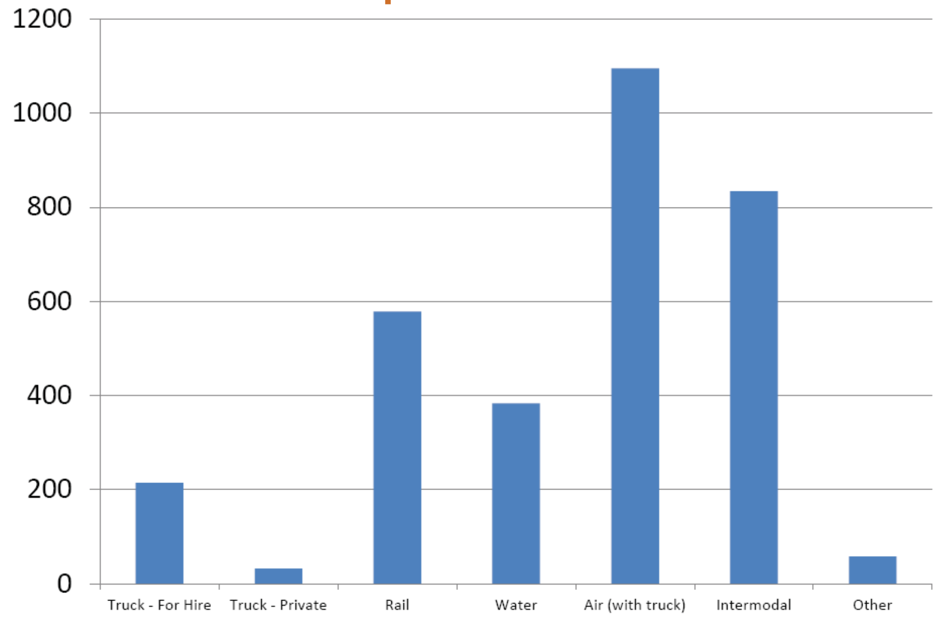
Percentage of Hazardous Material Tonnage by Transportation Mode



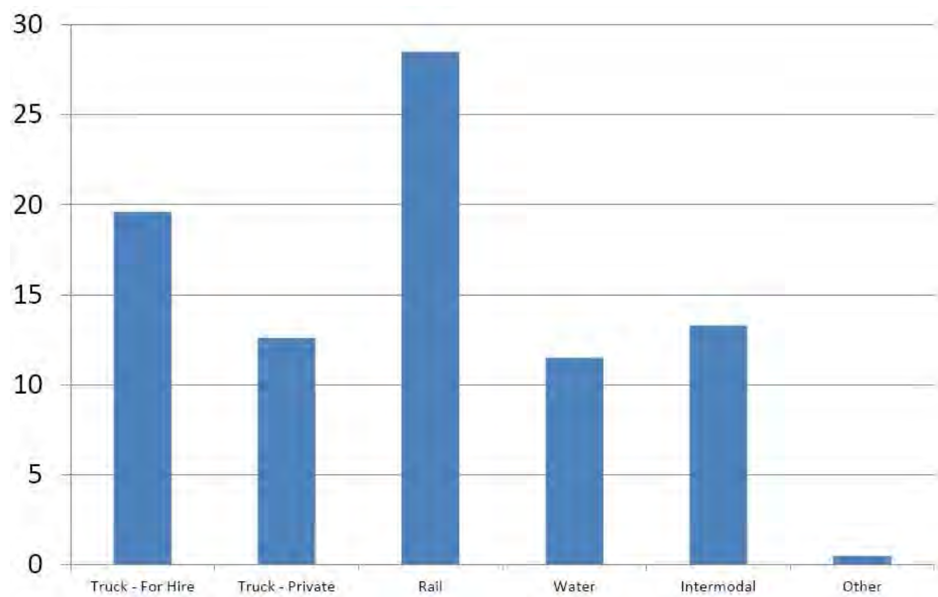
Source: 2007 Commodity Flow Survey

Average Hazardous Material Trip Length (Miles) by Transportation Mode



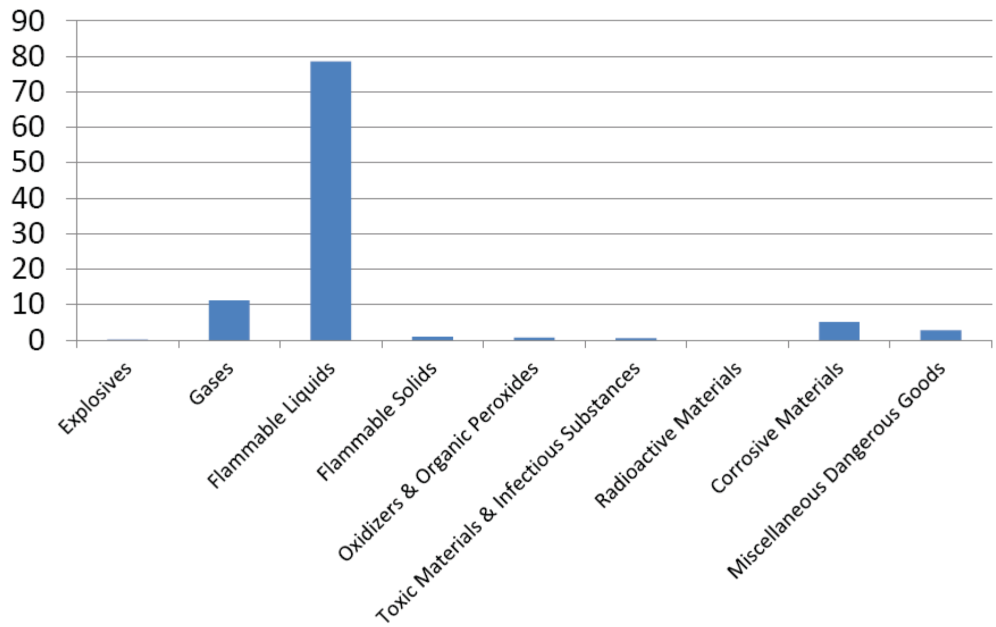
Source: 2007 Commodity Flow Survey

Percentage of Hazardous Material Ton-Miles by Transportation Mode



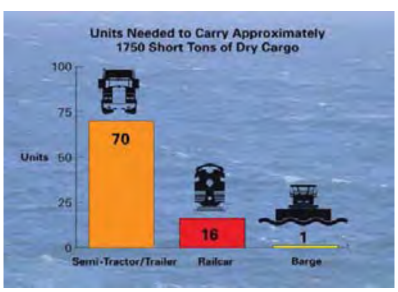
Source: 2007 Commodity Flow Survey

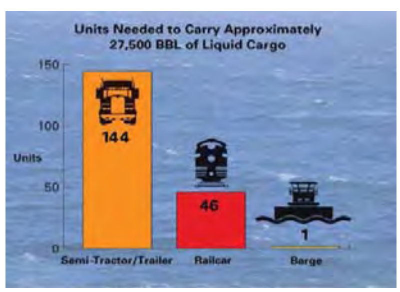
Percentage of Hazardous Material Tonnage by Hazard Class

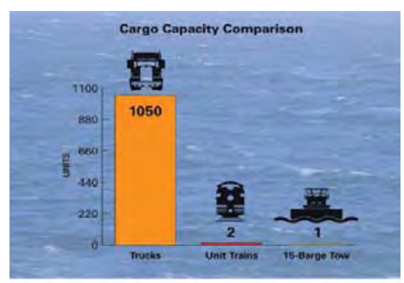


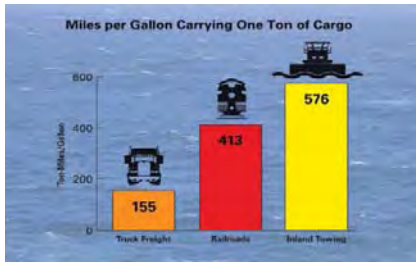
Source: 2007 Commodity Flow Survey

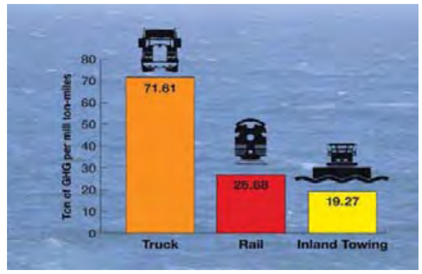
Economic Considerations





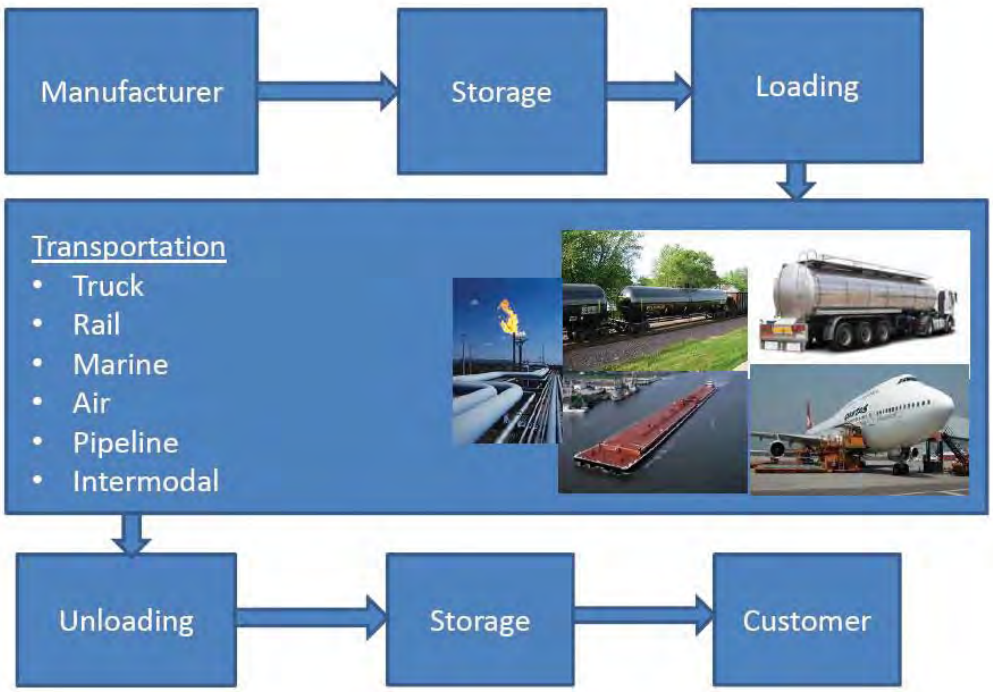






Source: C. James Kreese, et al., A Modal Comparison of Domestic Freight Transportation Effects on the General Public, Texas Transportation Institute, Texas A & M University System, December 2007

Generalized Supply Chain Flow Chart



Hypothetical Shipment: Supply Chain Roles

Petrochemicals are shipped via rail from a chemical plant in Houston, Texas, to a manufacturer in Philadelphia. The finished product, also considered a hazardous material, is then transported by truck to the Port of New York for ocean shipping to Europe.

Hypothetical Shipment: Supply Chain Roles

- **Chemical Plant**
  - Prepare shipping documents
  - Load commodity using approved procedures by certified employees
  - Maintain an emergency response plan
- **Railroad**
  - Accept shipping documents and prepare additional documents as required
  - Inspect cars prior to loading
  - Inspect cars after loading
  - Provide appropriate placards
  - Place car within the train in an approved configuration
  - Inspect car before moving

Hypothetical Shipment: Supply Chain Roles

- **Railroad (continued)**
  - Maintain shipping documents
  - Maintain emergency response information
  - Transport to interchange with another railroad
  - Inspect car at interchange
  - Transfer shipping documents to second carrier
  - Second railroad places car in appropriate position within train
  - Deliver to manufacturer
- **Manufacturer (Incoming)**
  - Accept car and inspect
  - Accept shipping papers
  - Unload car
  - Store commodities in approved manner

Hypothetical Shipment: Supply Chain Roles

- **Manufacturer (Outgoing)**
  – Prepare appropriate shipping documents
  – Load truck
- **Trucking Firm**
  – Accept and maintain shipping documents
  – Inspect load
  – Provide appropriate placards
  – Transport load
- **Port Facility**
  – Accept load and shipping documents
  – Store in appropriate location
  – Prepare additional required shipping documentation for overseas shipping
  – Move to ship

Hazardous Materials Shipment Supply Chain Process Maps

See handout

In-Class Group Discussion

- Compare the HM Shipment Supply Chain Process Maps for TL and LTL Truck; Rail; and Ocean Intermodal
  - For which modal alternative are there more opportunities for delays and bottlenecks? Identify the bottlenecks and explain your answer
  - For which modal alternative are there more risks for an HM incident (spill or release)?
  - Suggest ways to reduce the delays/bottlenecks in the process maps without simultaneously increasing the risk of an HM incident

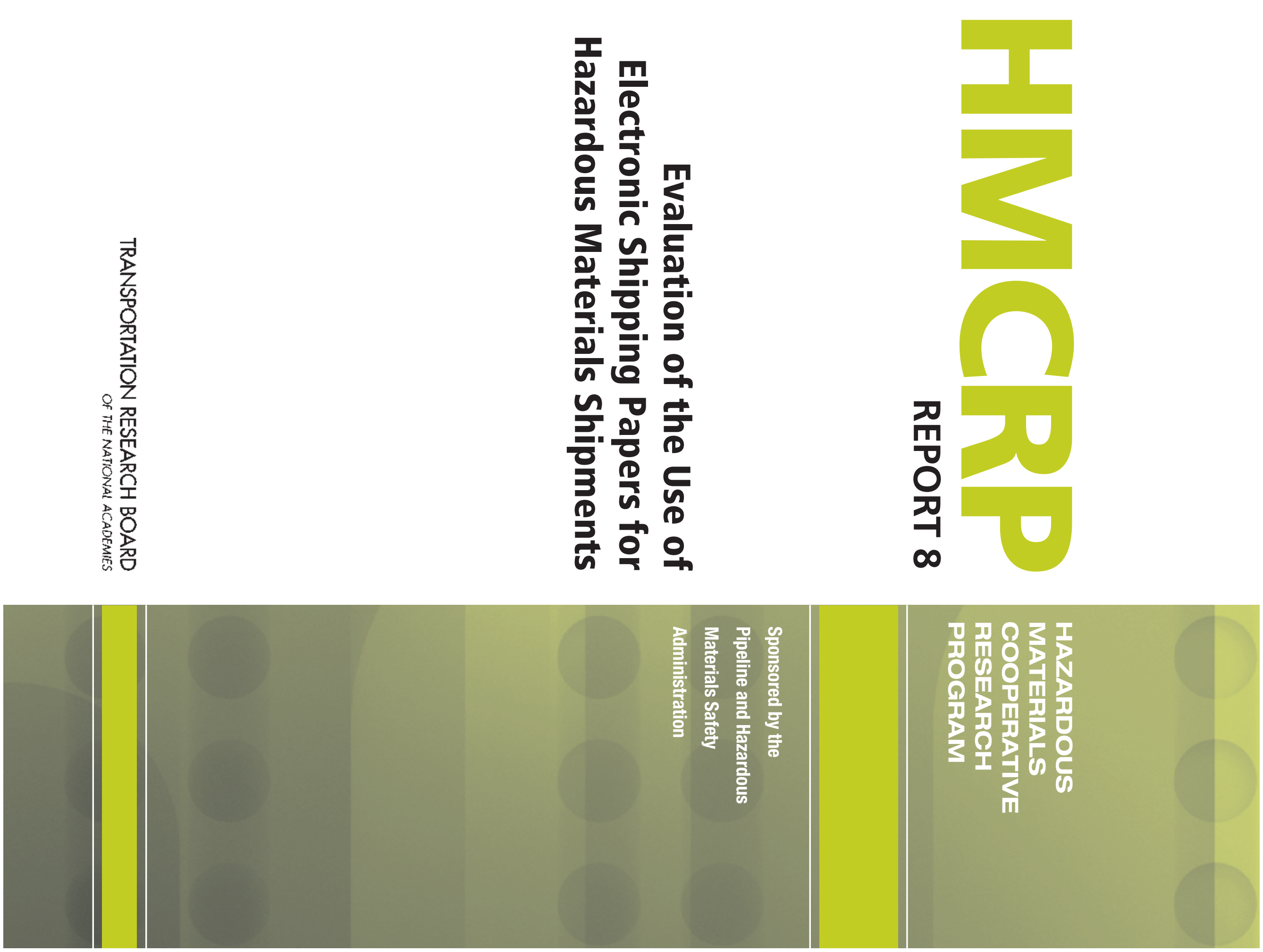
Key Takeaways

- The transportation of hazardous materials is a major shipping activity involving many freight modes and service providers
- The majority of shipments are made by truck, with pipeline, rail and waterway trips representing longer-haul and larger bulk movements
- Choice of transport mode is based on several factors, including commodity type, shipment volume, safety and security risk, and regulatory requirements
- A variety of operational issues must be considered from a logistics perspective

Additional Resource

- HM-16 Project: Model Post-Secondary Education Curricula for the Transportation of Hazardous Materials
- William Tate, et al., Evaluation of the Use of Electronic Shipping Papers for Hazardous Materials Shipments, HMCRP Report 8, Transportation Research Board, Washington DC, 2012.

Hazardous Materials Cooperative Research Program
TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES



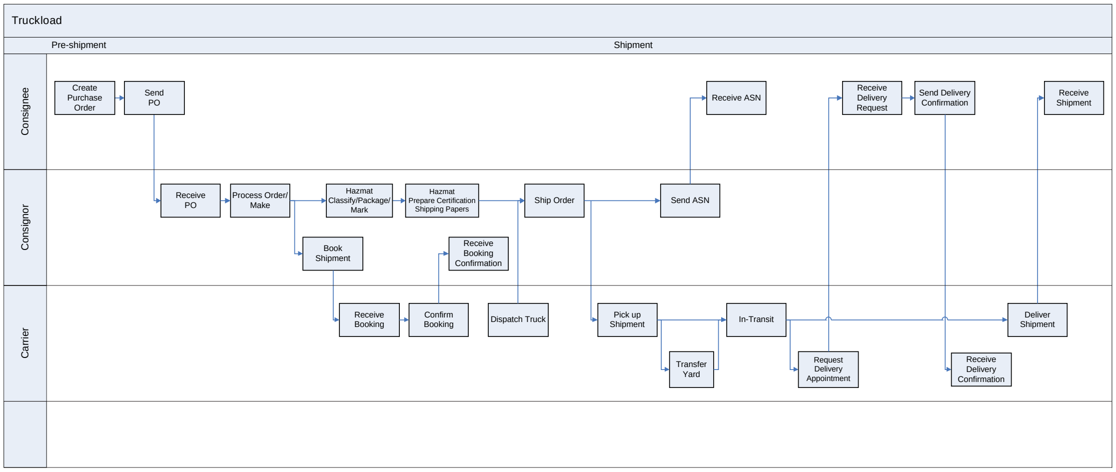


Figure 1. Truckload process map.

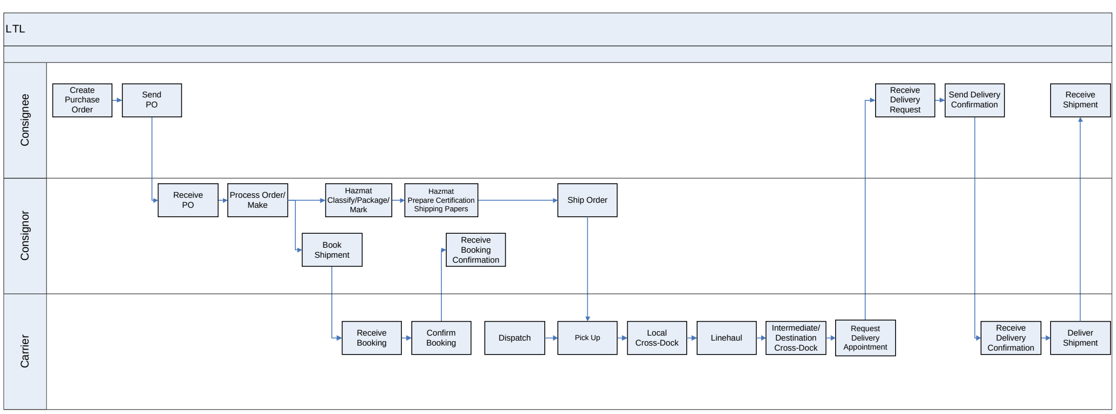


Figure 2. Less-than-truckload process map.

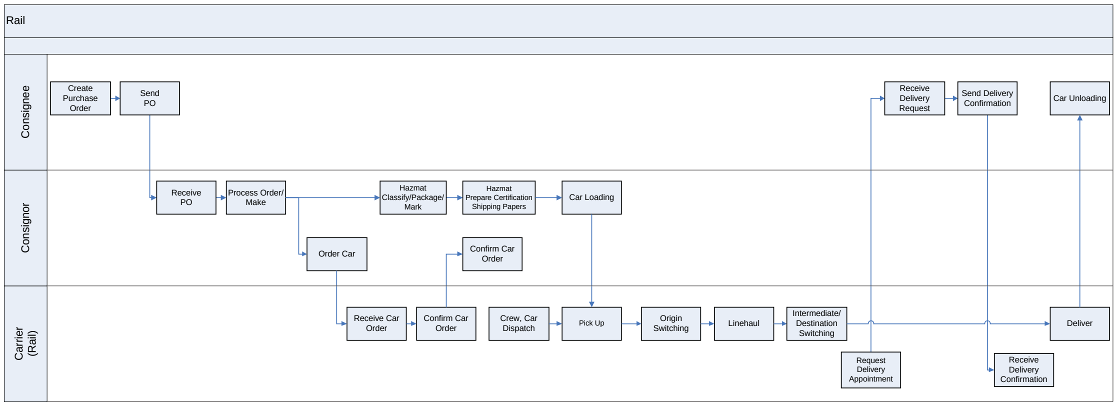


Figure 3. Rail process map.

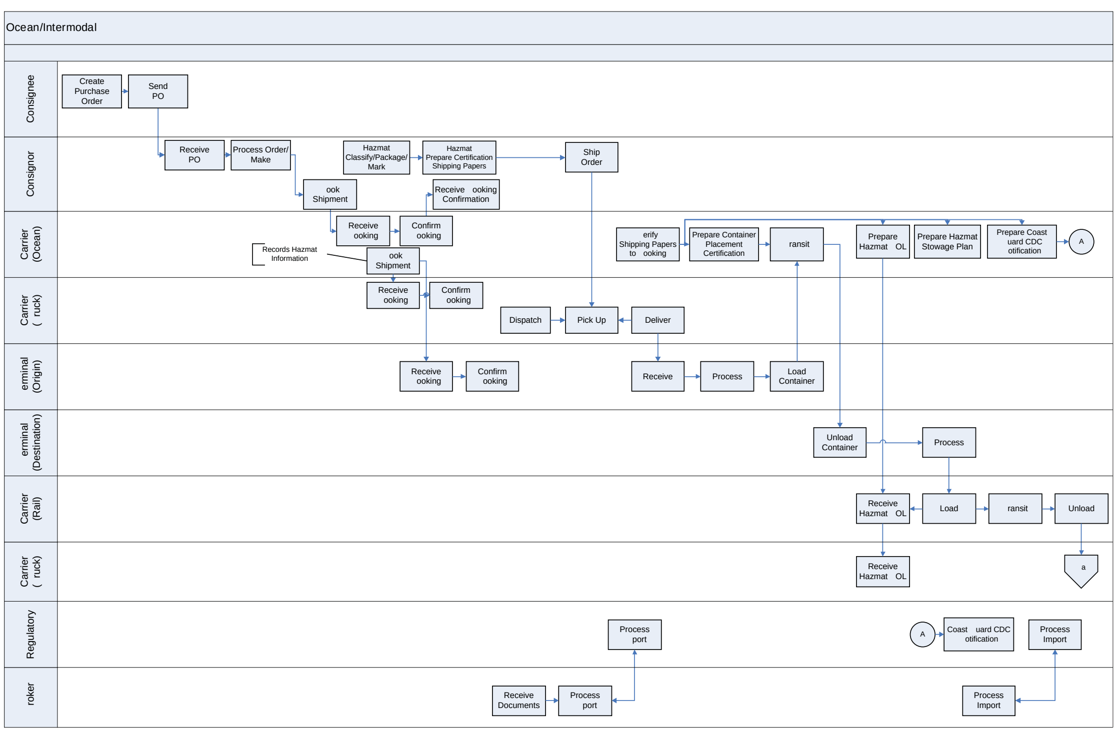


Figure 4. Ocean intermodal process map.

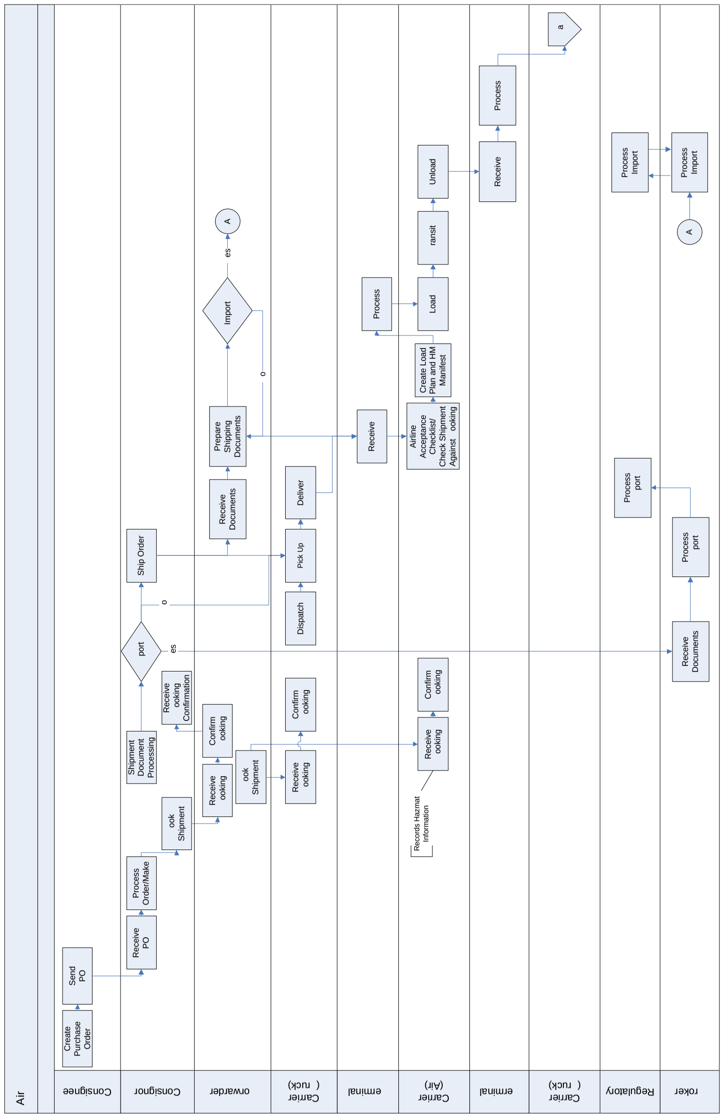


Figure 5. Air process map.

Table 1. Process map element descriptions.

Activity Identifiers	Role	Definition
Create PO	Consignee (receiver)	he consignee will create a PO, which is a legally inding document used to track shipped goods and link them with invoices he PO provides the PO num er, a description of the goods, the quantity ordered, and delivery dates (earliest and latest), and identifies the shipper, roker, and container freight station for delivery as well as uyer specific information such as the rand and/or division placing the order
Send PO	Consignee (receiver)	he purchasing arm of the consignee will forward the PO to the consignor his can e done through fa , e mail, file transfer, or traditional letter mail
Receive PO	Consignor (shipper)	he consignor will then confirm receipt of the PO y telephone or one of the aforementioned methods
Process order/make	Consignor	he consignee will check whether the item is in stock If it is, it will issue stock for shipping If not, the vendor will egin the production process for its manufacture in accordance with the PO his item will then e considered the consignment
ook shipment (order car for rail)	Consignor	he consignor will select a carrier for the consignment and send the carrier a ooking he ooking will include information a out the product, its destination, and delivery dates Additionally, it will include information on the types/quantities of hazmat
Receive ooking (receive car order for rail)	Carrier	he carrier will accept the ooking and plan the means of transportation for the consignment
Confirm ooking (confirm car order for rail)	Carrier	he carrier will then send confirmation to the consignor and schedule a pick up time
Receive ooking confirmation (confirm car order for rail)	Consignor	he consignor will receive the ooking confirmation and prepare the consignment for shipping at the scheduled pick up time
Record hazmat information (ocean and air)	Carrier	he carrier will note specific information for the proper receipt, documentation, handling, stowage, and reporting associated with hazmat shipments rained designated hazmat personnel will take, or later validate, the ooking
Hazmat shipment classify/package/mark	Consignor	If the consignment contains hazmat, the consignor will mark the shipment in accordance with federal, state, or international regulations
Hazmat shipment prepare certification shipping papers	Consignor	Additionally, the consigner will prepare hazmat shipping papers, which include some of the following information identification num er, PS , hazard class, packing group, additional descriptions, emergency response num ers, and shipper s certification
Dispatch (crew, car dispatch for rail)	Carrier	he carrier will dispatch a truck (or rail crew, locomotive, and car) to pick up the consignment from the consignor at the scheduled pick up time
Ship order (car loading for rail)	Consignor	he consignment will e loaded onto the truck or rail car, accompanied y hazmat shipping papers
Pick up shipment	Carrier	he consignment will e picked up y the carrier, which can e a separate activity from the loading In the case of rail, the car is retrieved y a locomotive and crew
Deliver shipment	Carrier	he carrier (a) transfers the shipment to the ne t party or ( ) completes the delivery of the consignment to the uyer
Receive shipment	Carrier	he carrier or intermediary accepting transfer of the shipment from another carrier
erify shipping papers to ooking (ocean) Airline acceptance checklist (air)	erminal, carrier	Upon receipt, the carrier or its representative (terminal) will verify shipping documents and markings to the ooking to ensure a match
Prepare container placement certificate (ocean)	Carrier	he ocean carrier will complete a certificate completed for handling containerized hazmat shipments
Process shipment	erminal	A terminal receives a shipment on ehalf of an ocean or air carrier and processes the shipment sometimes involving container loading for loading onto the craft or vessel
Prepare hazmat OL (ocean)	Carrier	A OL prepared y the ocean carrier with description and disposition instructions to e tendered to interline or on forwarding carriers

(continued on next page)

Table 1. (Continued).

Activity Identifiers	Role	Definition
Receive hazmat ill of lading (ocean)	Carrier	Receipt of the hazmat OL y the interline or on forwarding carrier
Prepare hazmat stowage plan (ocean)	Carrier	A vessel stowage plan prepared y the ocean carrier that identifies the location of all hazmat on oard the vessel his will include description and quantity of each item as well
Prepare U S Coast uard (USC) certain dangerous cargo (CDC) notification	Carrier	he USC requires pre arrival notification of CDCs under C R CDC listing is not a comprehensive list of all hazmat items
Create load plan and hazmat manifest (air)	Carrier	Similar to the ocean carrier stowage plan, the air carrier will create a load plan and create a hazmat manifest that descri es the location, description, and quantity of all items on the aircraft he pilot will carry a copy (sometimes a reviated) of the hazmat manifest
Send advance shipping notification (AS)	Consignor	Pu lishing the AS is a key point in the delivery of the consignment his message contains key information such as gross weight and delivery date/time It identifies the goods eing shipped and their quantity, style, size, and color
Receive AS	Consignee, carrier	he AS will e used to prepare for receipt and processing of the shipment
Local cross dock (L L)	Carrier	Unloading consignments from an incoming truck or rail car and loading these consignments directly onto out ound trucks with little or no storage in etween his may e done to change type of conveyance, to sort material intended for different destinations, or to com ine material from different origins into transport vehicles (or containers) with the same, or similar, destination
Origin switching (rail)	Carrier	Rail car switching from local to line haul trains
ransfer yard (L)	Carrier	A different driver or interlined carrier may e used from the one that made the pickup he transfer of the trailer occurs at the transfer yard
Load, unload container (rail, ocean)	erminal, carrier	Process of moving containers on or off ships or rail cars
In transit or line haul	Carrier	he primary movement of the consignment from the point of origin or transfer to the point of destination or transfer hen more than one carrier, vehicle, or driver are involved, this does not typically include the pickup and delivery of the shipment or ocean and air shipments, this refers to the port to port movement
Intermediate/destination cross dock (L L)	Carrier	Intermediate or destination terminal unloading of consignments from an incoming truck and loading these consignments directly onto out ound trucks with little or no storage in etween
Intermediate/destination switching (rail)		Rail car switching from line haul trains for local delivery or for transfer to other lines or interlining rail carriers
Receive documents (air, ocean)	roker	A customs house roker receipt of documents necessary to su mit to the customs authority for e port or import clearance
Process e port (air, ocean)	roker, regulatory	he process of su mitting and clearing consignment documentation for e port
Process import (air, ocean)	roker, regulatory	he process of su mitting and clearing consignment documentation for import
Receive USC CDC notification	Regulatory	Receipt y the USC of the CDC
Request delivery appointment	Carrier	As the shipment is nearing the consignee s delivery point, the shipper will request a delivery appointment
Receive delivery request	Consignee	Upon receiving of the delivery request, the consignee will continue preparations for the receipt of the consignment
Send delivery confirmation	Consignee	If the consignee is ready for delivery, it will confirm the delivery appointment with the shipper
Receive delivery confirmation	Carrier	he shipper will then ensure that the consignment is delivered at the correct place and time
Deliver shipment	Carrier	he carrier (a) transfers the shipment to the ne t party or ( ) completes the delivery of the consignment to the uyer

Slide 1

ILLINOIS - RAILTEC

OVERVIEW OF RAILROAD FREIGHT TRANSPORTATION SAFETY

CEE498 TSR -Transportation Safety and Risk






Dr. Rapik Saat, Ph.D.

Rail Transportation and Engineering Center – RailTEC

Department of Civil & Environmental Engineering

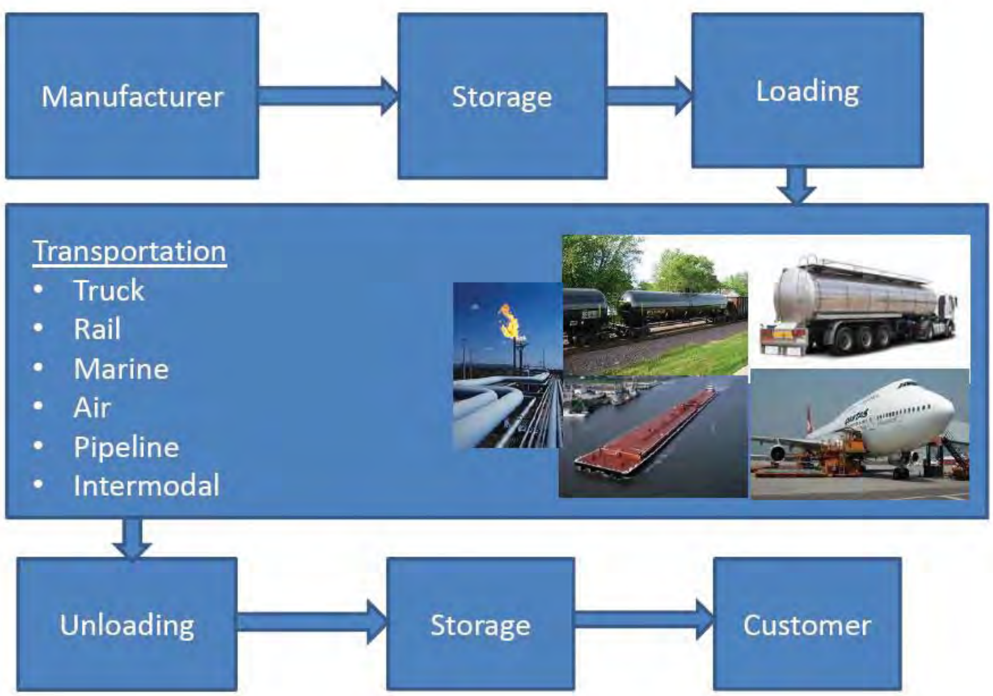
University of Illinois at Urbana-Champaign, U.S.A.

RAILTEC
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

Administrative

- Review class schedule
  - Goal next two weeks to cover rail and highway freight transportation safety and risk introduction, case studies and SOPs
  - 9/25-10/9: Rail/highway route-specific risk analysis bootcamp (group project)
  - 10/2: Five-minute individual term-project presentation and brainstorming
- SOP this Wednesday
  - Complete reading and quiz before 5pm Wednesday

Review: Generalized Supply Chain Flow Chart



In-Class Group Discussion

- Compare the HM Shipment Supply Chain Process Maps for TL and LTL Truck; Rail; and Ocean Intermodal
  – For which modal alternative are there more opportunities for delays and bottlenecks? Identify the bottlenecks and explain your answer
  – For which modal alternative are there more risks for an HM incident (spill or release)?
  – Suggest ways to reduce the delays/bottlenecks in the process maps without simultaneously increasing the risk of an HM incident

Learning Outcomes

At the end of this lecture students will be able to:

1. Recognize the extent of rail freight transportation industry and infrastructure in the U.S.
2. Understand recent U.S. railroad safety statistics and trends

Rail is the principal means of economically moving large, heavy freight long distances overland

Rail uniquely combines speed and energy efficiency

U.S. Rail Freight Transportation Industry

The U.S. Freight Railroad Industry: 2011

Type of Railroad	Number	Miles Operated*	Employees	Freight Revenue ($ billions)
Class I	7	95,387	158,623	$65.0
Non-Class I	561	43,188	17,317	4.0
Total	568	138,575	175,940	$68.9

*Excludes trackage rights. Source: AAR

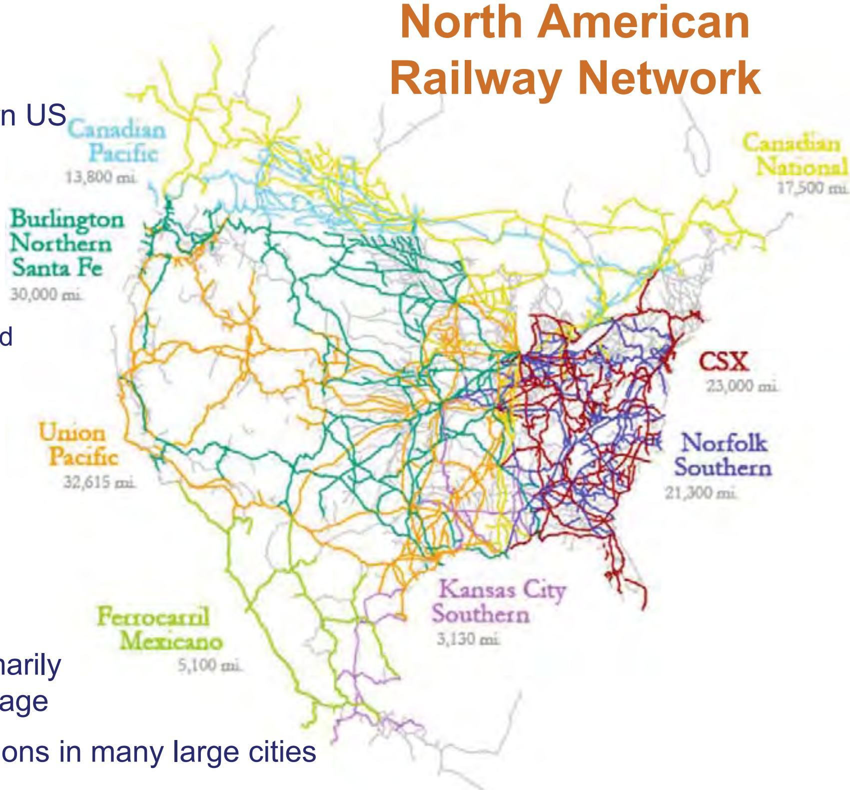
Major (Class 1) Railways

…and over 500 short line & regional railways

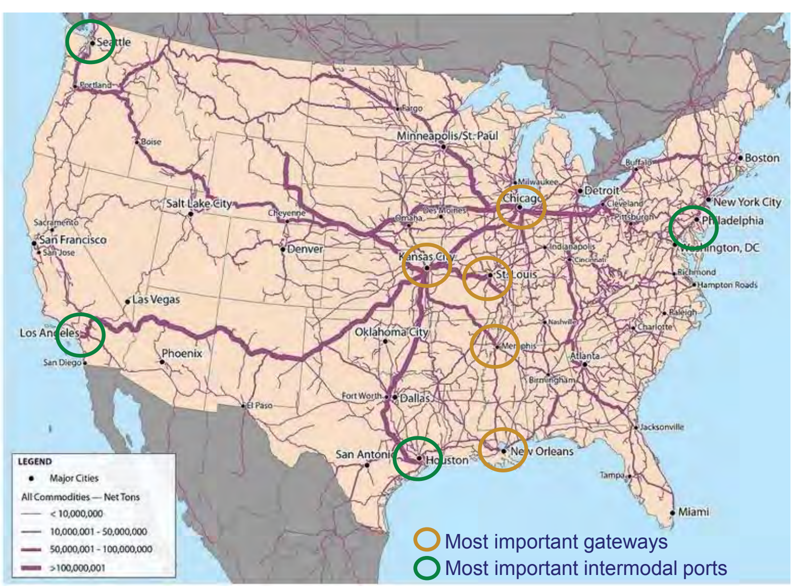
North American Railway Network

- Seven large **(Class 1)** freight railways
  - **CSX & NS** in eastern US
  - **BNSF & UP** in west
  - **CN & CP** in Canada & central US
  - **KCS** is a medium-sized railway in central US
- 500 **Short-line** and **Regional** railways
- **Amtrak** operates passenger trains throughout the US

  Outside the Northeast Corridor these are primarily on freight railway trackage
- **Commuter rail** operations in many large cities



U.S Rail Network Showing Freight Traffic Volume (2010)



Most important gateways:

- Chicago
- St. Louis
- Kansas City
- Memphis
- New Orleans

Most important intermodal ports:

- Los Angeles
- Houston
- Baltimore
- Seattle

Source:FRA, Office of Railroad Policy and Development, based on Surface Transportation Board's 2010 Carload Waybill Sample. Intermodal Terminals Database; D. P. Minddendorf for the Bureau of Transportation Statistics U.S. D.O.T.

Commodities Transported by Rail (2012)

Source: AAR

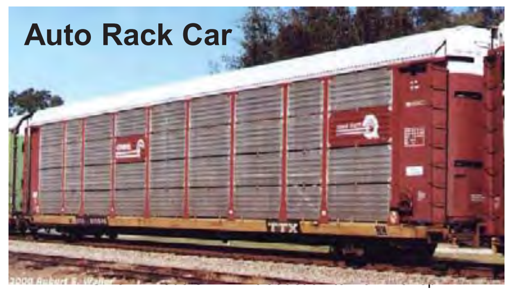
Tonnage and Revenue of Commodities Transported by Rail (2012)

Commodity Group	Tons Originated (000)	Tons Originated % of Total	Gross Revenue** (million)	Gross Revenue** % of Total
Coal	727,094	40.2 %	$14,717	21.6 %
Chemicals & allied prod.	189,263	10.5	9,216	13.5
Farm products	143,537	7.9	5,309	7.8
Non-metallic minerals	132,169	7.3	2,646	3.9
Misc. mixed shipments*	115,399	6.4	8,803	12.9
Food & kindred products	107,734	6.0	5,413	8.0
Metallic ores	75,352	4.2	748	1.1
Metals & products	51,533	2.9	2,730	4.0
Petroleum & coke	45,232	2.5	2,289	3.4
Stone, clay & glass prod.	43,921	2.4	1,725	2.5
Waste & scrap materials	42,568	2.4	1,284	1.9
Pulp, paper & allied prod.	32,077	1.8	2,181	3.2
Lumber & wood products	27,203	1.5	1,582	2.3
Motor vehicles & equip.	22,848	1.3	4,877	7.2
All other commodities	50,683	2.8	4,546	6.7
Total	**1,806,613**	**100.0 %**	**$68,067**	**100.0 %**

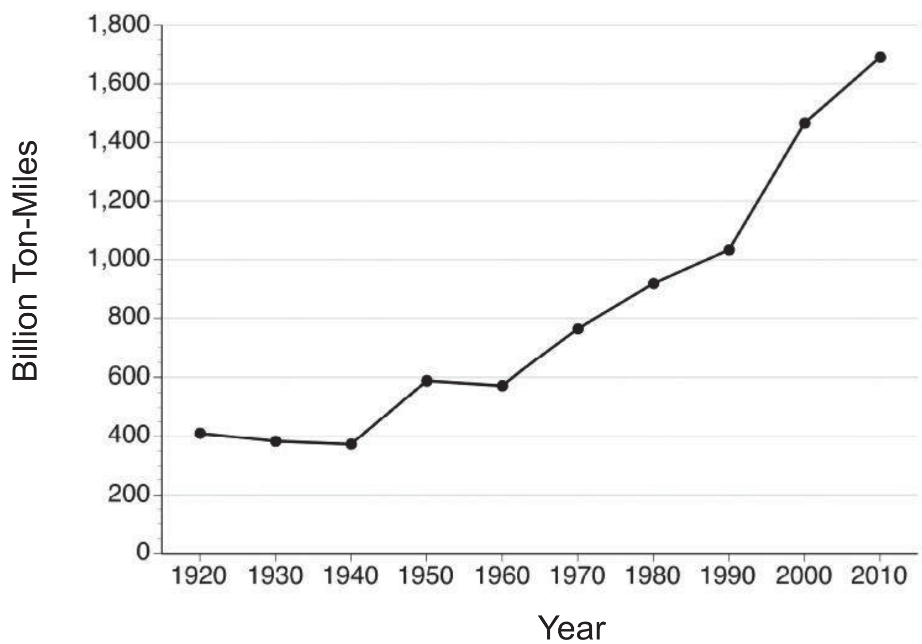
*Miscellaneous mixed shipments is almost all intermodal traffic. Some intermodal traffic is also included in commodity-specific categories.
** Gross Revenue is not adjusted for absorption (incentive rebates etc.) or correction.

Source: AAR Class I Railroad Statistics, April 2013.

Types of freight cars



Growth in U.S Rail Freight Traffic 1920-2010



Sources: Federal Railroad Administration website.

Key Takeaways

- Rail transportation plays a major role in freight transportation
- Railroads have continued to improve safety significantly over the last decade.
- The most troubling railroad safety problems arise from factors largely outside railroad control.

RAILWAY TRANSPORTATION RISK ASSESSMENT TEMPLATE

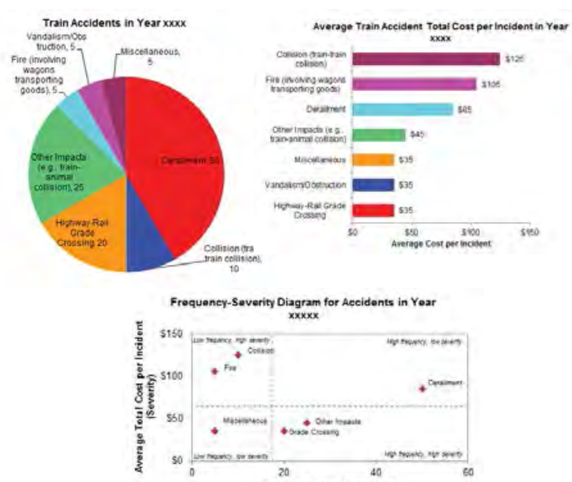
CEE498 TSR -Transportation Safety and Risk

Dr. Rapik Saat, Ph.D.

Rail Transportation and Engineering Center – RailTEC

Department of Civil & Environmental Engineering

University of Illinois at Urbana-Champaign, U.S.A.



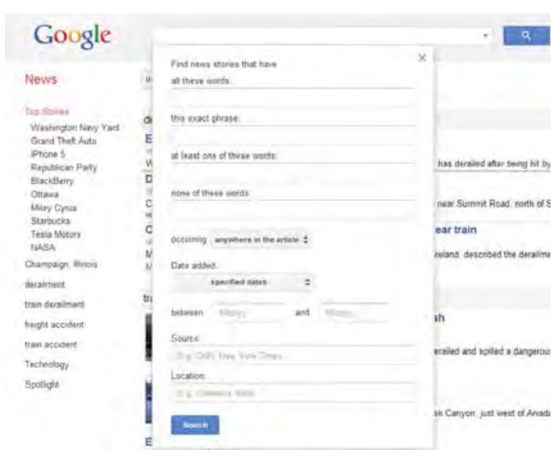
Learning Outcomes

At the end of this lecture students will be able to:

1. Perform data collection process and basic data analysis of historical railroad accidents
2. Identify various data for transportation risk analysis

Railway Transportation Risk Assessment Template – Risk Identification and Prioritization

- The objective in this phase is to get an overall overview of the total accidents by <u>types</u> and <u>causes</u> to identify important threats/hazards to help prioritizing resources accordingly
  1. Use the template to analyze accidents during a specific time period. Useful resources: Google News Analysis, Wikipedia.



Wikipedia List of Rail Accidents

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List of rail accidents (2010–present)

From Wikipedia, the free encyclopedia

This is a list of rail accidents since 2010.

See also:

Lists of rail accidents
Before 1880
1880–1899 • 1900–1929
1930–1949 • 1950–1959
1960–1969 • 1970–1979
1980–1989 • 1990–1999
2000–2009 • **2010–present**
List of rail accidents by death toll
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Rail transport
Operations
Track
Maintenance
High-speed railways
Track gauge
Stations
Trains
Locomotives
Rolling stock
Companies
History
Attractions
Terminology
By Country
Accidents
Modelling
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Notable train accidents, 2010–present
2010s: 2010 2011 2012 2013
See also—External links—References

2010s [edit source | edit beta]

2010 [edit source | edit beta]

- 2 January 2010
  - **India** — The first of three accidents in Uttar Pradesh near the town of Etawah, about 170 miles (270 kilometres) southwest of Lucknow, the capital of Uttar Pradesh state, when the Lichchavi Express entering the station in heavy fog runs into the stationary Magadh Express train stopped there. Ten people, including the driver of one of the trains, were injured.[1] At least 10 people were reported to have been killed.[2]
  - **India** — The Gorakhdham Express and Prayagraj Express collide near the Panki railway station in Kanpur, about 100 kilometres (62 mi) southwest of Lucknow, left five people dead and about 40 injured.[3]
  - **India** — At Pratapgarh, 61 kilometres (38 mi) from Allahabad, the Sarayu Express ploughs into a tractor trailer at an unmanned railway crossing. Though nobody is injured, the engine of the train is severely damaged.[4]
  - **India** — All seven coaches of the Arunachal Pradesh Express, running between Murkongselek and Rangiya derail between Helem and Nij Bogaon in Assam, India in the early hours of the day. No passengers were hurt.[5]
- 3 January 2010 — **Turkey** — Two passenger trains collide at Bilecik. One of the drivers is killed and seven passengers were injured.[6]

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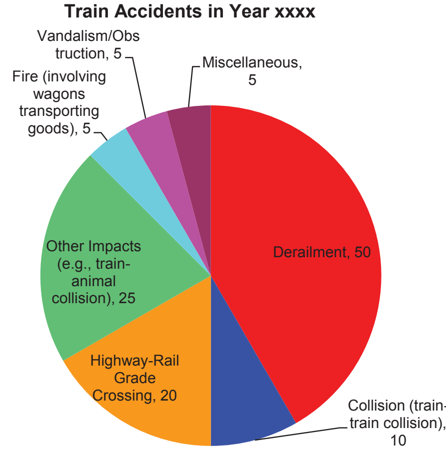
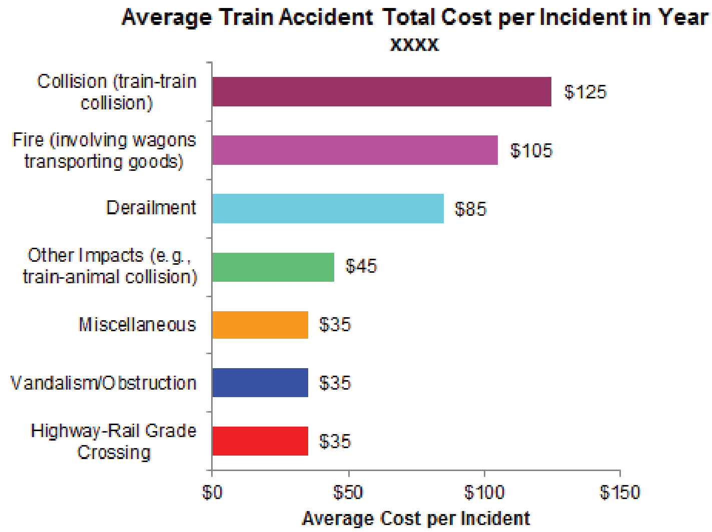
Railway Transportation Risk Assessment Template – Risk Identification and Prioritization

2. For each accident during a specific year period, classify the accident type as follow:
   - Derailment
   - Collision (train-train collision)
   - Highway-Rail Grade Crossing
   - Other Impacts (e.g., train-animal collision)
   - Fire (involving wagons transporting goods)
   - Vandalism/Obstruction
   - Miscellaneous.



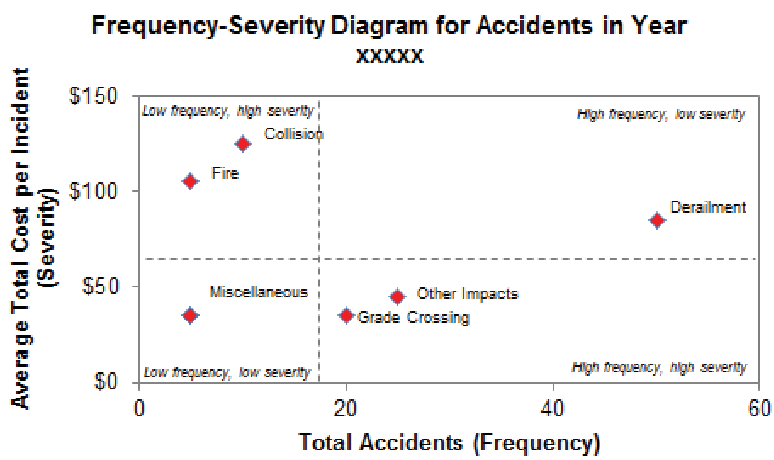
Railway Transportation Risk Assessment Template – Risk Identification and Prioritization

3. For each accident during a specific year period, identify direct, indirect and total costs, and plot the average total cost by accident type



Railway Transportation Risk Assessment Template – Risk Identification and Prioritization

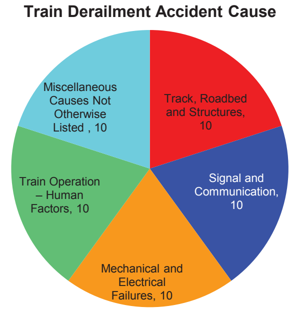
4. Plot the frequency and average total cost by accident type

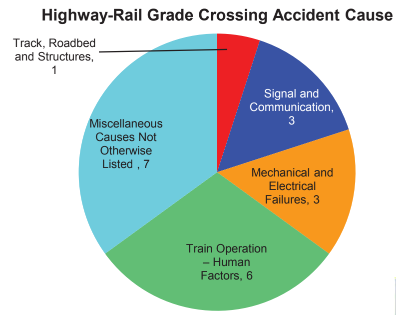


Railway Transportation Risk Assessment Template – Risk Identification and Prioritization

5. For each accident during a specific year period, identify the root cause and classify the accident cause as:
   - Track, Roadbed and Structures
   - Signal and Communication
   - Mechanical and Electrical Failures
   - Train Operation – Human Factors
   - Miscellaneous Causes Not Otherwise Listed

   Note: For guidance to classify the accident cause, refer to the list of train accident cause codes publish by the U.S. Federal Railroad Administration (FRA).
6. Repeat cost and frequency-severity analyses





Miscellaneous Data Sources

National Transportation Atlas Databases 2013

http://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/national_transportation_atlas_database/2013/index.html

- **Points**
  - Public-Use Airports
  - Alternative Fuels Stations
  - Amtrak Stations
  - U.S. Border Crossings
  - Dams
  - Intermodal Terminal Facilities
  - Intermodal Passenger Connectivity
  - National inventory of navigable inland waterway locks
  - National Bridge Inventory
  - National Populated Places
  - U.S. Army Corps of Engineers Ports
  - U.S. Army Corps of Engineers Ports
  - Railroad Bridges
  - Highway-Rail Grade Crossings
  - Travel Monitoring Analysis System
- **Polygon**
  - Bureau of the Census Urbanized Area Boundaries
  - Core Based Statistical Areas
  - The 113th Congressional Districts Boundaries
  - U.S. County Boundaries
  - U.S. County Political
  - Freight Analysis Framework Regions
  - Hydrographic Features
  - U.S. Military Installations
  - Metropolitan Planning Organization
  - Non Attainment Areas
  - National Park System Boundary Dataset
  - U.S. State Boundaries
  - U.S. State Political Boundaries
- **Polyline**
  - Freight Analysis Network
  - Hazardous Material Routes
  - Highway Performance Monitoring System
  - National Highway Planning Network
  - Railway Network
  - Public Use Airport Runways
  - Fixed-Guideway Transit Facilities
  - U.S. Army Corps of Engineers Navigable Waterway Network

ESRI Data & Maps

Downloadable from UIUC Webstore

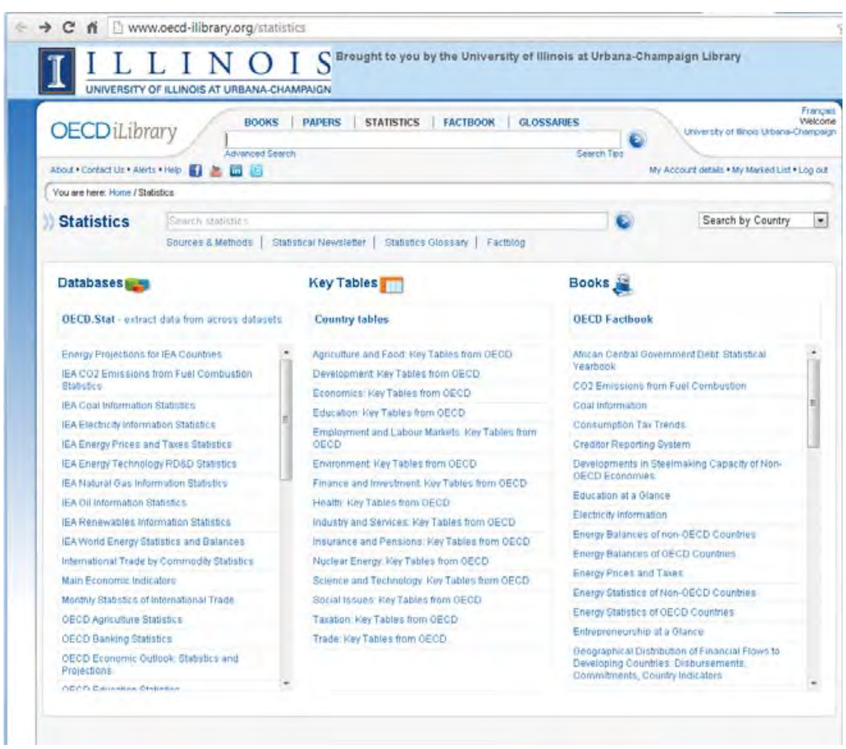
- A set of ready-to-use maps and data layers, including a variety of basemap and thematic layers for the world with scale-dependent rendering and labeling and the ability to turn layers on and off.
- Over 130 pre-symbolized and pre-authored vector data layers and detailed metadata for North America, Europe, and the world.
- Updated data such as the 2010 U.S. Census datasets and new datasets including the debut of World Countries and first order World Administrative Area datasets using detailed source data from DeLorme® mapping company.

International Association of Oil and Gas Producers

http://publications.ogp.org.uk/?committeeid=41

Risk assessment data directory - Process release frequencies	434-01	2010 Mar
Risk assessment data directory - Summary	434	2010 Mar
Risk assessment data directory - Blowout frequencies	434-02	2010 Mar
Risk assessment data directory - Storage incident frequencies	434-03	2010 Mar
Risk assessment data directory - Riser & pipeline release frequencies	434-04	2010 Mar
Risk assessment data directory - Human factors in QRA	434-05	2010 Mar
Risk assessment data directory - Ignition probabilities	434-06	2010 Mar
Risk assessment data directory - Consequence modelling	434-07	2010 Mar
Risk assessment data directory - Mechanical lifting failures	434-08	2010 Mar
Risk assessment data directory - Land transport accident statistics	434-09	2010 Mar
Risk assessment data directory - Water transport accident statistics	434-10	2010 Mar
Risk assessment data directory - Aviation transport accident statistics	434-11	2010 Mar
Risk assessment data directory - Occupation risk	434-12	2010 Mar
Risk assessment data directory - Structural risk for offshore installations	434-13	2010 Mar
Risk assessment data directory - Vulnerability of humans	434-14	2010 Mar
Risk assessment data directory - Vulnerability of plant/structure	434-15	2010 Mar
Risk assessment data directory - Ship/installation collisions	434-16	2010 Mar
Risk assessment data directory - Major accidents	434-17	2010 Mar
Risk assessment data directory - Construction risk for offshore units	434-18	2010 Mar
Risk assessment data directory - Evacuation, escape & rescue	434-19	2010 Mar
Risk assessment data directory - Guide to finding and using reliability data for QRA	434-20	2010 Mar
Risk assessment data directory - Appendix 1	434-A1	2010 Mar

OECD Statistics



RAILROAD FREIGHT TRANSPORTATION RISK ASSESSMENT CASE STUDIES

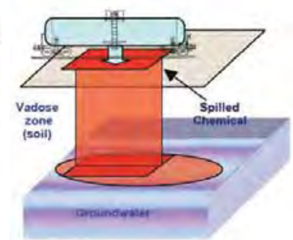
CEE498 TSR -Transportation Safety and Risk

Dr. Rapik Saat, Ph.D.

Rail Transportation and Engineering Center – RailTEC

Department of Civil & Environmental Engineering

University of Illinois at Urbana-Champaign, U.S.A.



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Learning Outcomes

At the end of this lecture students will be able to:

1. Understand how to apply the basic risk concepts and tools on real case studies
2. Determine a suitable risk model and use it to quantify the risk associated with the transportation of a hazardous material.

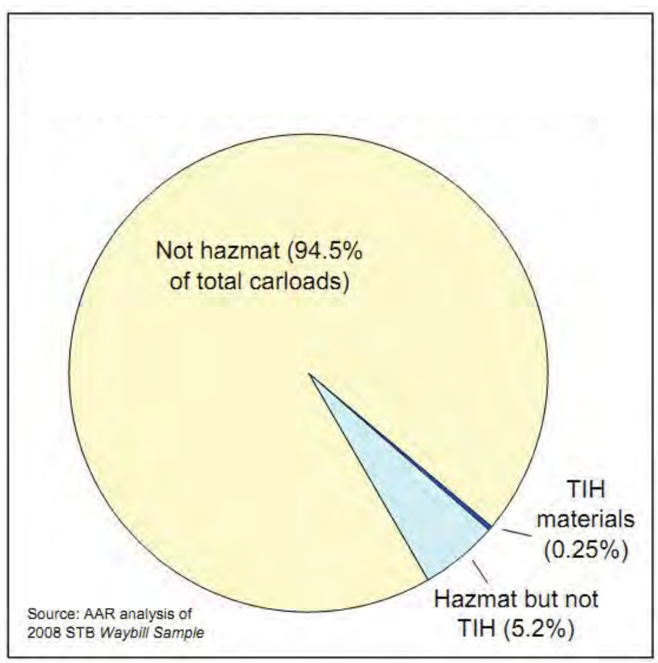
Railroad hazardous material transportation

- There were more than 2.24 million rail shipments of hazardous materials in North America in 2011
  - 72% of movements were in tank cars
  - Petroleum crude oil traffic increased to 81,000 shipments from 12,000 in 2009
- In 2010, 99.998 percent of rail hazmat shipments reached their destination without a release caused by a train accident

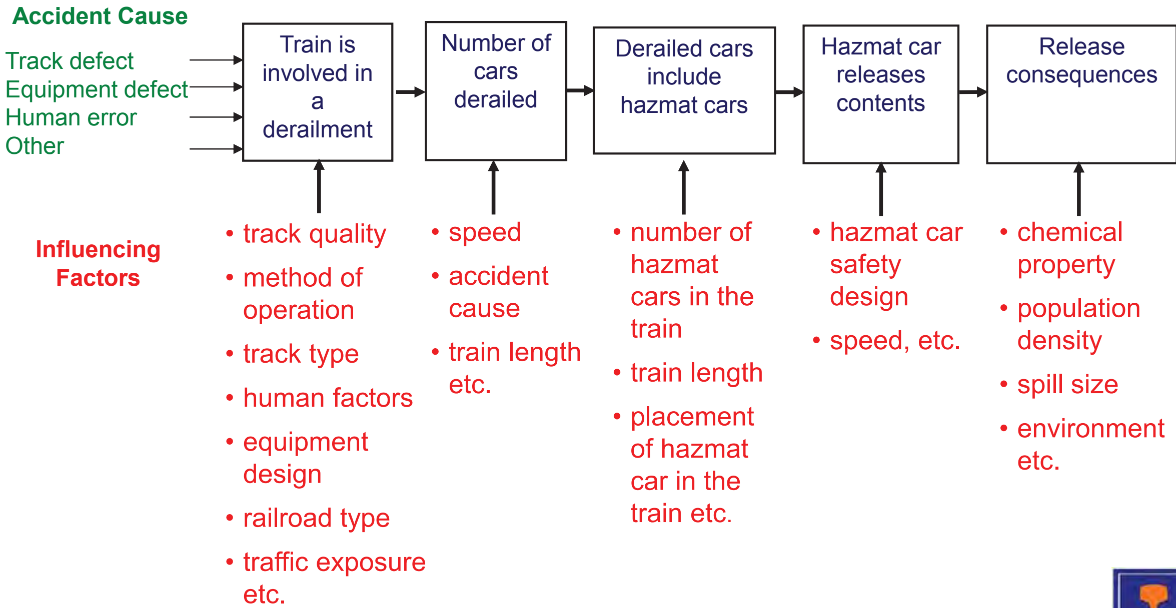
Source: Association of American Railroads

Proportion of hazmat and non-hazmat railroad traffic

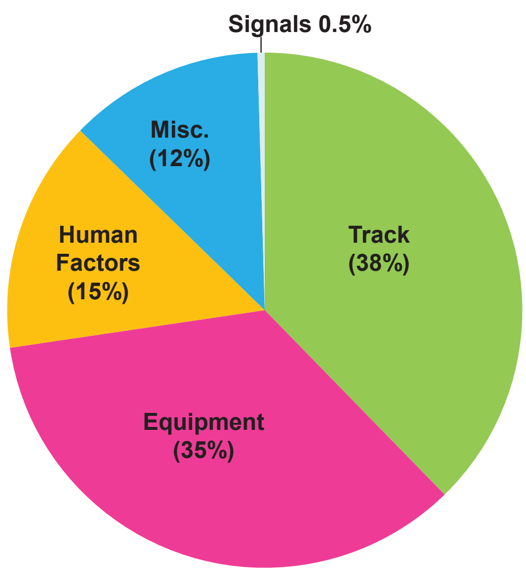
- Hazmat traffic accounts for a small proportion of total rail carloads, but are associated with a major share of rail insurance costs and liability risks (AAR)



Chain of events leading to hazmat car release

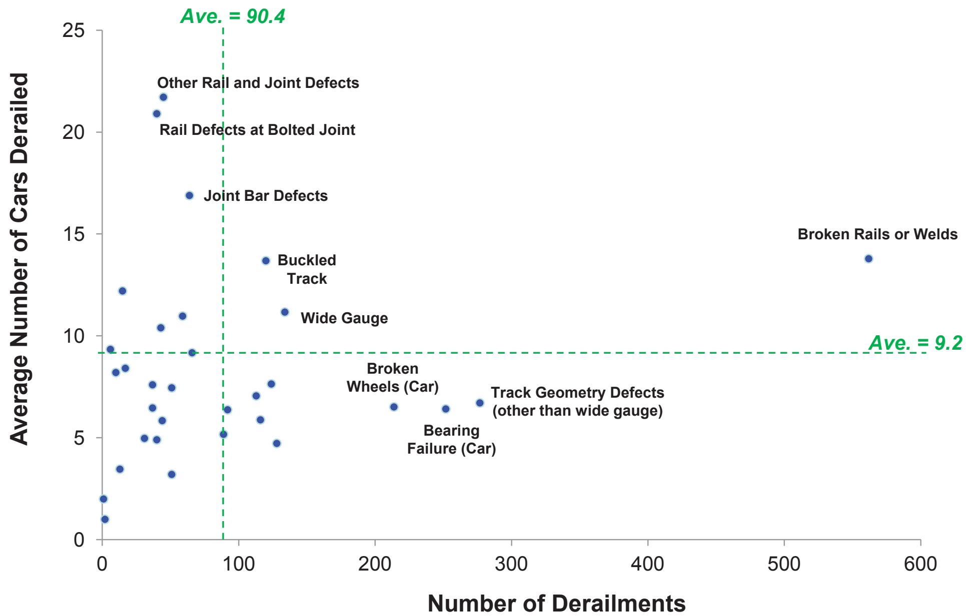


U.S. Class I railroad mainline derailments by accident cause group: 2000-2009



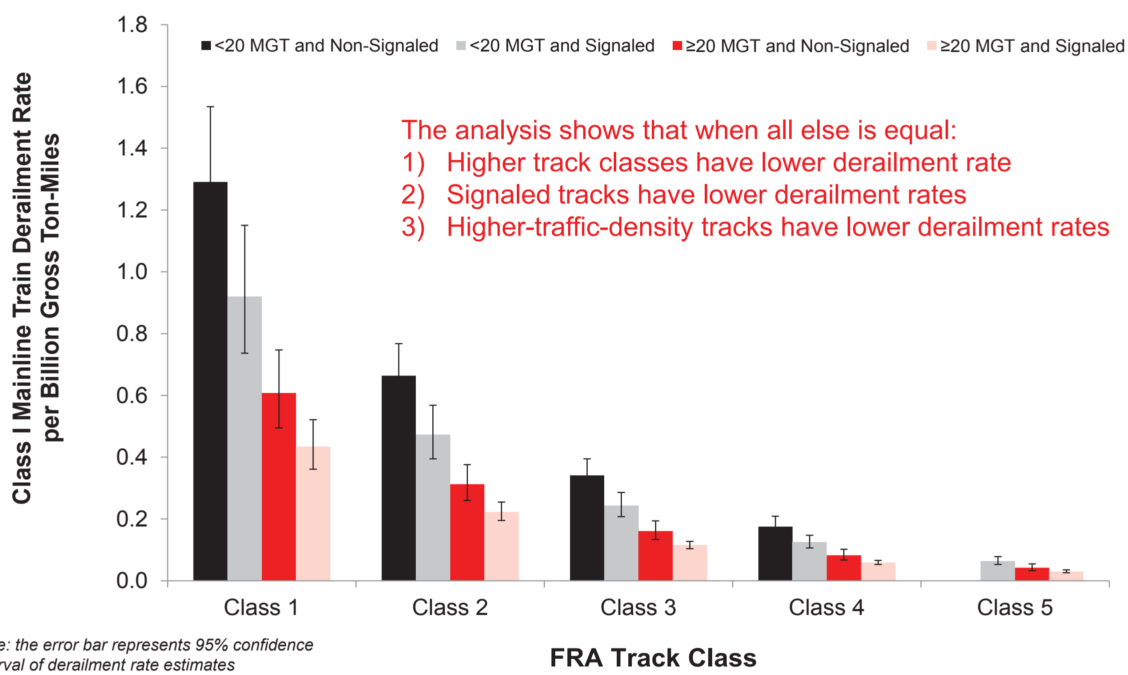
Notes:
1. FRA Railroad Accident/Incident Reporting System (RAIRS) database, 2000-2009
2. Total of 3,995 train derailments involving Class I trains derailed on Class I railroad mainline track, track classes 1 to 5
3. Includes BNSF, UP, CSX, NS, KCS, CP (SOO) and CN (GTW)
4. Excludes derailments due to train collisions and highway-rail crossing collisions

Frequency-severity graph of track- and equipment-related Class I mainline derailments, 2000-2009



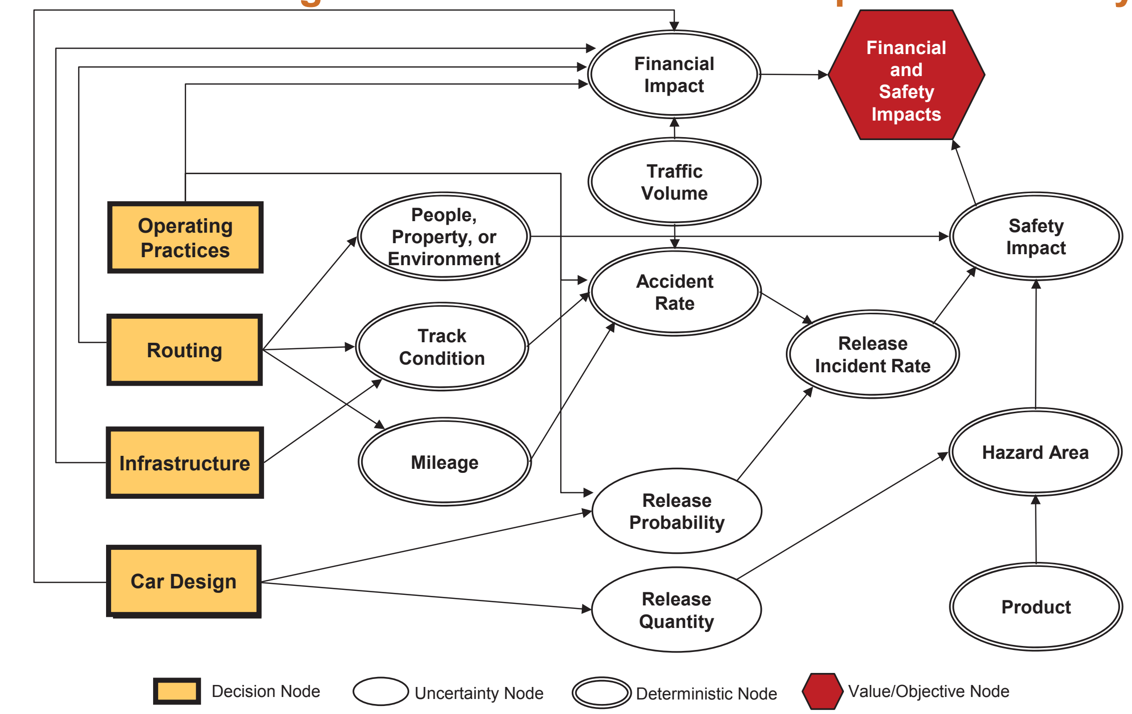
Note:
1. *Total of 2,893 track- and equipment-related derailments from 2000-2009, involving Class I trains derailed on Class I mainline track*
2. *Includes BNSF, UP, CSX, NS, KCS, CP (SOO) and CN (GTW)*
3. *Excludes derailments due to train collisions and highway-rail crossing collisions*

Estimated freight-train derailment rates and confidence intervals

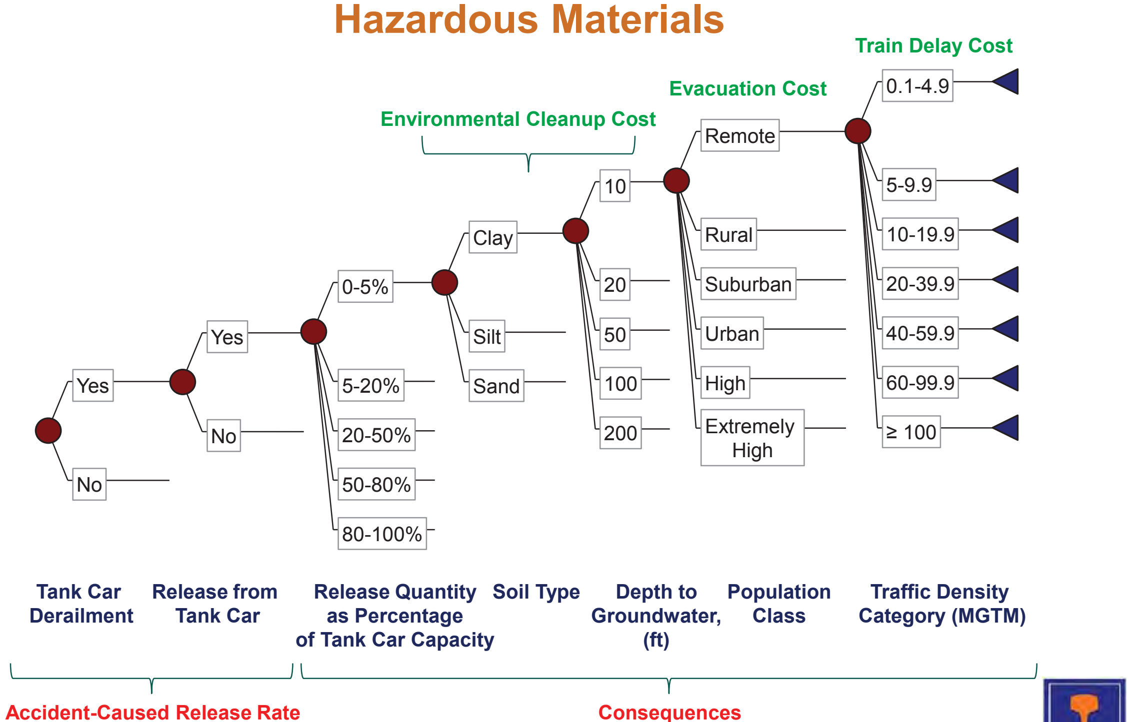


Note: the error bar represents 95% confidence interval of derailment rate estimates

Influence diagram showing relationships of factors affecting hazardous materials transportation safety



Environmental Risk Analysis Of Railroad Transportation Of Hazardous Materials



Basic definition of hazardous materials transport risk

- Basic risk equation = probability of an event multiplied by the consequence of that event

$$R = P_A \times P_{R|A} \times Q \times C$$

- Probability of a hazardous materials(HM) release event is typically the product of a series of other probabilities
  - Probability of a derailment occurring (**P_A**) } **Train Accident**
  - Probability that the HM car releases product (**$P_{R|A}$**)
  - Probability distribution of quantity lost (**Q**) (can also be expressed as average quantity lost) } **Tank Car**
- Consequences to people, property, or the environment is determined by what, where and when the material is spilled (**C**)

Probability analysis

- Accident-caused release rate metric was used to estimate the annual rate of a release event:

$$P_R = P_A \times P_{R|A} \times M$$

where:

P_A = tank car derailment annual rate per car-mile (Anderson & Barkan 2004)

$P_{R|A}$ = tank car conditional probability of release (Treichel et al. 2006)

M = total number of car miles

References:

Anderson, R. T., and Barkan, C. P. L. (2004). "Railroad accident rates for use in transportation risk analysis." *Transportation Research Record: Journal of the Transportation Research Board,* (1863), 88-98.

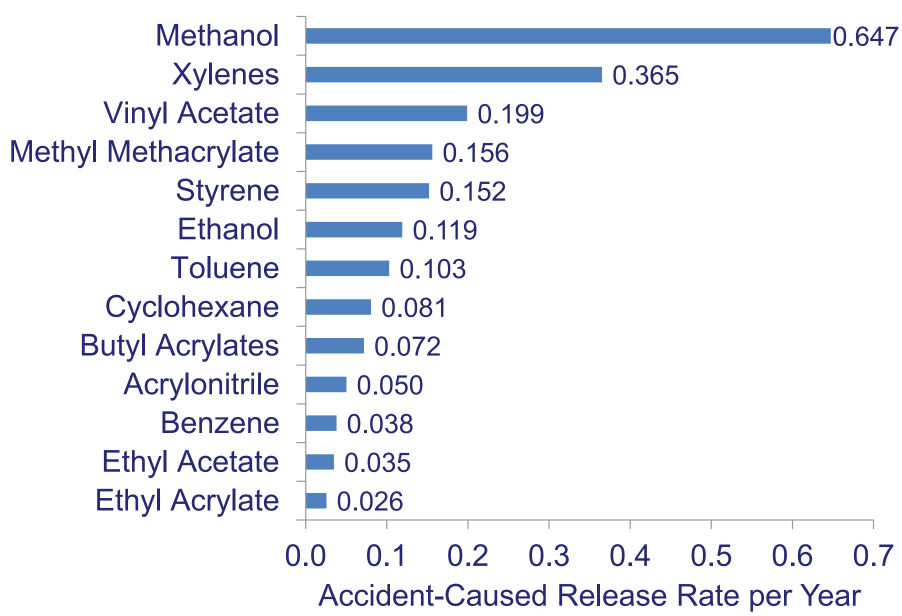
Treichel, T. T., Hughes, J. P., Barkan, C. P. L., Sims, R. D., Philips, E. A., and Saat, M. R. (2006). *Safety Performance of Tank Cars in Accidents: Probability of Lading Loss.* RSI-AAR Railroad Tank Car Safety Research and Test Project, Association of American Railroads, Washington, DC.

Chemicals of Interest's Routes & Annual Car Miles

Commodity Name	Average Shipment Distance (miles)	Annual Carloads	Annual Car Miles
Acrylonitrile	486	2,892	1,406,133
Benzene	435	3,543	1,541,225
Butyl Acrylates	714	4,077	2,910,782
Cyclohexane	470	4,331	2,036,186
Ethanol	737	4,091	3,013,480
Ethyl Acetate	758	1,163	881,173
Ethyl Acrylate	564	1,151	649,216
Methanol	918	17,814	16,361,224
Methyl Methacrylate	725	5,437	3,944,250
Styrene	696	8,856	6,167,904
Toluene	810	3,216	2,604,849
Vinyl Acetate	810	6,210	5,033,087
Xylenes	928	9,950	9,234,437

Accident-caused release rate summary

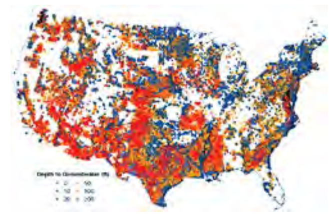
(The "probability" or frequency term in the risk definition)



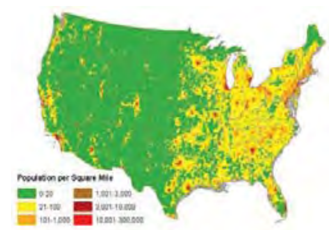
Consequence analysis

- Impacts to Soil and Groundwater
  - Hazardous Materials Transportation Environmental Consequence Model (HMTECM) was used to estimate soil and groundwater cleanup cost
  - Accounts for physicochemical properties, soil type and depth to groundwater
- Population Exposure
  - US Emergency Response Guidebook (ERG) was used to determine hazard area
  - Impact in terms of evacuation cost was estimated
- Train Delay
  - Estimate impact due to additional costs related to locomotives, railcars, fuel and labor
  - Accounts for traffic density to estimate total number of trains delayed

Soil Type



Depth to Groundwater



Population Density

References:

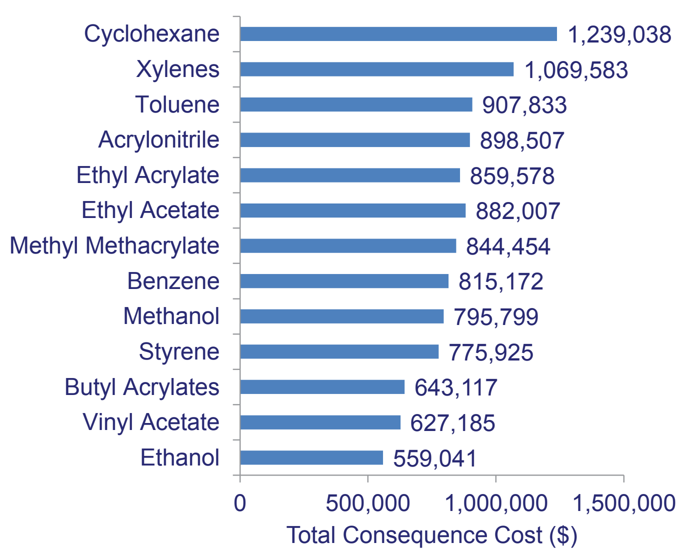
Yoon, H., Werth, C.J., Barkan, C.P.L., Schaeffer, D.J. & Anand, P. 2009, "An environmental screening model to assess the consequences to soil and groundwater from railroad-tank-car spills of light non-aqueous phase liquids", Journal of hazardous materials, vol. 165, no. 1-3, pp. 332-344.

Schafer, D.H. & Barkan, C.P.L. 2008, "A prediction model for broken rails and an analysis of their economic impact", *Proceedings of the AREMA Annual Conference, Salt Lake City, UT.*

Total expected consequence cost

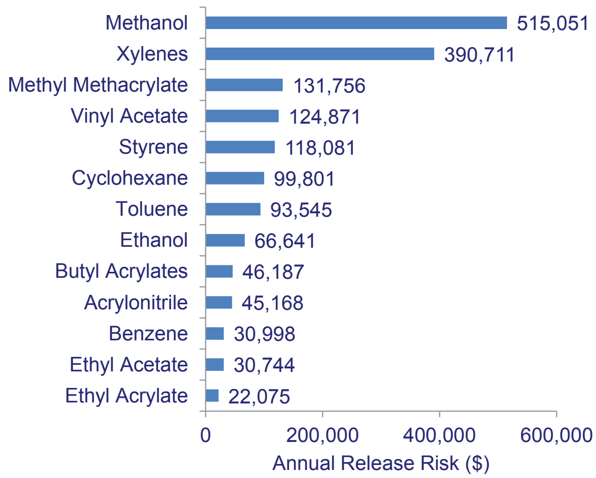
- Expected Cleanup Cost + Evacuation Cost + Train Delay Cost

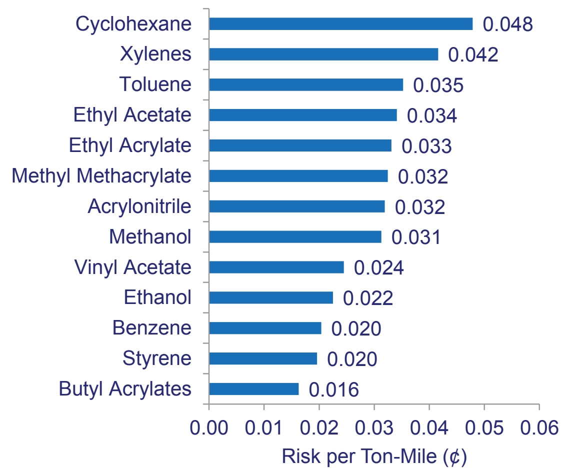
(The consequence term in the risk definition)



Risk estimation

- Accident-Caused Release Rate x Total Expected Consequence Cost

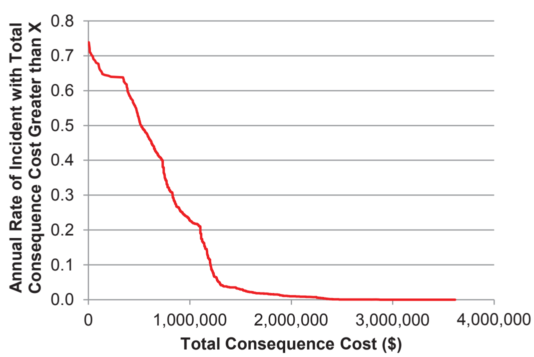




Annual Risk

Risk per Ton-Mile

Risk Profile



Example risk profile for rail transportation of methanol

Potential applications

- Evaluating cost effectiveness of alternate design tank cars
- Evaluating alternate routes
- Increase emergency response preparedness
- Evaluating infrastructure improvement
- Evaluating shipment risk cost

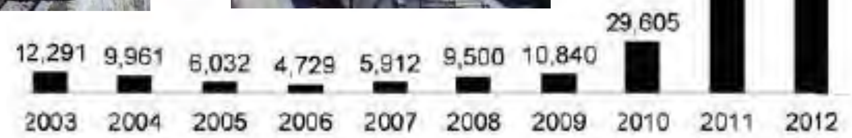
Risk Analysis of the Epping-Port Arthur BNSF Crude Oil Route

Overview of Crude Oil Transportation by Rail

Crude Oil as a Percentage of Total Class I Carload Originations by Year

Average for 2008	Average for 2012	Fourth quarter of 2012	First quarter of 2013
0.3%	0.8%	1.1%	1.4%

Rail Carloads of Crude Oil Involving U.S Class I Railroads



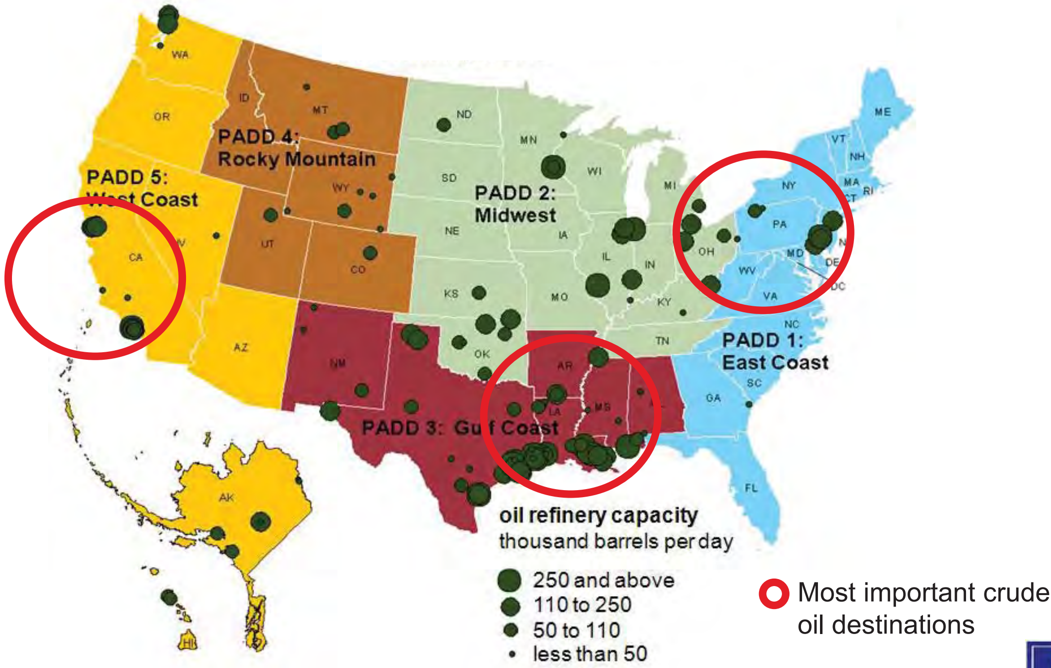
Sources: Association of American Railroads and http://www.twinportsrail.com/

Origin of Crude Oil: U.S Shale Deposits (2011)

Most important shale deposits

Source: U.S. Energy Information Administration.

Destination of Crude Oil: U.S. Refinery Locations



Source: U.S. Energy Information Administration.

Necessity of Crude Oil Transportation by Rail

- Increases in crude oil production have exceeded both the capacity of the storage facilities (e.g. Cushing) and the capacity of existing pipelines
- Refineries are concentrated in traditional crude oil production areas far from new production regions
- Long and rigorous process to obtain the necessary permits required reduces the economic viability of building new refineries close to production areas
- Transportation by rail offers several advantages:
  - Transportation capacity
  - Geographical flexibility
  - Fast infrastructure development
  - Safety and efficiency

Source: AAR. Moving Crude Oil by Rail. 2013

The Lac-Megantic Derailment

- On July 6, 2013 (Saturday), at approximately 1:14 am, an unattended 73-car freight train carrying crude oil derailed in Lac-Mégantic, Quebec, Canada
- The resultant fire and explosions from the accident caused the death of 47 people and the destruction of half of Lac-Mégantic's downtown area
- More than 2,000 people were evacuated
- It is the worst crude oil rail accident in North American history and the deadliest rail accident in Canada in the past 150 years

Explosion originated by the derailment of the 73 tank car crude oil train.

Aerial view of Lac-Megantic's Downtown after the accident .

Basic Route Information
Epping, ND - Port Arthur, TX BNSF Route

Origin	Inergy facility. Epping, ND.
Destination	GT Omniport. Port Arthur, TX.
Track Owner	BNSF
Total Length (Miles)	1,907.6
Segments	930
Distribution of Track Class* Class 1 Class 2 Class 3 Class 4 Class 5	 0.5% 3.6% 19.6% 60.2% 13.3%
Method of Operation* Non-Signaled Signaled	 24.8% 73.2%
Average Population Density per Squared Miles	290

Expansion of the Inergy crude oil transfer station near Epping, N.D.

A BNSF train of tanker cars crosses a trestle on the outskirts of Minot, N.D.

* Note: These percentages do not add up to 100%. Segments with unknown values for track class or method of operation (approximately 2% of the route) were neglected.

Origin: North Dakota Crude Oil Rail Loading Facilities (2013)

Name on Map	Railroad	Capacity (Mbbl/d)
Inergy	BNSF	160
Bakken Oil Express	BNSF	100
Red River Supply	BNSF	90
Enbridge	BNSF	80
Hess	BNSF	70
Plains BNSF	BNSF	65

The Inergy facility in numbers:

- Largest North Dakota's crude oil terminal
- 120,000 bbl/d rail loading capacity
- Ability to handle up to 120 car unit trains
- 720,000 bbl crude oil storage capacity

Source: North Dakota Pipeline Authority 2013 and Inergy, L.P. website: http://www.inergylp.com/

Destination: Port Arthur GT Omniport

The GT Omniport terminal in numbers:

- 100,000 bbl/d rail unloading capacity
- Storage of up to 250 rail cars (1,200 after expansion)
- Refineries capacity of over 1 million bbl/d within 8 miles

GT Omniport Unloading Area

GT Omniport Refinery Area

Largest Gulf Coast Crude Oil Refineries with Rail Unloading Facilities

Location	Name	Capacity (bbl/d)	Railroad
Port Arthur, TX	GT Omniport	100,000	BNSF, UP, KCS
Artesia, NM	Holly Frontier Navajo	70,000**	BNSF
Beaumont, TX	Jefferson	70,000*	KCS
El Dorado, AR	Delek	50,000	BNSF, UP
Hull, TX	Keyera	50,000*	UP
Corpus Christi, TX	Trafigura	30,000	BNSF, UP

*In operation only partially. Still under construction or expansion
** In operation early 2014

Source: RBN Energy, LLC website: http://www.rbnenergy.com

Crude Oil Transportation Risk Model

$$R_{AB} = \frac{1}{C_m} * \sum_{i,j,k} P_{ijk}(A) * P_{ijm}(R|A) * Ex.Area_i * AvgPopDen_i$$

- R is risk (expected population affected) per crude oil barrel transported from location A to location B
- C_m is the capacity in barrels of type *m* tank car

Probability

- $P_{ijk}(A)$ is the probability that a tank car is derailed on track segment *i* with FRA track class *j* and method of operation *k*
- $P_{ijm}(R|A)$ is the probability that a type *m* tank car derailed on track segment *i* with FRA track class *j* releases product in a derailment

Consequences

- $Ex.Area_i$ is the area affected by fire when a release occurs on track segment *i*
- $AvgPopDen_i$ is the average population density within the affected area along track segment *i*

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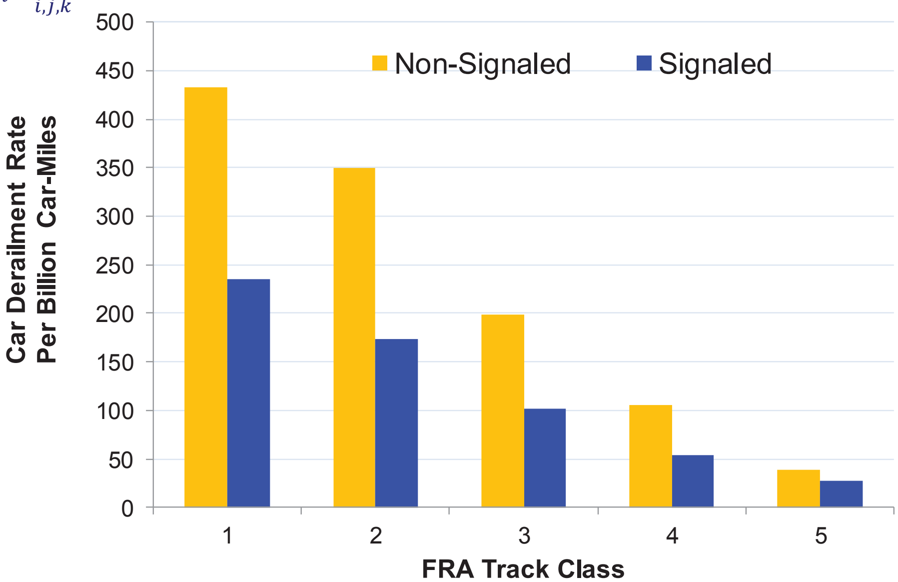
Class I Mainline Car Derailment Rates (2005-2009)

$$R_{AB} = \frac{1}{C_m} * \sum_{i,j,k} P_{ijk}(A) * P_{ijm}(R|A) * Ex.Area_i * AvgPopDen_i$$



Source: Liu, X., M.R. Saat, C.P.L. Barkan. (2013). Analysis of freight-train derailment rates in the United States. Accident Analysis and Prevention (under review).

Route Distribution of FRA Track Class and Method of Operation

Mode of Operation	FRA Track Class					
	1	2	3	4	5	Total
Signal	2.1	17.4	313.2	794.2	253.6	1,380.5
Non-Signal	7.0	50.7	60.1	353.9	0.3	471.9
Total	9.1	68.1	373.2	1,148.1	253.9	

Mode of Operation	FRA Track Class					
	1	2	3	4	5	Total
Signal	0.1%	0.9%	16.4%	41.2%	12.7%	71.3%
Non-Signal	0.4%	2.7%	3.1%	18.6%	0.0%	24.7%
Total	0.5%	3.6%	19.6%	59.7%	12.8%	

Note: Both tables represent the distribution of the route in miles.

Conditional Probability of Release

$$R_{AB} = \frac{1}{C_m} * \sum_{i,j,k} P_{ijk}(A) * P_{ijm}(R|A) * Ex.Area_i * AvgPopDen_i$$

– The speed-dependent conditional probability of release (CPR) was calculated for each segment following the equation:

$$CPR = A * S$$

A: coefficient that depends on the type of tank car
S: derailment speed (based on segment track class)

– Tank car types 111A100W1, 111A100W2, 111A100W3, 111A100W5 and 211A100W1 were used for the analysis as they are the most utilized cars, accounting for over 65% of the entire fleet:

$$CPR = 0.0096 * S$$

	Track class				
	1	2	3	4	5
Speed (mph)	10	25	40	60	70
CPR for 111A100W1	0.096	0.24	0.384	0.576	0.672

Source: Liu et al. 2013. Safety Effectiveness of Integrated Risk Reduction Strategies for the Transportation of Hazardous Materials by Rail. Kawprasert. 2010. Dissertation.Quantitative Analysis Hazmat Transportation by Railroad.

Exposed Area

$$R_{AB} = \frac{1}{C_m} * \sum_{i,j,k} P_{ijk}(A) \; * \; P_{ijm}(R|A) * Ex.Area_i * AvgPopDen_i$$

– "Exposed Area" is defined as the area where DOT recommends that people be evacuated or sheltered in place in a hazardous material release incident

– Worst case scenario was assumed:

- Night release
- Large spill (>60 gallons)
- Fire occurs

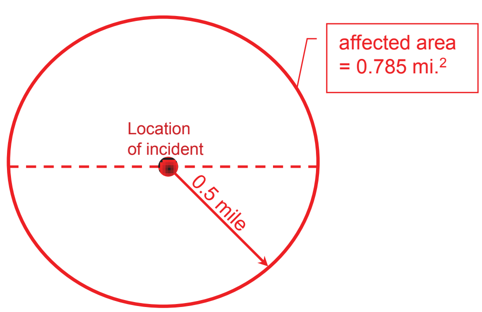
ID No.	Guide	NAME OF MATERIAL	SMALL SPILLS (From a small package or small leak from a large package) First ISOLATE in all Directions Meters (Feet)	Then PROTECT persons Downwind during- DAY Kilometers (Miles)	NIGHT Kilometers (Miles)	LARGE SPILLS (From a large package or from many small packages) First ISOLATE in all Directions Meters (Feet)	Then PROTECT persons Downwind during- DAY Kilometers (Miles)	NIGHT Kilometers (Miles)
3494	131	Petroleum sour crude oil, flammable, toxic	30 m (100 ft)	0.2 km (0.1 mi)	0.2 km (0.1 mi)	60 m (200 ft)	0.5 km (0.3 mi)	0.7 km (0.5 mi)

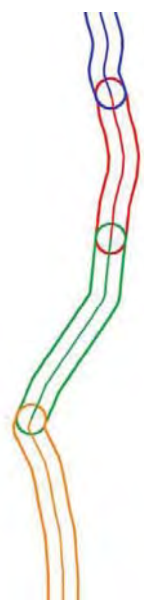
Note: The figure shows partially the Table 1 "Initial Isolation and Protective Action Distances" in page 342 of the document
Source: DOT 2012 Emergency Response Guidebook

Exposed Area

$$R_{AB} = \frac{1}{C_m} * \sum_{i,j,k} P_{ijk}(A) \; * \; P_{ijm}(R|A) * Ex.Area_i * AvgPopDen_i$$

- Following ERG recommendations, ½-mile radius evacuation was assumed for the determined conditions
- Using GIS software, ArcMap™, a buffer with this distance was created for each segment along the route





½-mile radius buffer for each element in a section of the route

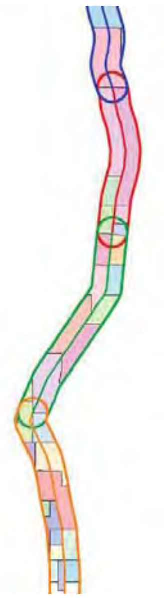
Average Population Density

$$R_{AB} = \frac{1}{C_m} * \sum_{i,j,k} P_{ijk}(A) \; * \; P_{ijm}(R|A) * Ex.Area_i * AvgPopDen_i$$

- An overlay of the route's buffer and population density was created using ESRI 2010 census tract data and GIS software, ArcMap™
- Aproximately 556,400 people live within a ½-mile radius of the route
- The average population density in the buffer area corresponding to each segment was determined

Distribution of the Average Population Density

Pop. Density (persons per square mile)	Length (miles)	%Length
> 3000	26.3	1.4%
1000 - 3000	140.4	7.4%
100 - 1000	421.5	22.1%
20 - 100	472.7	24.8%
< 20	846.7	44.4%



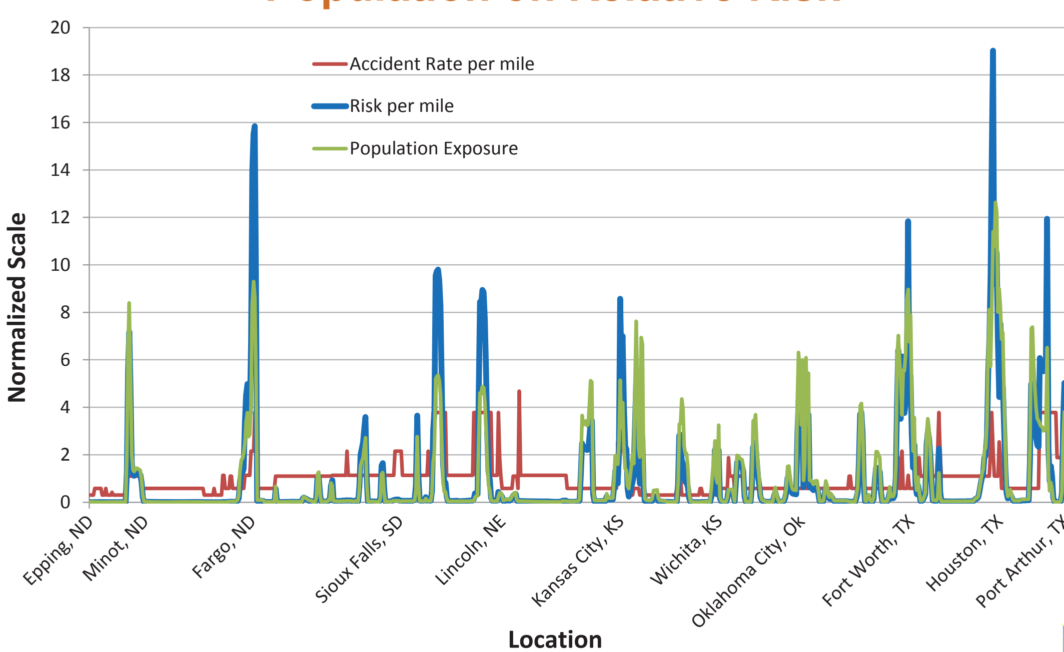
Overlay of the route's ½-mile radius buffer and the population density

Note: Each color in the figure indicates a different population density.

Epping - Port Arthur: Population Density

Epping - Port Arthur: Distribution of Risk by Segment

Epping - Port Arthur: Effect of Accident Rate and Population on Relative Risk



Note: The normalized scale is based on the average value for each represented series. A segment with a value in the normalized scale of 15 means that it is 15 times greater than the average for that series.

Epping - Port Arthur: Risk Summaries

Risk Level	Length (miles)	% Length	Risk (pop affected per tank car)	Risk (pop affected per gallon) *	% Risk
> 1.0E-04	152.7	8.0%	1.01E-02	3.18E-07	60.8%
1.0E-04 - 1.0E-05	474.1	24.9%	5.46E-03	1.72E-07	32.9%
1.0E-05 - 1.0E-06	688.8	36.1%	9.40E-04	2.95E-08	5.7%
1.0E-06 - 1.0E-07	496.5	26.0%	1.08E-04	3.39E-09	0.6%
< 1.0E-07	40.3	2.1%	4.00E-06	1.26E-10	0.0%

Route risk from Epping, ND to Port Arthur, TX:

– 1.662E-02 people affected per tank car

– 5.227E-07 persons/barrel

– Statistically, 1.6 people will be affected per every 100-car unit train

– This train will tranport about 3,180,000 gallons (75,700 barrels)

*Note: The capacity of the 111A100W1 was assumed to be 31,800 gallons.
These values aim to provide an idea of the risk per gallon transported. They only make sense when the amount transported is multiple of 31,800 gallons. That is each tank car is full.

Potential risk reduction strategies

Infrastructure

Track class upgrade

Reduce accident occurrence

Operational

Speed reduction

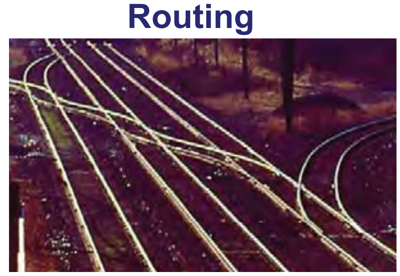
Reduce accident severity

Railcar/Container

Tank car safety design

Reduce incidence and severity of releases

Routing



Alternative routings

Reduce consequence of releases

Example risk reduction strategy optimization: Tank car safety design

Tank car weight vs. capacity tradeoff

Maximum Gross Rail Load (GRL) = Lading Capacity + Light (Empty Weight)

Sulfuric Acid

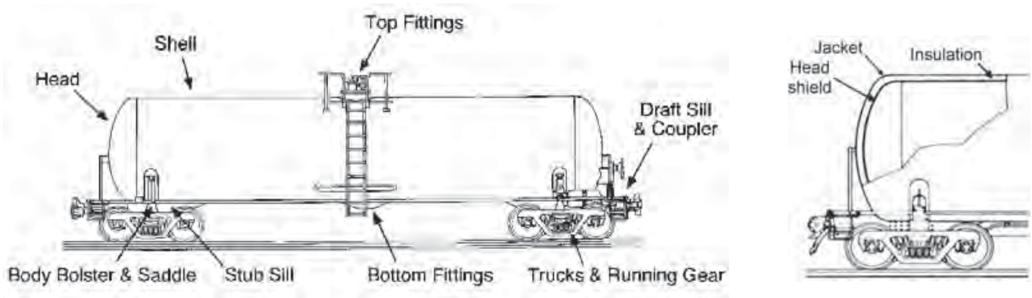
Density = 14.26 lbs./gallon
ca. 13,000 gallon tank

Alcohol

Density = 6.58 lbs./gallon
ca. 29,000 gallon tank

- Tank cars can be made safer by increasing tank thickness and adding various protective features, but these increase the weight and cost of the car and reduce its capacity and consequent transportation efficiency
- Formal consideration of this tradeoff between tank car safety and transportation efficiency, and use of optimization techniques to address this tradeoff represent the first phase involved in tank car safety design optimization

Tank car risk reduction options (RROs)



- Principal approaches considered to enhance tank car safety design:
  - Thicker/stronger head and/or head shield
  - Thicker/stronger shell
  - Adding top fittings protection
  - Removing bottom fittings
- Stronger tank and better-protected fittings ***improve accident performance***
- Also increase weight and cost, thereby ***reduce transport efficiency***
- Thus there is a ***tradeoff*** between enhanced safety and transport efficiency

Estimating tank car safety performance

- More than 40 thousand records of tank cars involved in accidents have been recorded since 1970 in the RSI-AAR Tank Car Accident Database
- Resultant database provides a robust source of information for quantitative analysis of tank car safety design
- Treichel et al (2006) developed a logistic regression model to estimate tank car conditional probability of release

$$P_{Ri|A} = 0.533\, e^{L(i)} / (1 + e^{L(i)})$$

- The calculated regression equations for the four release sources are:

L(HEAD) = - 0.4492 - 1.1672 HST - 1.9863 HMT - 0.9240 INS - 0.4176 SHELF- 0.4905 YARD

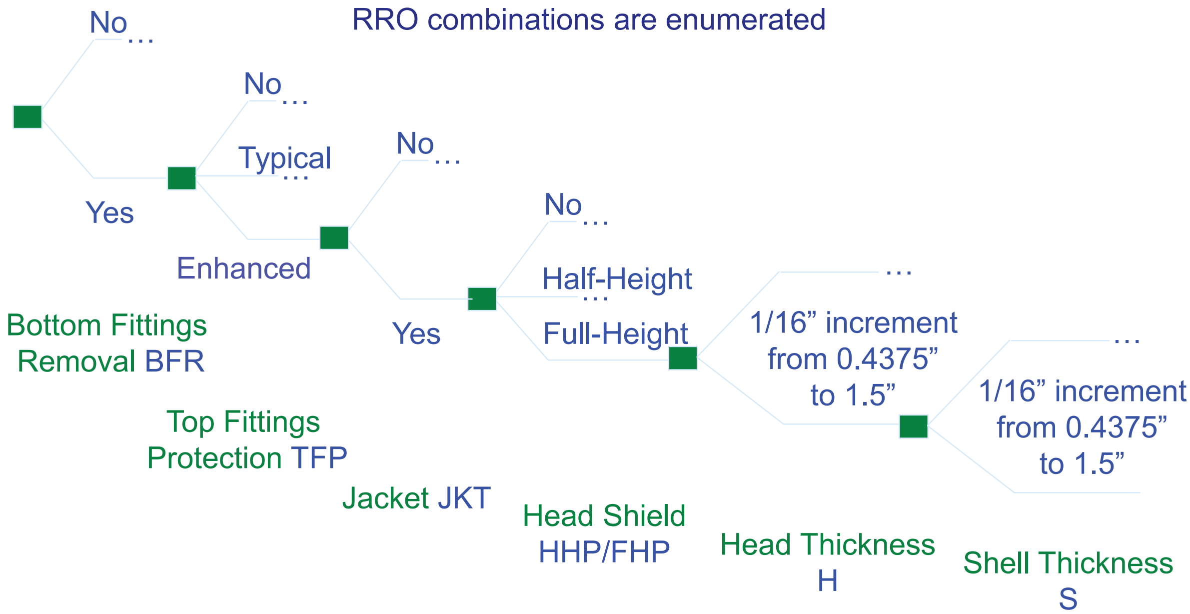
L(SHELL) = 0.4425 - 0.6427 INS - 4.1101 STS - 1.5119 YARD

L(TOP FITTINGS) = - 1.0483 - 0.8354 PRESS - 0.8388 INS + 0.1809 SHELF - 0.3439 YARD

L(BOTTOM FITTINGS) = - 1.4399 - 0.3758 INS - 0.5789 SHELF - 1.4168 YARD

Enumeration of all tank car RROs

The safety performance and weight for all possible RRO combinations are enumerated



2 x 3 x 2 x 3 x 18 x 18 = 11,664 combinations

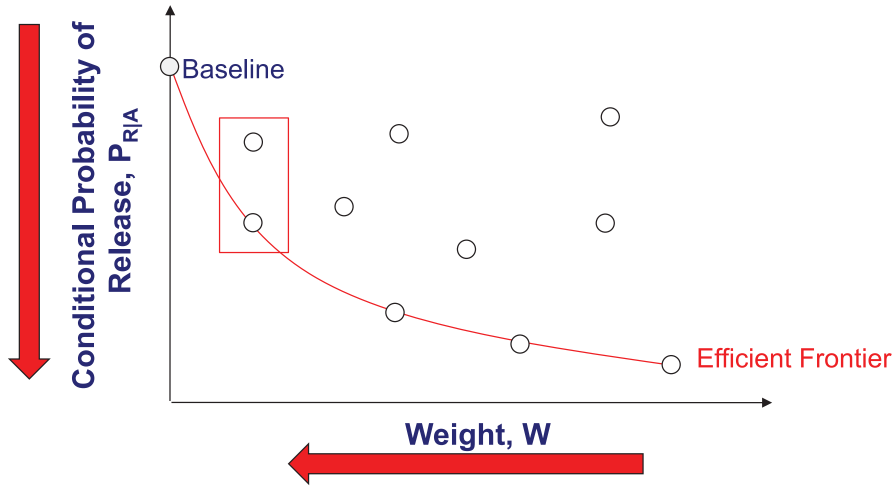
Enumeration of the conditional probability of release

- The conditional probability of release were enumerated with 1/16” incremental head and shell thicknesses, up to 1.5”

Head Thickness (inch)

Shell Thickness (inch)	0.4375	0.5000	0.5625	0.6250	0.6875	. . .
0.4375	0.3090	0.3051	0.3014	0.2981	0.2951	
0.5000	0.2981	0.2940	0.2901	0.2867	0.2835	
0.5625	0.2889	0.2846	0.2806	0.2770	0.2737	
0.6250	0.2813	0.2769	0.2728	0.2690	0.2657	
0.6875	0.2751	0.2705	0.2663	0.2625	0.2590	
. . .						

Stepwise algorithm used to identify the Pareto-optimal (non-dominated) solutions



1) Compute **W**, $\mathbf{P_{R|A}}$ and **ΔW** for all $\mathbf{RRO_i}$; set *i* = 0 (base case);
2) From $\mathbf{RRO_i}$, find **RRO** with the smallest **ΔW** and lower $\mathbf{P_{R|A}}$ than current $\mathbf{P_{R|A\mathit{i}}}$
3) Insert solution $\mathbf{RRO_{i+1}}$ that has the minimum $\mathbf{P_{R|A}}$ among **RRO** identified in step 2 to the set of Pareto-optimal solutions, **S**
4) Repeat steps 2 and 3 for all feasible solutions

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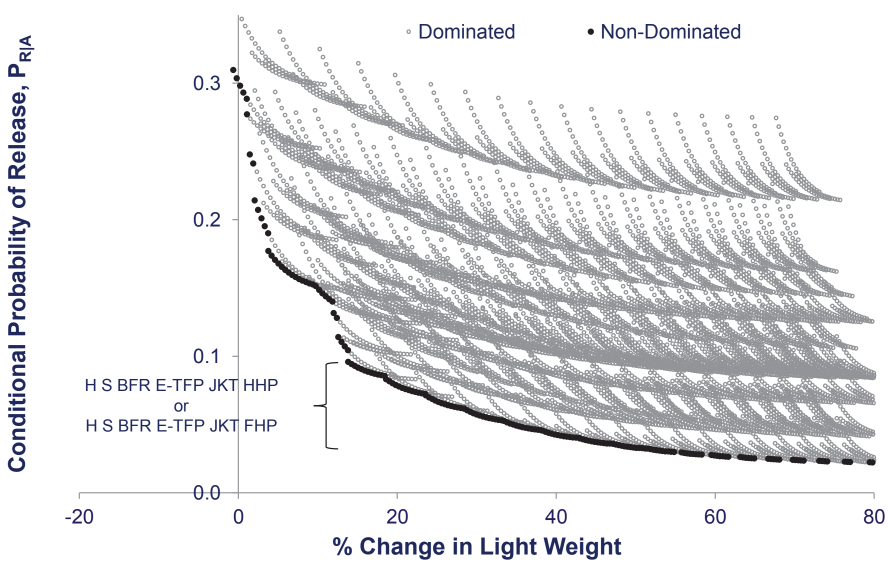
Identifying Pareto-optimal solutions - CPR

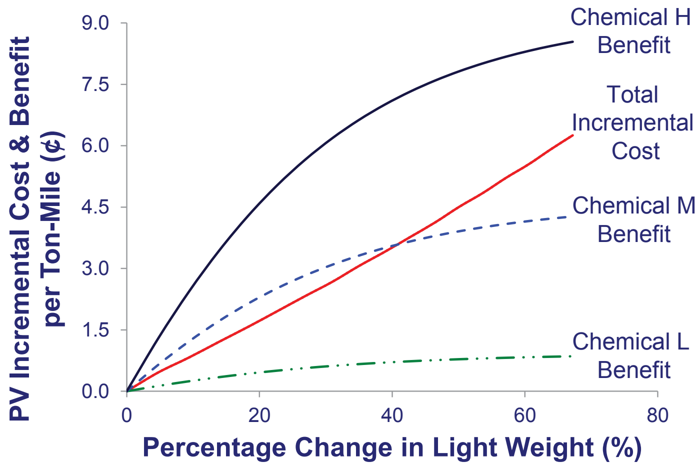
Enumeration of the effect of all possible RRO combination design solutions on **weight** and **CPR**

(263,000-lb maximum GRL, 30,000-gallon baseline tank car)

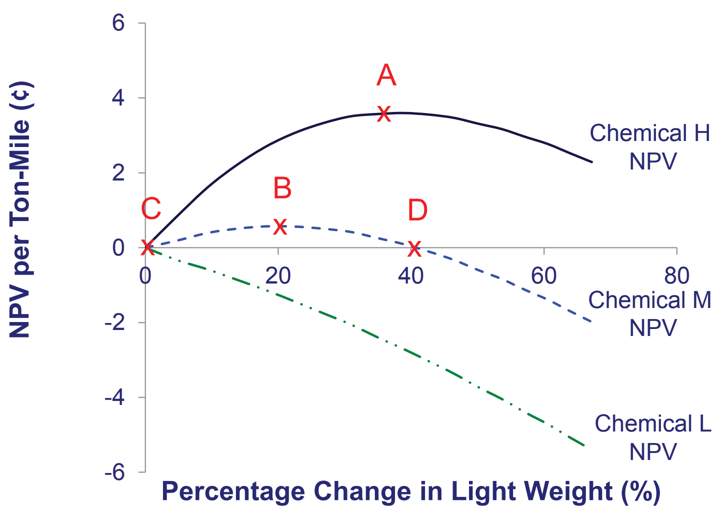


Cost effectiveness evaluation – PV benefits & cost

Max NPV = $PV_{Benefit} - PV_{Incremental\ Cost}$



Cost effectiveness evaluation - NPV



Example risk reduction strategy optimization: Railroad infrastructure/track class upgrade

Kawprasert, A. and C.P.L.Barkan 2009. *Communication and Interpretation of Results of Route Risk Analyses of Hazardous Materials Transportation by Railroad*. Transportation Research Record - Journal of the Transportation

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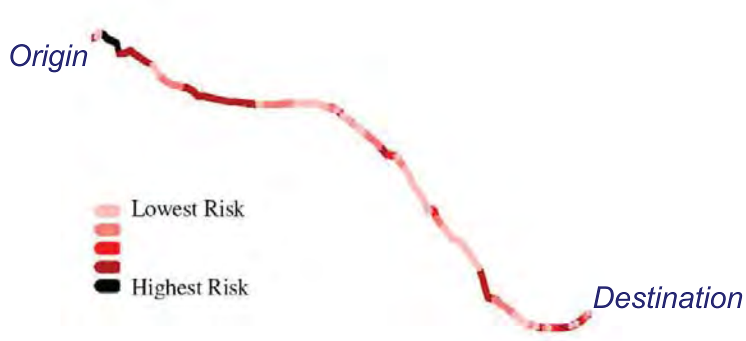
Route-specific risk analysis



- Route-specific risk analysis may enable identification of high-risk "hot spots"

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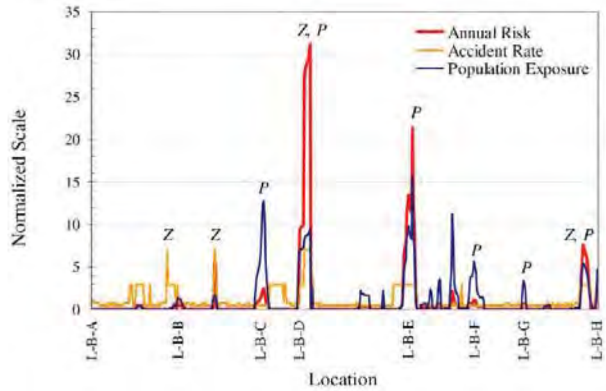
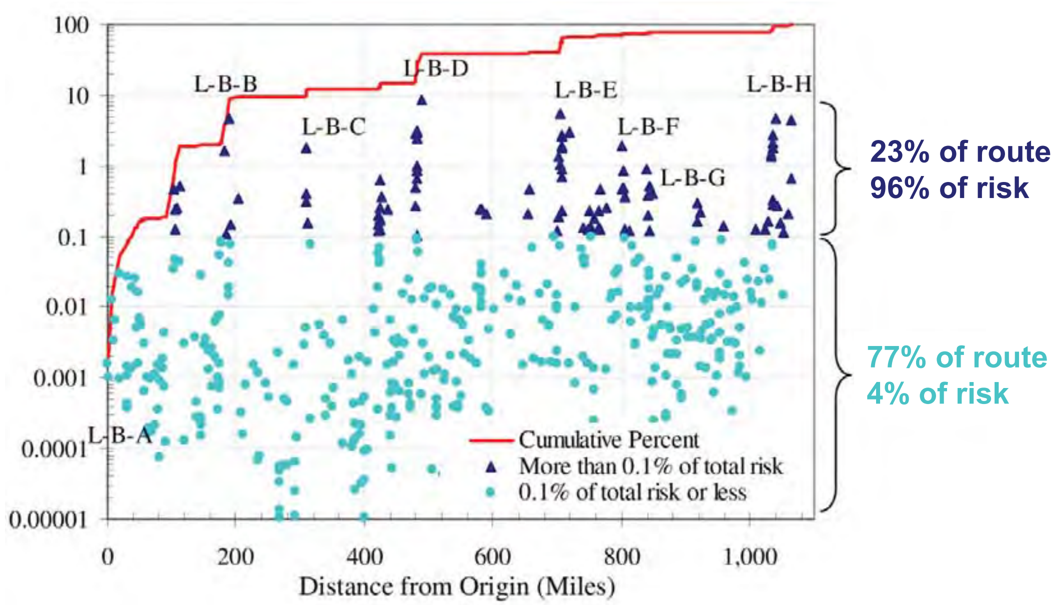
Route-specific risk analysis



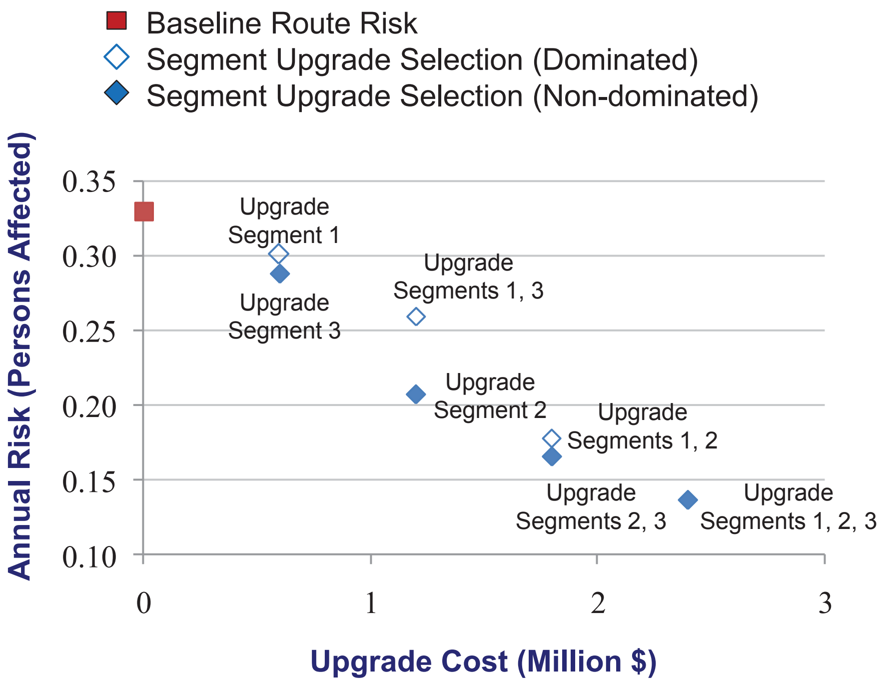
- Risk is due to accident rate and population exposure
- Highest risk areas are where these coincide

Risk along a route is highly concentrated

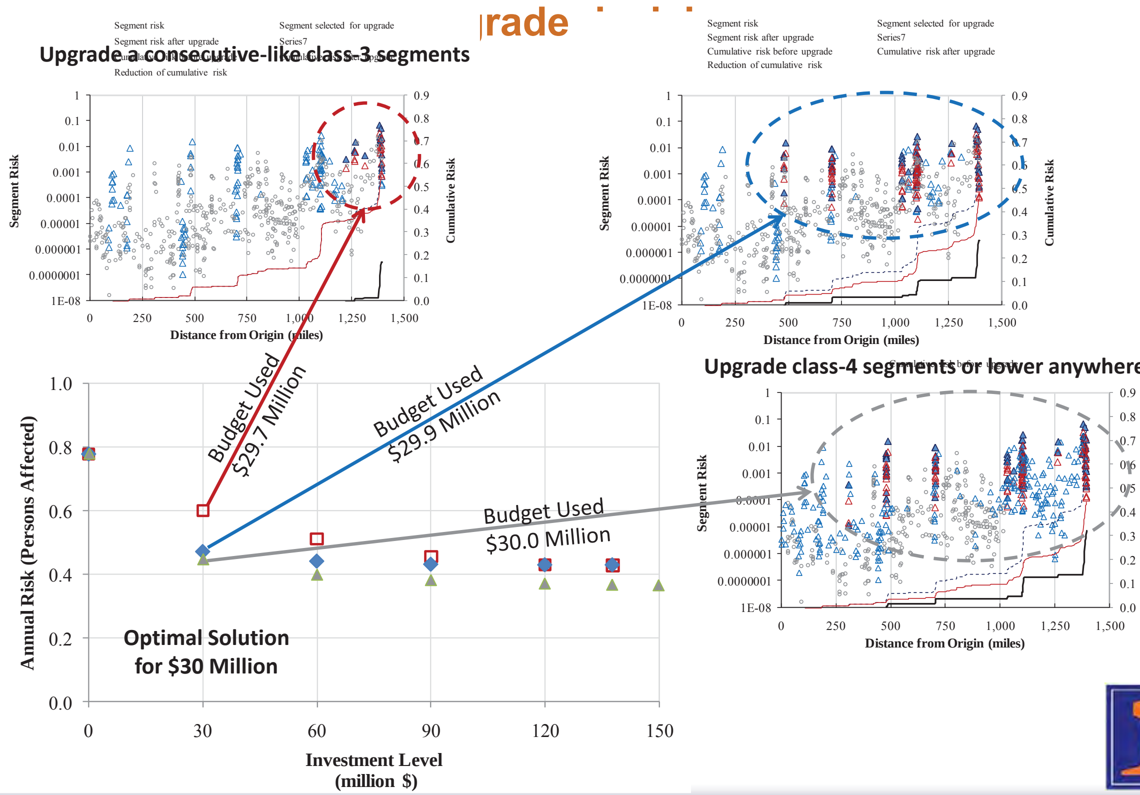


- Small portion of infrastructure segments account for majority of risk
- Enables efficient prioritization of risk reduction strategies

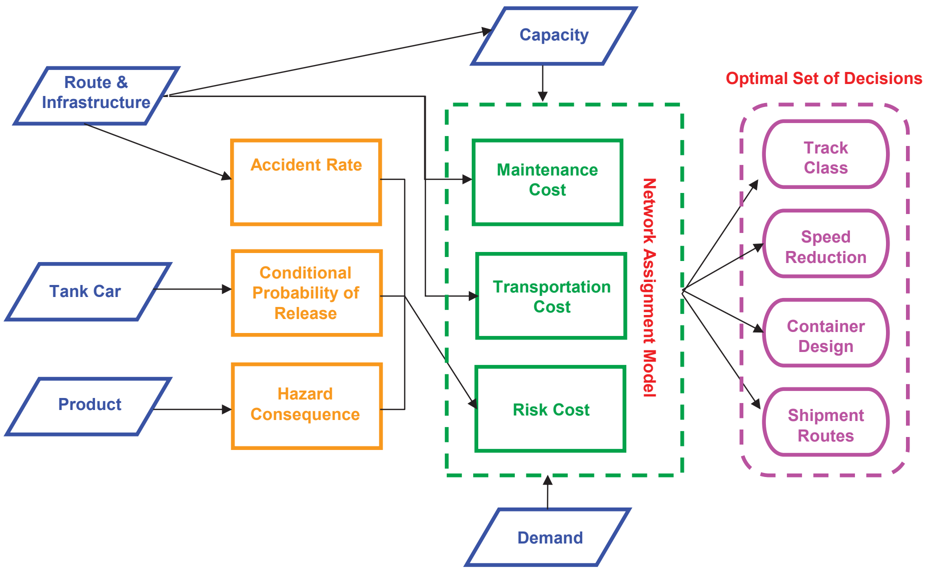
Illustration of Pareto optimality for segment-specific infrastructure upgrade



Graphical representation of optimal track class ...rade



Integrated optimization model to manage the risk of transporting hazardous materials on railroad networks



Lai, Y-C, A. Kawprasert, C.Y. Lin, M.R. Saat, C.H. Liang, and C.P.L. Barkan 2011. *Integrated Optimization Model to Manage the Risk of Transporting Hazardous Materials on Railroad Networks*. Transportation Research Record - Journal of the Transportation Research Board 2261: 115-123.

Example integrated optimization model

Model Formulation

$$\min \underbrace{\sum_{(i,j)\in A}\sum_{v\in V}\sum_{q\in Q} H_{ij}^{vq} y_{ij}^{vq}}_{\text{Maintenance cost}} + \underbrace{\sum_{(i,j)\in A}\sum_{k\in K}\sum_{t\in T} C_{ij} x_{ij}^{kt}}_{\text{Transportation cost}} + \underbrace{\sum_{(i,j)\in A}\sum_{v\in V}\sum_{q\in Q} R_{ij}^{vq} y_{ij}^{vq}}_{\text{Risk cost}}$$

Subject to:

$$\sum_{k\in K}\sum_{t\in T}(x_{ij}^{kt} + x_{ji}^{kt}) \le \sum_{v\in V}\sum_{q\in Q} U_{ij}^{q} y_{ij}^{vq} \quad \forall (i,j)\in A, (i<j)$$ Capacity constraint

$$\sum_{v\in V}\sum_{q\in Q} y_{ij}^{vq} = 1 \quad \forall (i,j)\in A, (i<j)$$ Track class and car composition constraint

$$\sum_{k\in K}(x_{ij}^{kt} + x_{ji}^{kt}) \le \sum_{v\in V}\sum_{q\in Q} N_{t}^{v} y_{ij}^{vq} \quad \forall (i,j)\in A, (i<j), t\in T$$ Linking constraint for decision variables

$$\sum_{j\in\partial^{+}(j)} x_{ij}^{kt} - \sum_{j\in\partial^{-}(j)} x_{ji}^{kt} = \begin{cases} D_{kt} z_{kt} & \text{if } i \in s_{kt} \\ -D_{kt} z_{kt} & \text{if } i \in e_{kt} \\ 0 & \text{otherwise} \end{cases} \quad \forall i\in N, k\in K, t\in T$$ Flow conservation constraint

$$\sum_{t\in T} z_{kt} = 1 \quad \forall k\in K$$ Car type constraint

$$x_{ij}^{kt} \in \text{positive integer}, \quad \forall (i,j)\in A, k\in K, t\in T,$$
$$y_{ij}^{vq} \in \{0,1\}, \quad \forall (i,j)\in A, v\in V, q\in Q,$$
$$z_{kt} \in \{0,1\}, \quad \forall k\in K, t\in T$$
Decision Variables Constraint

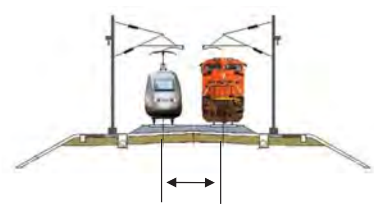
Identification of major risk factors for passenger trains on freight rail corridors



FRA Shared-Use Definitions

- ***Shared Track:*** tracks shared between passenger and freight or other service
- ***Shared Right of Way (ROW):*** dedicated high-speed passenger tracks separated from freight or other service tracks up to 25’
- ***Shared Corridor:*** dedicated high-speed passenger tracks separated from freight or other service tracks by 25-200’

Shared Track & Shared ROW

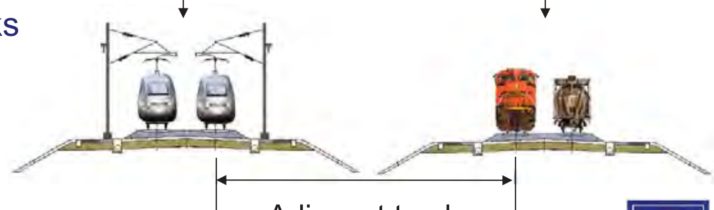


Adjacent track centers ≤ 25’
(trains do or do not share tracks per the definition)

Shared Corridor

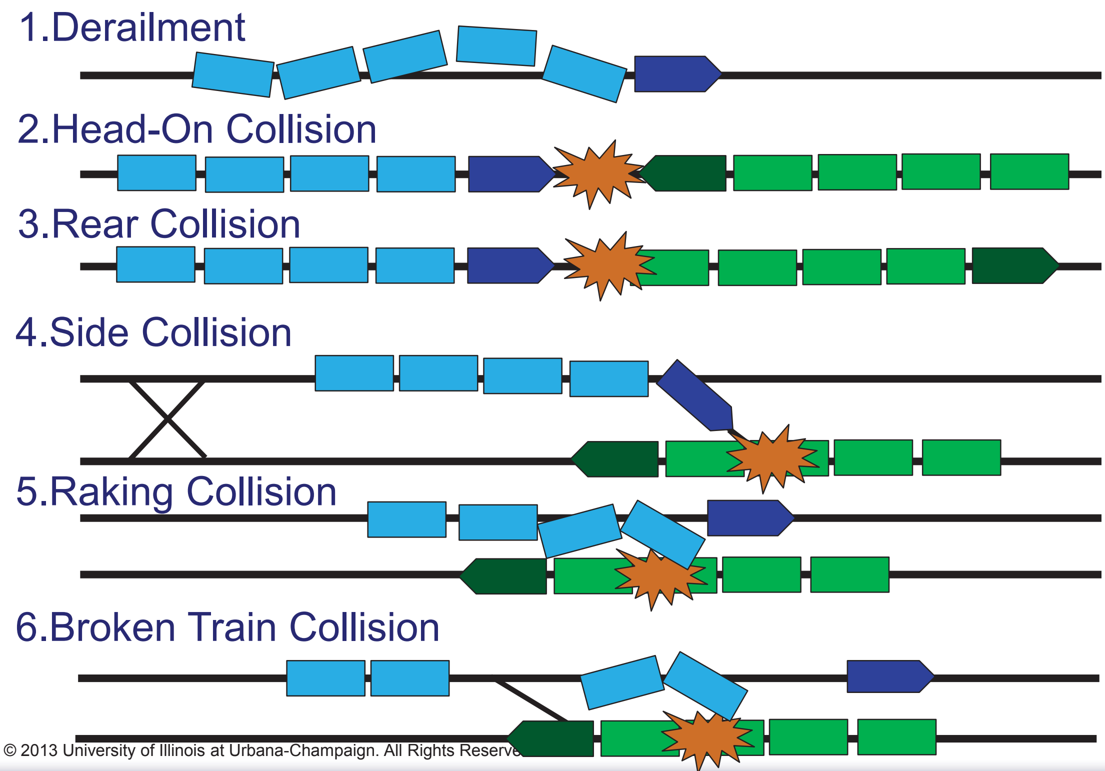
High-speed rail service

Freight or conventional passenger rail service



Adjacent track centers >25’ ≤ 200’

Derailment and collision scenarios



Accident scenarios

1.Single Track

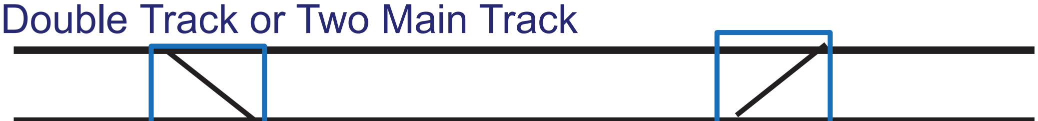
Head-on, rear, and broken train collision along the track

2.Single Track with Siding

Side collision Raking collision Side collision

Head-on, rear, and broken train collision along the track

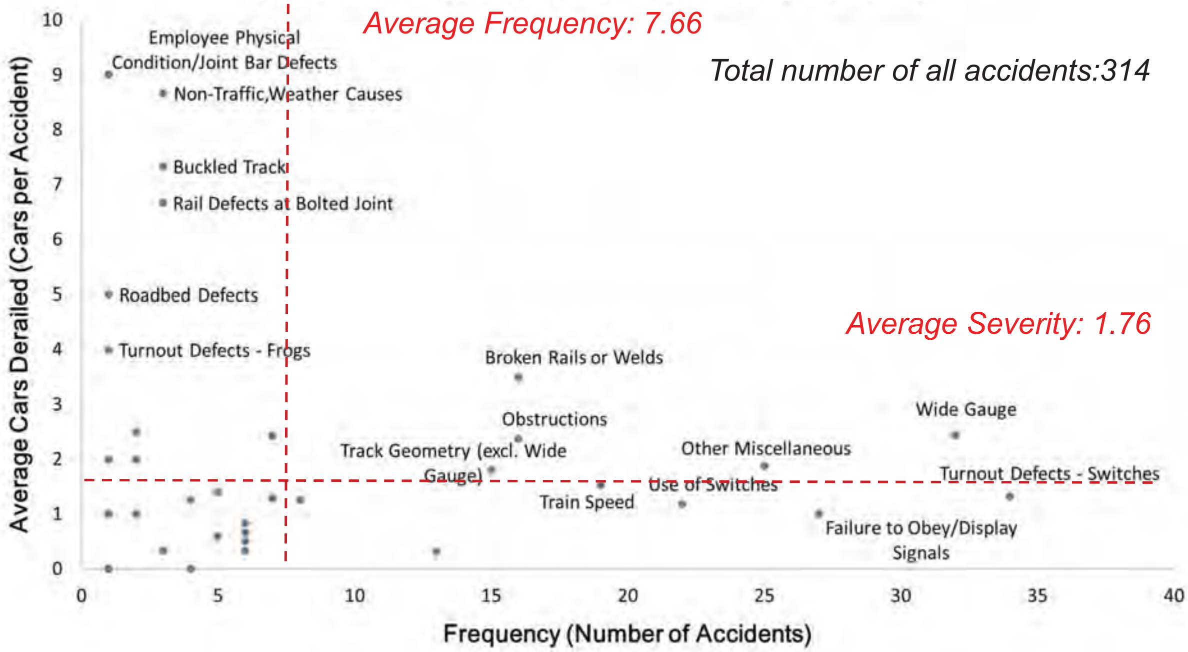
3.Double Track or Two Main Track



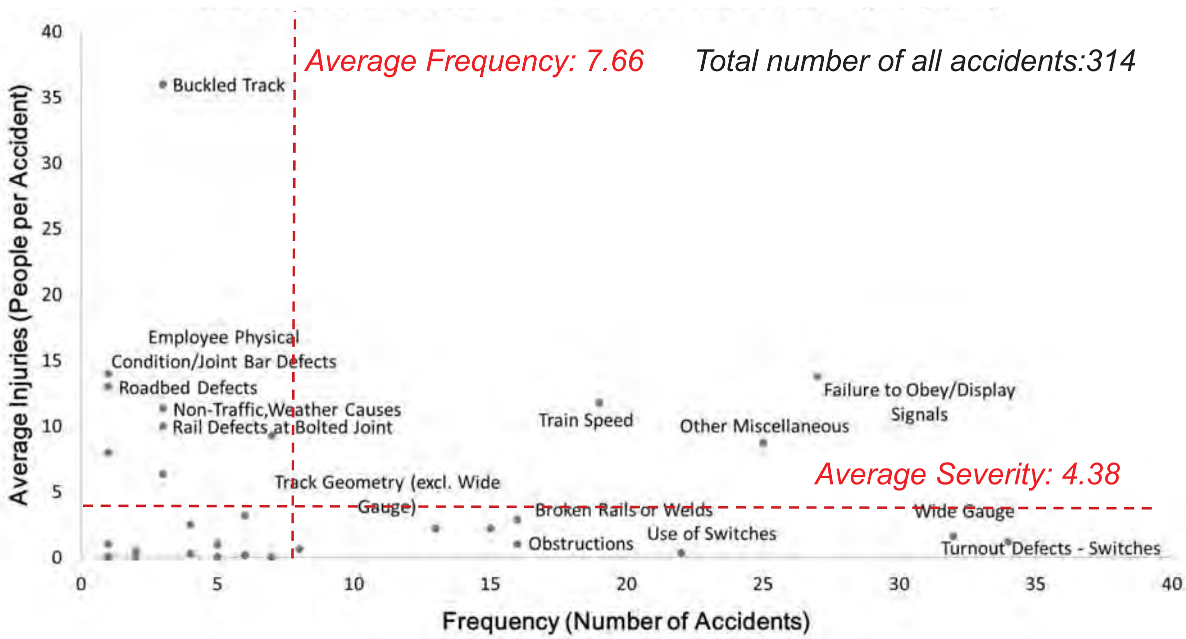
Side collision Side collision

Head-on, rear, raking, and broken train collision along the tracks

Frequency-severity diagram for mainline passenger train accidents (1997-2011): Average cars derailed



Frequency-severity diagram for mainline passenger train accidents (1997-2011): Average injuries



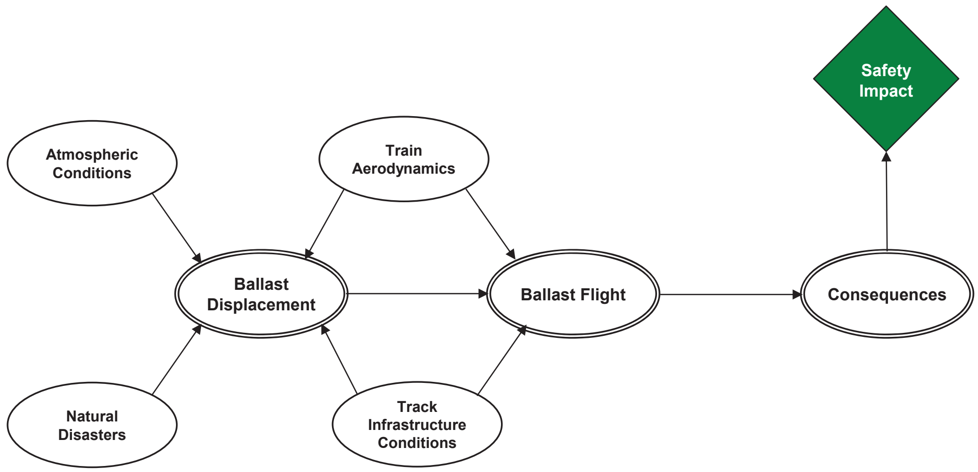
Research directions in shared rail corridor safety and risk

- Years 1-2: Identification of Risk Factors on Shared Rail Corridors*
- Years 3-4: Shared Corridor Risk Analysis Model Development (e.g. adjacent-track derailment risk)
- Years 5-6: Nationwide Shared Corridor Risk Assessment
- Years 7-8: Identification and Evaluation of Risk Reduction Strategies
- Years 9-10: Optimization of Risk Reduction Strategy Implementation

**To be accomplished under current NURail Center funding*

Identification of high-speed rail ballast flight risk factors and risk mitigation strategies

Preliminary ballast flight risk influence diagram



Uncertainty Node | Functional Node | Value/Objective Node

Strategic Development Plan for High-Speed Rail Ballast Flight Safety Risk Assessment and Management

Phase 1 – Risk Framework
- Perform literature review and interviews to identify potential causes and hazard consequences
- Identify potential risk mitigation strategies worldwide

Phase 2 – Risk Analysis
- Develop a ***qualitative*** risk assessment method
- Develop a ***semi-quantitative*** risk index
- Evaluate risk index for different , potential U.S. HSR scenarios

Phase 3 – Risk Management
- Prioritize risk scenarios
- Match high-risk scenarios with potential risk mitigation strategies
- Identify research needs

Potential extended research

PRESENT → **FUTURE**

Potential Ballast Flight Risk

Mitigated Risk Strategies

Key Takeaways

- There is always a risk associated with the transportation of hazardous materials. It is essential to properly understand and assess this risk.
- Risk models allow us to quantify this risk. Their results can assist in risk mitigation.

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OVERVIEW OF HIGHWAY FREIGHT TRANSPORTATION SAFETY

CEE498 TSR -Transportation Safety and Risk

Dr. Rapik Saat, Ph.D.

Rail Transportation and Engineering Center – RailTEC

Department of Civil & Environmental Engineering

University of Illinois at Urbana-Champaign, U.S.A.

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Learning Outcomes

At the end of this lecture students will be able to:

1. Recognize the extent of highway freight transportation infrastructure in the U.S.
2. Understand recent U.S. highway safety statistics and trends
3. Identify factors affecting highway truck accidents and releases

U.S. Highway Transportation Infrastructure

- Over 4 million miles of public roads
- 164,000 miles of roads comprising the National Highway System, including over 47,000 miles of Interstates
- Nearly 11 million commercial freight trucks

Commercial Truck Highway Network: 2011

Notes: This map should not be interpreted as the official National Network and should not be used for truck size and weight enforcement purposes. The National Network and the National Highway System (NHS) are approximately 200,000 miles in length, but the National Network includes 65,000 miles of highways beyond the NHS, and the NHS encompasses about 50,000 miles that are not part of the National Network. "Other NHS" refers to NHS mileage that is not included on the National Network. Conventional combination trucks are tractors with one semitrailer up to 48 feet in length or with one 28-foot semitrailer and one 28-foot trailer. Conventional combination trucks can be up to 102 inches wide.

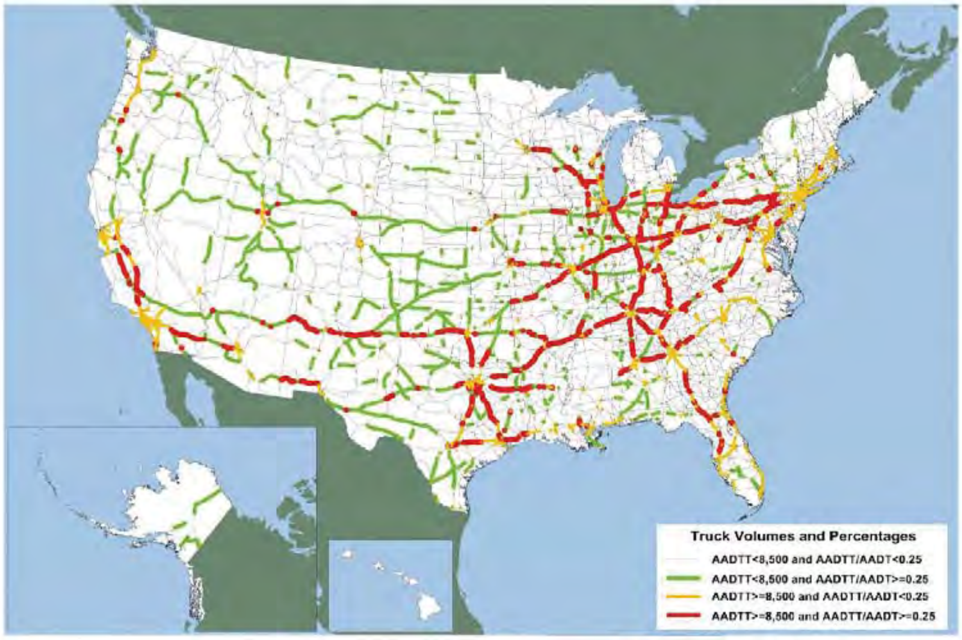
Source: U.S. DOT Federal Highway Administration Freight Facts and Figures 2012

Long-Haul Truck Traffic on the National Highway System: 2007

Note: Long-haul freight trucks typically serve locations at least 50 miles apart, excluding trucks that are used in movements by multiple modes and mail.
Source: U.S. Department of Transportation, Federal Highway Administration, Office of Freight Management and Operations, Freight Analysis Framework, version 3.4, 2012.

Source: U.S. DOT Federal Highway Administration Freight Facts and Figures 2012

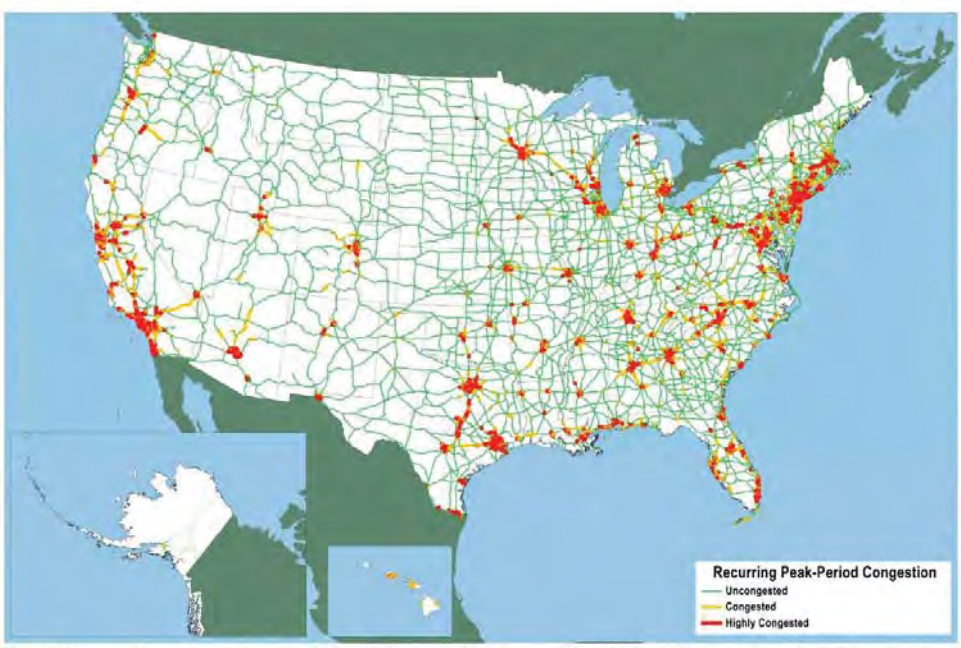
Major Truck Routes on the National Highway System: 2007



Notes: AADTT is average annual daily truck traffic and includes all freight-hauling and other trucks with six or more tires. AADT is average annual daily traffic and includes all motor vehicles.
Source: U.S. Department of Transportation, Federal Highway Administration, Office of Freight Management and Operations, Freight Analysis Framework, version 3.4, 2012.

Source: U.S. DOT Federal Highway Administration Freight Facts and Figures 2012

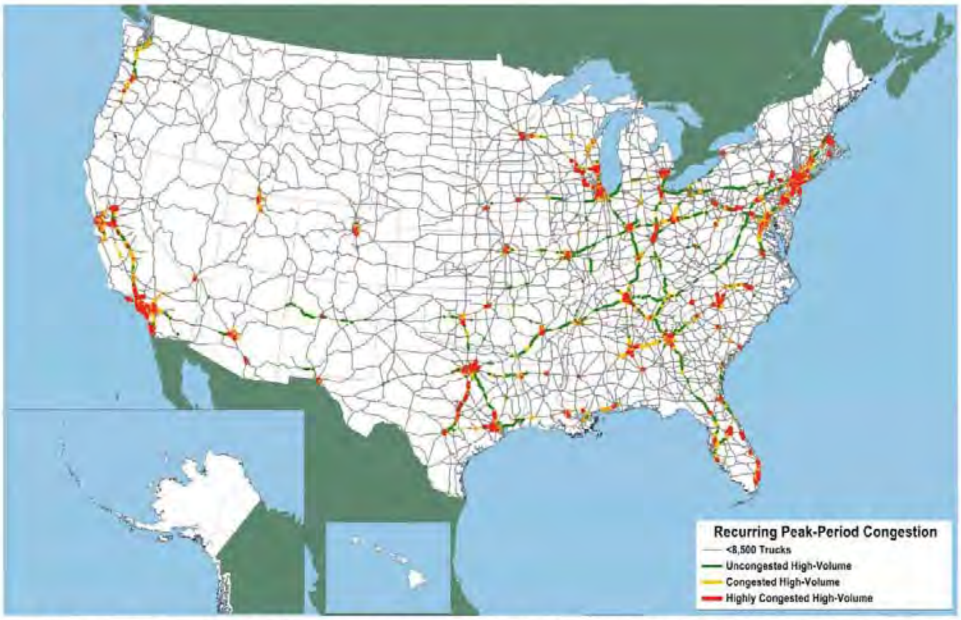
Peak-Period Congestion on the National Highway System: 2007



Notes: Highly congested segments are stop-and-go conditions with volume/service flow ratios greater than 0.95. Congested segments have reduced traffic speeds with volume/service flow ratios between 0.75 and 0.95.The volume/service flow ratio is estimated using the procedures outlined in the HPMS Field Manual, Appendix N.
Source: U. S. Department of Transportation, Federal Highway Administration, Office of Highway Policy Information, Highway Performance Monitoring System, and Office of Freight Management and Operations, Freight Analysis Framework, version 3.4, 2012

Source: U.S. DOT Federal Highway Administration Freight Facts and Figures 2012

Peak-Period Congestion on the National Highway System: 2007



Notes: High-volume truck portions of the National Highway System carry more than 8,500 trucks per day, including freight-hauling long-distance trucks, freight-hauling local trucks, and other trucks with six or more tires. Highly congested segments are stop-and-go conditions with volume/service flow ratios greater than 0.95. Congested segments have reduced traffic speeds with volume/service flow ratios between 0.75 and 0.95. The volume/service flow ratio is estimated using the procedures outlined in the HPMS Field Manual, Appendix N
Source: U. S. Department of Transportation, Federal Highway Administration, Office of Highway Policy Information, Highway Performance Monitoring System, and Office of Freight Management and Operations, Freight Analysis Framework, version 3.4, 2012

Source: U.S. DOT Federal Highway Administration Freight Facts and Figures 2012

Peak-Period Congestion on the National Highway System: 2007

Notes: High-volume truck portions of the National Highway System carry more than 8,500 trucks per day, including freight-hauling long-distance trucks, freight-hauling local trucks, and other trucks with six or more tires. Highly congested segments are stop-and-go conditions with volume/service flow ratios greater than 0.95. Congested segments have reduced traffic speeds with volume/service flow ratios between 0.75 and 0.95. The volume/service flow ratio is estimated using the procedures outlined in the HPMS Field Manual, Appendix N
Source: U. S. Department of Transportation, Federal Highway Administration, Office of Highway Policy Information, Highway Performance Monitoring System, and Office of Freight Management and Operations, Freight Analysis Framework, version 3.4, 2012

Source: U.S. DOT Federal Highway Administration Freight Facts and Figures 2012

Average Truck Speeds on Selected Interstate Highways: 2011

Source: U.S. Department of Transportation, Federal Highway Administration, Office of Freight Management and Operations, Freight Performance Measurement Program, 2012.

Source: U.S. DOT Federal Highway Administration Freight Facts and Figures 2012

Commercial Motor Carrier Compliance Review Activity by Safety Rating: 2011

Safety rating	Federal	State	Total	Percentage
Satisfactory	3,466	1,862	5,328	49%
Conditional	2,365	1,175	3,540	32%
Unsatisfactory	207	114	321	3%
Not rated	158	1,620	1,778	16%
Total	6,196	4,771	10,967	100%

Source: U.S. DOT Federal Highway Administration Freight Facts and Figures 2012

Roadside Safety Inspection Activity Summary by Inspection Type: 2000 and 2009-2011

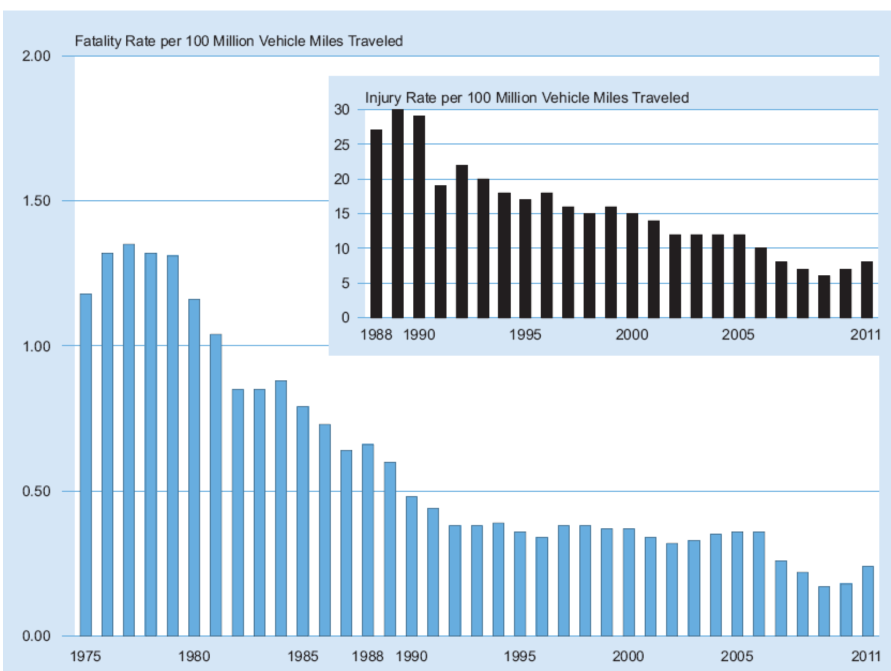
	2000		2009		2010		2011	
	Number	Percent	Number	Percent	Number	Percent	Number	Percent
All inspections								
Number of inspections	2,453,776	100.0	3,530,382	100.0	3,569,373	100.0	3,601,302	100.0
With no violations	639,593	26.1	1,176,351	33.3	1,225,324	34.3	1,342,133	37.3
With violations	1,814,183	73.9	2,354,031	66.7	2,344,049	65.7	2,259,169	62.7
Driver inspections								
Number of inspections	2,396,688	100.0	3,429,882	100.0	3,470,871	100.0	3,484,536	100.0
With no violations	1,459,538	60.9	2,100,760	61.2	2,316,960	66.8	2,422,611	69.5
With violations	937,150	39.1	1,329,122	38.8	1,153,911	33.2	1,061,925	30.5
With OOS violations	191,031	8.0	196,625	5.7	183,350	5.3	173,980	5.0
Vehicle inspections								
Number of inspections	1,908,300	100.0	2,349,072	100.0	2,413,094	100.0	2,425,973	100.0
With no violations	584,389	30.6	779,891	33.2	834,551	34.6	880,172	36.3
With violations	1,323,911	69.4	1,569,181	66.8	1,578,543	65.4	1,545,801	63.7
With OOS violations	452,850	23.7	506,878	21.6	480,416	19.9	491,730	20.3
Hazardous materials inspections								
Number of inspections	133,486	100.0	222,587	100.0	211,154	100.0	208,852	100.0
With no violations	101,098	75.7	153,219	68.8	180,522	85.5	183,150	87.7
With violations	32,388	24.3	69,368	31.2	30,632	14.5	25,702	12.3
With OOS violations	9,964	7.5	10,323	4.6	9,210	4.4	7,998	3.8

Key: OOS = out of service

Source: U.S. DOT Federal Highway Administration Freight Facts and Figures 2012

ILLINOIS - RAILTEC

Large Truck Occupant Fatality and Injury Rates per 100 Million Vehicle Miles Traveled



Source: U.S. DOT National Highway Traffic Safety Administration Traffic Safety Facts 2011

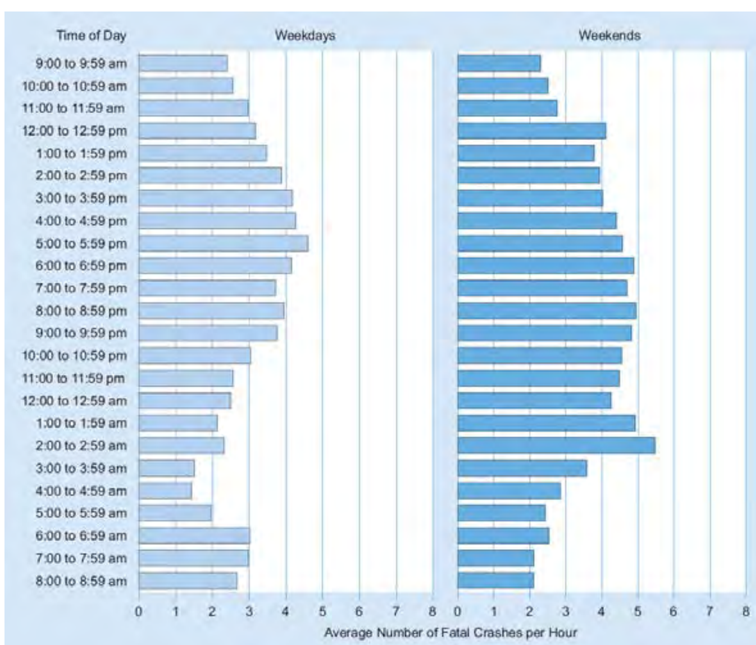
Persons Killed in Crashes Involving a Large Truck by Person Type and Crash Type

Year	Person Type					Total
	Truck Occupants by Crash Type			Other Vehicle Occupants	Nonoccupants	
	Single Vehicle	Multiple Vehicle	Total			
	Killed					
1975	643	318	*961*	3,106	416	**4,483**
1980	861	401	*1,262*	4,084	625	**5,971**
1985	634	343	*977*	4,227	530	**5,734**
1988	585	326	*911*	4,250	518	**5,679**
1990	485	220	*705*	4,071	496	**5,272**
1991	448	213	*661*	3,705	455	**4,821**
1992	396	189	*585*	3,460	417	**4,462**
1993	389	216	*605*	3,855	396	**4,856**
1994	451	219	*670*	4,013	461	**5,144**
1995	425	223	*648*	3,846	424	**4,918**
1996	412	209	*621*	4,087	434	**5,142**
1997	499	224	*723*	4,223	452	**5,398**
1998	486	256	*742*	4,215	438	**5,395**
1999	480	279	*759*	4,180	441	**5,380**
2000	484	270	*754*	4,114	414	**5,282**
2001	474	234	*708*	3,962	441	**5,111**
2002	449	240	*689*	3,886	364	**4,939**
2003	457	269	*726*	3,919	391	**5,036**
2004	469	297	*766*	4,042	427	**5,235**
2005	478	326	*804*	3,971	465	**5,240**
2006	500	305	*805*	3,797	425	**5,027**
2007	502	303	*805*	3,608	409	**4,822**
2008	430	252	*682*	3,151	412	**4,245**
2009	333	166	*499*	2,558	323	**3,380**
2010	339	191	*530*	2,797	359	**3,686**
2011	403	232	*635*	2,695	427	**3,757**

Source: U.S. DOT National Highway Traffic Safety Administration Traffic Safety Facts 2011

ILLINOIS - RAILTEC

Average Fatal Crashes per Hour, by Time of Day, Weekdays and Weekends



Source: U.S. DOT National Highway Traffic Safety Administration Traffic Safety Facts 2011

Vehicles Involved in Crashes by Vehicle Type and Crash Severity

Vehicle Type	Crash Severity: Fatal Number	Fatal Percent	Injury Number	Injury Percent	Property Damage Only Number	Property Damage Only Percent	Total Number	Total Percent
Passenger Car	17,442	39.7	1,571,000	57.0	3,740,000	56.6	**5,328,000**	**56.6**
Light Truck	16,740	38.1	1,026,000	37.2	2,582,000	39.0	**3,625,000**	**38.5**
Large Truck	3,608	8.2	63,000	2.3	221,000	3.3	**287,000**	**3.1**
Motorcycle	4,749	10.8	77,000	2.8	18,000	0.3	**100,000**	**1.1**
Bus	244	0.6	13,000	0.5	44,000	0.7	**57,000**	**0.6**
Other	535	1.2	6,000	0.2	7,000	0.1	**14,000**	**0.1**
Total	***43,945**	**100.0**	**2,756,000**	**100.0**	**6,612,000**	**100.0**	**9,412,000**	**100.0**

*Includes 627 vehicles of unknown type involved in fatal crashes.

Source: U.S. DOT National Highway Traffic Safety Administration Traffic Safety Facts 2011

Vehicles Involved in Single-and Two-Vehicle Crashes by Vehicle Maneuver and Crash Severity

Vehicle Maneuver	Crash Severity: Fatal Number	Fatal Percent	Injury Number	Injury Percent	Property Damage Only Number	Property Damage Only Percent	Total Number	Total Percent
Going Straight	23,539	62.3	1,242,000	55.1	3,011,000	49.9	**4,276,000**	**51.4**
Turning Left	2,364	6.3	276,000	12.2	556,000	9.2	**834,000**	**10.0**
Stopped in Traffic Lane	454	1.2	226,000	10.0	770,000	12.8	**996,000**	**12.0**
Turning Right	339	0.9	73,000	3.2	264,000	4.4	**337,000**	**4.0**
Slowed in Traffic Lane	311	0.8	121,000	5.4	359,000	5.9	**481,000**	**5.8**
Merging/Changing Lanes	665	1.8	59,000	2.6	290,000	4.8	**350,000**	**4.2**
Negotiating Curve	8,218	21.7	134,000	6.0	278,000	4.6	**420,000**	**5.0**
Backing Up	117	0.3	15,000	0.7	156,000	2.6	**171,000**	**2.1**
Passing Other Vehicle	740	2.0	19,000	0.8	70,000	1.2	**89,000**	**1.1**
Starting in Traffic Lane	228	0.6	55,000	2.4	150,000	2.5	**205,000**	**2.5**
Leaving Parking Space	20	0.1	6,000	0.3	34,000	0.6	**40,000**	**0.5**
Making U-Turn	152	0.4	13,000	0.6	37,000	0.6	**50,000**	**0.6**
Entering Parking Space	10	*	2,000	0.1	18,000	0.3	**20,000**	**0.2**
Disabled in Traffic Lane	33	0.1	2,000	0.1	5,000	0.1	**6,000**	**0.1**
Other Maneuver	345	0.9	13,000	0.6	37,000	0.6	**50,000**	**0.6**
Total	****37,813**	**100.0**	**2,253,000**	**100.0**	**6,035,000**	**100.0**	**8,326,000**	**100.0**

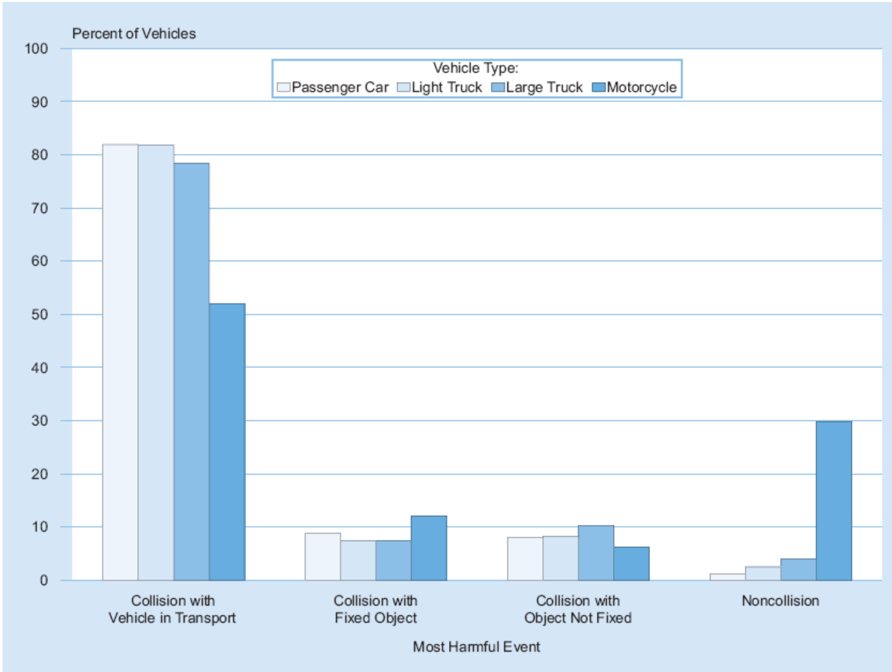
*Less than 0.05 percent.

**Includes 278 vehicles involved in fatal crashes with unknown vehicle maneuver.

Source: U.S. DOT National Highway Traffic Safety Administration Traffic Safety Facts 2011

Slide 18

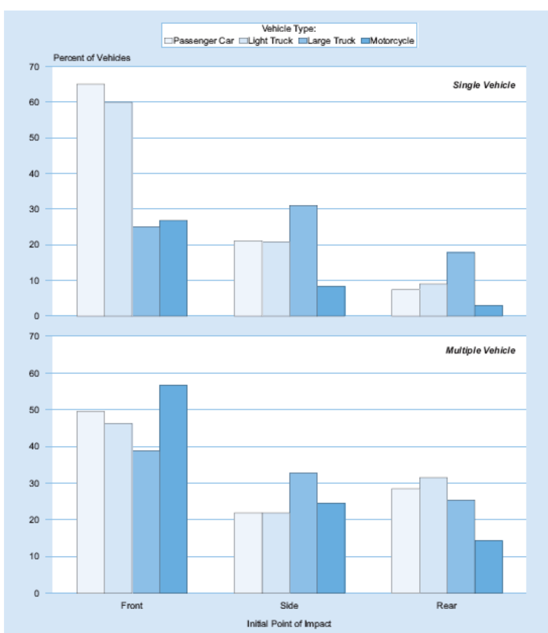
Percent of Vehicles in Crashes, by Most Harmful Event and Vehicle Type



Source: U.S. DOT National Highway Traffic Safety Administration Traffic Safety Facts 2011

Slide 19

Percent of Vehicles in Crashes, by Initial Point of Impact, Crash Type, and Vehicle Type



Source: U.S. DOT National Highway Traffic Safety Administration Traffic Safety Facts 2011

Large Trucks Involved in Crashes by Truck Type, Rollover Occurrence, and Crash Severity

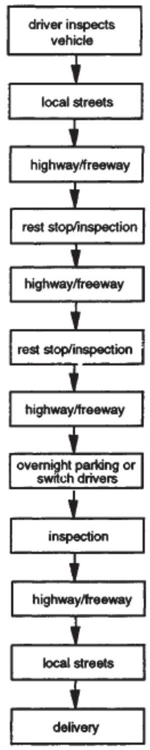
Truck Type	Rollover Occurrence: Yes Number	Rollover Occurrence: Yes Percent	Rollover Occurrence: No Number	Rollover Occurrence: No Percent	Total Number	Total Percent
Fatal Crashes						
Single-Unit Truck	171	16.3	879	83.7	**1,050**	**100.0**
Combination Truck	319	12.5	2,239	87.5	**2,558**	**100.0**
Total	**490**	**13.6**	**3,118**	**86.4**	**3,608**	**100.0**
Injury Crashes						
Single-Unit Truck	2,000	6.2	28,000	93.8	**30,000**	**100.0**
Combination Truck	3,000	9.0	30,000	91.0	**33,000**	**100.0**
Total	**5,000**	**7.7**	**58,000**	**92.3**	**63,000**	**100.0**
Property-Damage-Only Crashes						
Single-Unit Truck	1,000	0.8	108,000	99.2	**109,000**	**100.0**
Combination Truck	3,000	2.9	109,000	97.1	**112,000**	**100.0**
Total	**4,000**	**1.9**	**217,000**	**98.1**	**221,000**	**100.0**
All Crashes						
Single-Unit Truck	3,000	2.1	137,000	97.9	**140,000**	**100.0**
Combination Truck	7,000	4.4	141,000	95.6	**147,000**	**100.0**
Total	**9,000**	**3.3**	**278,000**	**96.7**	**287,000**	**100.0**

Source: U.S. DOT National Highway Traffic Safety Administration Traffic Safety Facts 2011

Highway Quantitative Transportation Risk Analysis

CCPS 1995 – Chemical Transportation Risk Analysis

Typical Truck Transport Operation



Truck Incidents - Initiating and Contributing Causes

Human errors	*Equipment failures*	*System or procedural failures*	*External events*
Driver impairment	Nondedicated trailer	Driver incentives	Vandalism/sabotage
Speeding	RR crossing guard failure	Driver training	Snow
Driver overtired	Leaking valve	Carrier selection	Rain
Enroute inspection	Leaking fitting	Container specification	Ice
Contamination	Brake failure	Route selection	Fog
Heating and cooling	Insulation/thermal protection failure	Emergency response training	Wind
Overfilling	Relief device failure	Speed enforcement	Flood/washout
Inerting	Tire failure	Driver rest periods	Rockslide/landslide
Other vehicle's driver	Soft shoulder	Maintenance	Fire at rest areas/parking areas
Taking tight turns/ramps too quickly (overturns)	Overpressure	Inspection	Hurricane
Unsecured load	Material defect	Time of day restrictions	Tornado
	Vacuum		Earthquake
	Steering failure		Existing accident
	Sloshing		
	High center of gravity		
	Corrosion		
	Bad weld		
	Excessive grade		
	Poor intersection design		
	Suspension system		
	Fifth wheel failure		

Truck Incidents – General Categories

- Vehicular collisions
- Collisions with fixed objects
- Vehicle overturnings
- Railroad grade crossing accidents
- Non-accident-initiated releases

Parameters Influencing Accident Rates

- Key parameters:
  - Urban versus rural routes
  - Divided versus undivided highway
- Location-specific conditions (e.g. excessive grade, obstructions to vision, poorly designed intersections)
- Weather conditions
- Carrier safety performance

Highway Class		*Truck Accident Rate (per 10^6 vehicle miles)*	*Release Probability*
Area	*Roadway*		
Rural	Two-lane	2.19	0.086
Rural	Multilane, undivided	4.49	0.081
Rural	Multilane, divided	2.15	0.082
Rural	Freeway (limited access)	0.64	0.090
Urban	Two-lane	8.66	0.069
Urban	Multilane, undivided	13.92	0.055
Urban	Multilane, divided	12.47	0.062
Urban	One-way street	9.70	0.056
Urban	Freeway (limited access)	2.18	0.062

[a]Harwood and Russell (1992); Transportation Data Source 4-27.

Parameters Influencing Release Probabilities

- Vehicle and container characteristics (e.g. material and wall thickness, double wall, protective shielding devices)
- Accident environments (e.g. high or low speed, overturning)
- Product (e.g. material phase - liquid or gas, material temperature and pressure)

Highway Class		*Truck Accident Rate (per 10^6 vehicle miles)*	*Release Probability*
Area	*Roadway*		
Rural	Two-lane	2.19	0.086
Rural	Multilane, undivided	4.49	0.081
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Rural	Freeway (limited access)	0.64	0.090
Urban	Two-lane	8.66	0.069
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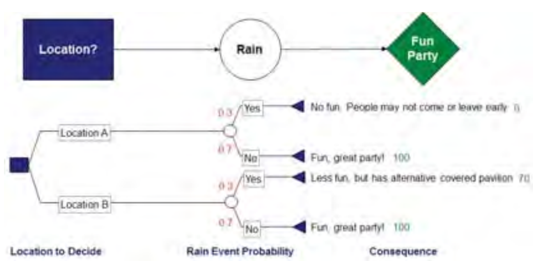
Urban	Multilane, divided	12.47	0.062
Urban	One-way street	9.70	0.056
Urban	Freeway (limited access)	2.18	0.062

[a]Harwood and Russell (1992); Transportation Data Source 4-27.

In-Class Group Assignment

- Develop 1) influence diagram and 2) decision tree for a highway hazardous materials transportation risk

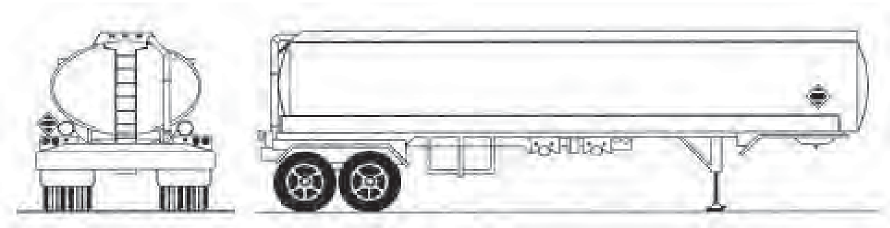


Motor Carrier Bulk Containers

Motor Carrier Bulk Containers

- Information for the following slides was obtained from:
  - Guidelines for Chemical Transportation Risk Analysis Appendix A: Standard Container Illustrations and Specifications (p. 313 – 323)
  - OFA Hazmat/WMD Awareness Revised 2009 Unit 3 training module: http://www.chagrinsehazmat.com/Ohio_Hazmat_%20TAC.htm

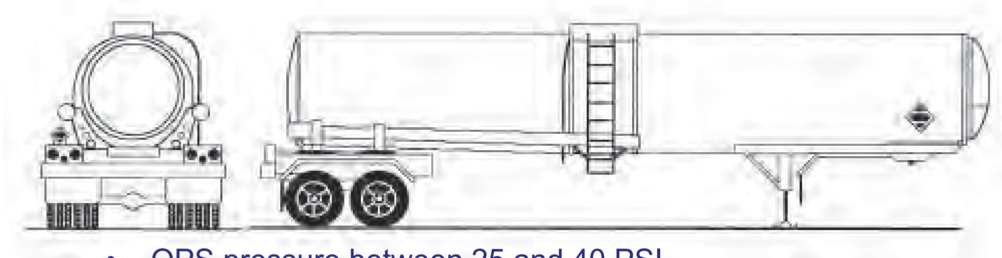
MC-306/DOT-406
Atmospheric Pressure Cargo Tank Truck



- OPS pressure less than 3 PSI
- Transports 2,000 to 9,500 gallons of flammable and combustible liquids or poisonous materials
- Single shell aluminum with oval cross-section
- Multi-compartment design with compartments separated by double bulkheads separated by a vented/drained air space
- Recessed manholes/rollover protection
- Bottom valves
- Usually has vapour recovery system

MC-306/DOT-406
Atmospheric Pressure Cargo Tank Truck

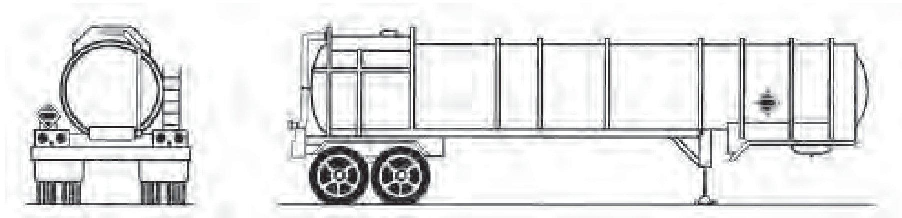
MC307/407
Low-pressure Chemical Cargo Tank Truck



- OPS pressure between 25 and 40 PSI
- Transports 2,000 to 8,000 gallons of flammable liquids and mild corrosives
- Typically double shell that may be rubber lined/steel with a horseshoe or round shape
- Multi-compartment design with compartments separated by double bulkheads separated by a vented/drained air space
- Single or double top manhole
- Single outlet discharge for each compartment
- Stiffening rings and rollover protection

MC307/407
Low-pressure Chemical Cargo Tank Truck

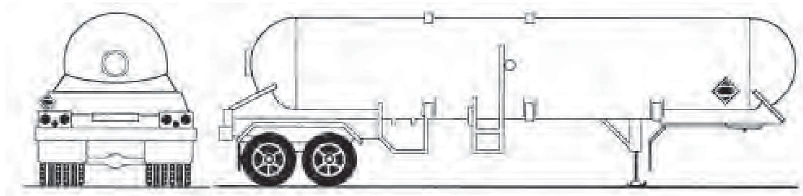
MC312/412
Corrosive Cargo Tank Truck



- OPS pressure less than 75 PSI
- Transports high density liquids and corrosives such as acetyl chloride, hydrochloric acid, and sodium hydroxide solutions
- Multi-compartment, tube-shaped design characterized by small diameter
- Typically constructed of steel, stainless steel or aluminum and often lined with corrosive resistant material
- Top loading at rear or center with loading area typically covered with corrosive resistant material
- Stiffening rings, rollover protection and splash guards also provide rollover protection.

MC312/412
Corrosive Cargo Tank Truck

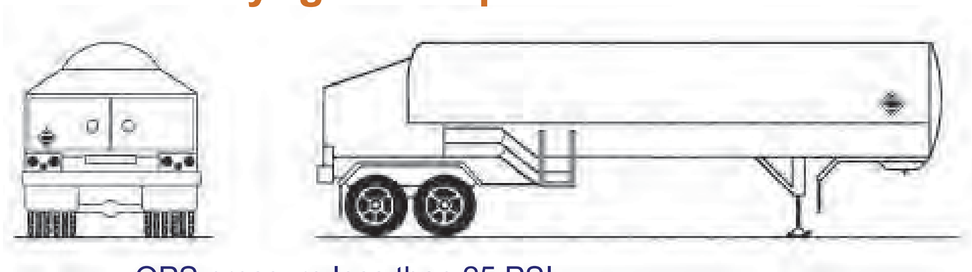
MC331
High-Pressure Gas Cargo Tank Truck



- OPS pressure up to 300 PSI
- Transports liquefied (compressed) gasses and very hazardous liquids (i.e. LPG, Poison Inhalation Hazards)
- Containers are never filled completely as vapour space is needed during transit (overfilling can cause hydrostatic failure)
- Single compartment, non-insulated design with dome-shaped ends
- Typically constructed of steel, painted white or another reflective color

MC331
High-Pressure Gas Cargo Tank Truck

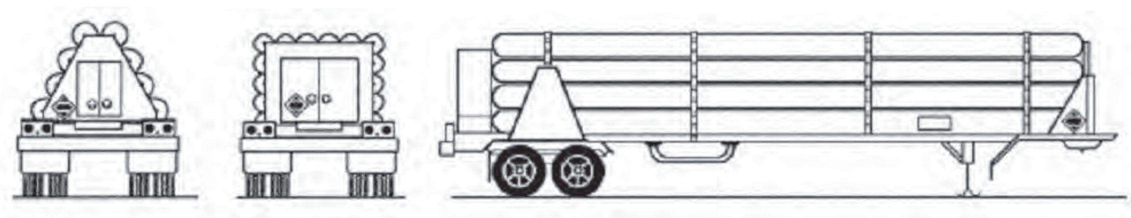
MC338
Cryogenic Liquid Tank Truck



- OPS pressure less than 25 PSI
- Transports liquefied (refrigerated) gasses (i.e. liquid helium)
- "Container within a container" design with annular space totally surrounding the inner container to prevent heat transfer (not to refrigerate)
- Outer contained constructed of steel and inner container constructed of steel alloys (due to cold temperatures)
- Allows venting to refrigerate the load
- Round tank with cabinet at rear

MC338
Cryogenic Liquid Tank Truck

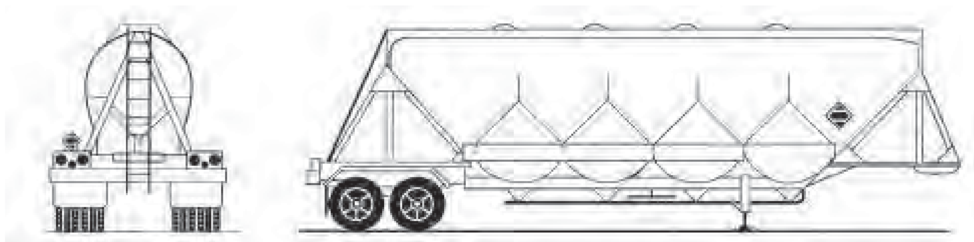
Tube Trailers



- OPS pressure between 3,000 and 5,000 PSI
- Transports compressed gas
- Individual steel cylinders stacked and banded together in modular or nested shape
- Bolted manhole at the front or rear of the cylinder
- Protected valves located at the rear

Tube Trailers

Dry Bulk Cargo Tanker

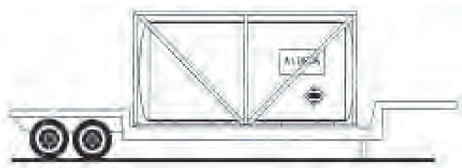


- OPS pressure less than 22 PSI (typically not under pressure)
- Hopper design
- Top side manholes
- Bottom valves (air assisted loading and unloading)

Dry Bulk Cargo Tanker

Inter-Modal Containers

Pressure Tank



Cryogenic Tank

- Smaller in size
- Designed for use in Rail, Marine, and over-the-road use
- Tanks are surrounded by a metal frame

Tube Tank

Inter-Modal Containers

Key Databases

Pipeline and Hazardous Material Safety Administration Hazardous Material Database

- Accidents reported by motor carriers resulting in at least one of the following:
  - A fatality or injury
  - Unintentional release of hazardous material
  - Evacuation
  - Closure of a highway, main road or secondary road
  - For cargo tanks of at least 1,000 gallons, at least $500 in damages to the lading retention system

* Information in the following section was obtained from: U.S. DOT PHMSA "Guide for Preparing Hazardous Materials Incidents Reports" Revised January 2004.

PHMSA Hazardous Material Database

25. See instructions and enter the appropriate failure codes found at the end of the instructions. Be sure to enter the codes from the list that corresponds to the particular packaging type checked above. Enter the number of codes as appropriate to describe the incident. Enter the most important failure point in line 1. If there are more than two failure points, provide in this format in part VI.

1. What Failed: ___ ___ ___ How Failed: ___ ___ ___ Causes of Failure: ___ ___ ___

2. What Failed: ___ ___ ___ How Failed: ___ ___ ___ Causes of Failure: ___ ___ ___

Failure Codes for Cargo Tank Motor Vehicles – What failed?	
101 Air Inlet	118 Flange
105 Bolts or Nuts	119 Frangible Disc
106 Bottom Outlet Valve	120 Fusible Pressure Relief Device or Element
107 Check Valve	121 Gasket
110 Cover	122 Gauging Device
115 Discharge Valve or Coupling	123 Heater Coil
116 Excess Flow Valve	124 High Level Sensor
117 Fill Hole	125 Hose

* Question #25 is an excerpt from form 5800.1

PHMSA Hazardous Material Database

Failure Codes for Cargo Tank Motor Vehicles – What Failed?	
126 Hose Adaptor or Coupling	137 Manway or Dome Cover
127 Inlet (Loading) Valve	138 Mounting Studs
131 Lifting Lug	139 O-Ring or Seals
132 Liner	141 Piping or Fittings
133 Liquid Line	142 Piping Shear Section
134 Liquid Valve	143 Pressure Relief Valve or Device - Non-Reclosing
135 Loading or Unloading Lines	144 Pressure Relief Valve or Device - Reclosing
136 Locking Bar	145 Remote Control Device

PHMSA Hazardous Material Database

Failure Codes for Cargo Tank Motor Vehicles – What failed?	
146 Sample Line	155 Valve Seat
148 Sump	156 Valve Spring
150 Tank Shell	157 Valve Stem
151 Thermometer Well	158 Vapor Valve
152 Threaded Connection	159 Vent
153 Vacuum Relief Valve	160 Washout
154 Valve Body	161 Weld or Seam

PHMSA Hazardous Material Database

25. See instructions and enter the appropriate failure codes found at the end of the instructions. Be sure to enter the codes from the list that corresponds to the particular packaging type checked above. Enter the number of codes as appropriate to describe the incident. Enter the most important failure point in line 1. If there are more than two failure points, provide in this format in part VI.

1. What Failed: ___ ___ ___ How Failed: ___ ___ ___ Causes of Failure: ___ ___ ___
2. What Failed: ___ ___ ___ How Failed: ___ ___ ___ Causes of Failure: ___ ___ ___

Failure Codes for Cargo Tank Motor Vehicles – How Failed?	
301 Abraded	307 Gouged or Cut
302 Bent	308 Leaked
303 Burst or Ruptured	309 Punctured
304 Cracked	310 Ripped or Torn
305 Crushed	311 Structural
306 Failed to Operate	312 Torn Off or Damaged

PHMSA Hazardous Material Database

25. See instructions and enter the appropriate failure codes found at the end of the instructions. Be sure to enter the codes from the list that corresponds to the particular packaging type checked above. Enter the number of codes as appropriate to describe the incident. Enter the most important failure point in line 1. If there are more than two failure points, provide in this format in part VI.

1. What Failed: ___ ___ ___ How Failed: ___ ___ ___ Causes of Failure: ___ ___ ___
2. What Failed: ___ ___ ___ How Failed: ___ ___ ___ Causes of Failure: ___ ___ ___

Failure Codes for Cargo Tank Motor Vehicles – Causes of Failure?	
501 Abrasion	507 Corrosion - Interior
502 Broken Component or Device	508 Defective Component or Device
503 Commodity Self-ignition	510 Deterioration or Aging
504 Commodity Polymerization	511 Dropped
505 Conveyer or Material Handling Equipment Mishap	512 Fire, Temperature, or Heat
506 Corrosion - Exterior	515 Human Error

PHMSA Hazardous Material Database

Failure Codes for Cargo Tank Motor Vehicles – How Failed?	
517 Improper Preparation for Transportation	525 Incorrectly Sized Component or Device
518 Inadequate Accident Damage Protection	526 Loose Closure, Component, or Device
519 Inadequate Blocking and Bracing	527 Misaligned Material, Component, or Device
520 Inadequate Maintenance	519 Inadequate Blocking and Bracing
521 Inadequate Preparation for Transportation	520 Inadequate Maintenance
522 Inadequate Procedures	521 Inadequate Preparation for Transportation
523 Inadequate Training	522 Inadequate Procedures
524 Incompatible Product	523 Inadequate Training

PHMSA Hazardous Material Database

Failure Codes for Cargo Tank Motor Vehicles – How Failed?	
524 Incompatible Product	530 Overpressurized
525 Incorrectly Sized Component or Device	531 Rollover Accident
526 Loose Closure, Component, or Device	532 Stub Sill Separation from Tank (Tank Cars)
527 Misaligned Material, Component, or Device	533 Threads Worn or Cross Threaded
528 Missing Component or Device	536 Vandalism
529 Overfilled	537 Vehicular Crash or Accident Damage

Federal Motor Carrier Safety Administration (FMCSA) Motor Carrier Management Information System (MCMIS)

- Populated by state police crash reports involving vehicles of motor carriers operating in the U.S.
- Separate reports are entered for each commercial motor vehicle involved in a crash.
  - Reports are distinguished by the Crash Report Number field.
- Each report contains about 80 data elements pertaining to the motor carrier, driver, vehicles, and circumstances of a crash.
- Data is stored in four sets:
  – Crash Master Table
  – Crash Carrier Table
  – Crash Driver Table
  – Crash Event Table

FMCSA – MCMIS Database

- Crash Master Table
  - Includes details about the vehicles involved in the crash, the location of the crash, environmental conditions at the time of the crash and if there were fatalities or injuries.
  - Includes the following fields associated with Hazardous Materials:
    - Vehicle Hazmat Placard (Yes/No)
    - Vehicle Hazmat Number
    - Vehicle Hazmat Material
    - Vehicle Hazmat Class ID (1 through 8) and
    - Hazmat Released (Yes/No)

FMCSA – MCMIS Database

- Crash Carrier Table
  - Includes details about the motor carrier.
- Crash Driver Table
  - Includes details about driver. This table is not available to the general public
- Crash Event Table
  - Includes details about the event that caused the crash. Crash event options are included in the following slide.

FMCSA – MCMIS Crash Event Options

1 = Non collision ran off road	12 = Collision involving pedestrian
2 = Non collision jackknife	13 = Collision involving motor vehicle in transport
3 = Non collision overturn (rollover)	14 = Collision involving parked motor vehicle
4 = Non collision downhill runaway	15 = Collision involving train
5 = Non collision cargo loss or shift	16 = Collision involving pedalcycle
6 = Non collision explosion or fire	17 = Collision involving animal
7 = Non collision separation of units	18 = Collision involving fixed object
8 = Non collision cross median/centerline	19 = Collision with work zone maintenance equipment
9 = Non collision equipment failure (brake failure, blown tires, etc.)	20 = Collision with other movable object (Substitutes for previous "Collision involving other object")
10 = Non collision other	21 = Collision with unknown movable object
11 = Non collision unknown	98 = Other

National Highway Traffic Safety Administration (NHTSA) General Estimates System (GES)

- Obtains its data from a nationally representative probability sample selected from the estimated 6.3 million police-reported crashes which occur annually.
- Includes crashes resulting in a fatality or injury or major property damage
- Provides data about all types of crashes involving all types of motor vehicles including:
  - Highway safety problem areas
  - A basis for regulatory and consumer information initiatives
  - The basis for cost and benefit analyses of highway safety initiatives

* NHTSA GES information obtained from National Automotive Sampling System (NASS) General Estimates System (GES) Analytical User's Manual (1988 – 2003). Report accessed at: ftp://ftp.nhtsa.dot.gov/GES/Ges_Doc/

NHTSA - GES

- Crashes occurring in the same survey year have an equal chance of being selected.
  - National estimates and probable errors associated with the estimates can be calculated.
- Three stage selection process:
  - Stage 1: Primary Sampling Units (PSUs)
    - Sample of 1,195 geographic areas grouped into 14 categories
  - Stage 2: Selection of Police Jurisdictions
    - Probability sample of jurisdictions in each PSU weighted based on number of crashes investigated
  - Stage 3: Selection of Police Accident Reports (PARs)
    - PARs are stratified by the data collector into 6 groups

NHTSA - GES

Data is stored in four sets :

- Accident Data Set
  - Crash characteristics and environmental conditions at the time of the crash.
- *Vehicle/Driver Data Set*
  - *Information describing the vehicles and drivers* involved in the crash.
- *Person Data Set*
  - Age, sex, and vehicle occupant restraint use, and injury severity of each person involved in the crash.
- The *Event Data Set*
  - *A brief description of each harmful event in a crash including* the vehicles or objects involved and the general area of vehicle damage. The most harmful event is identified.

Key Takeaways

INTRODUCTION TO HIGHWAY SAFETY MANUAL (HSM)

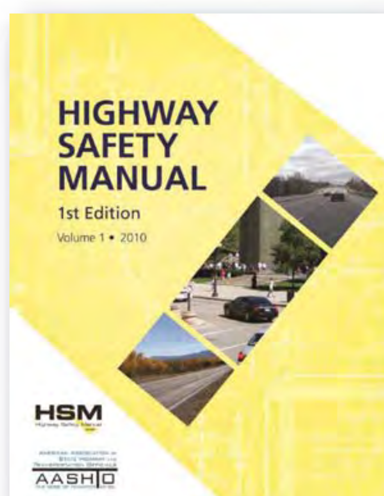
CEE498 TSR -Transportation Safety and Risk

Dr. Rapik Saat, Ph.D.

Rail Transportation and Engineering Center – RailTEC

Department of Civil & Environmental Engineering

University of Illinois at Urbana-Champaign, U.S.A.

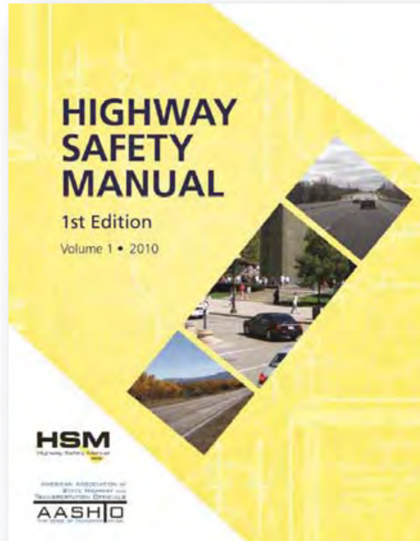


RAILTEC
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

Learning Outcomes

HSM:

- Purpose
- Audience
- Structure
- Benefits



Learning Outcomes

HSM:

- Purpose
- Audience
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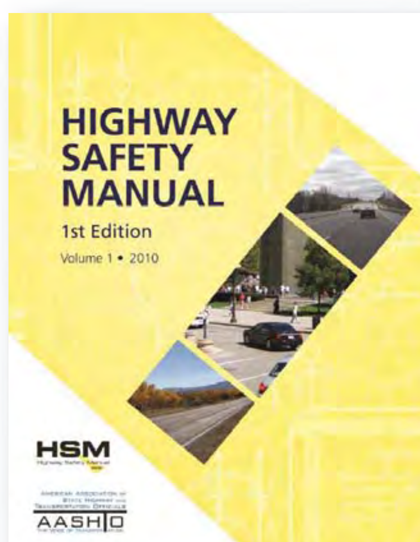
- Benefits



HSM Provides Methods for Developing Effective Roadway Safety Management Program

- Identifying sites with potential for safety improvement
- Diagnosing conditions at the site
- Evaluating conditions and identifying potential treatments at the sites
- Prioritizing and programming treatments
- Evaluating the effectiveness at reducing crashes of the programmed treatments

HSM Provides Predictive Method to Estimate Crash Frequency and Severity

- To make informed decisions throughout the project development process:
  - Planning
  - Design
  - Operations
  - Maintenance
- E.g. screening potential locations for improvement and choosing alternative roadway designs

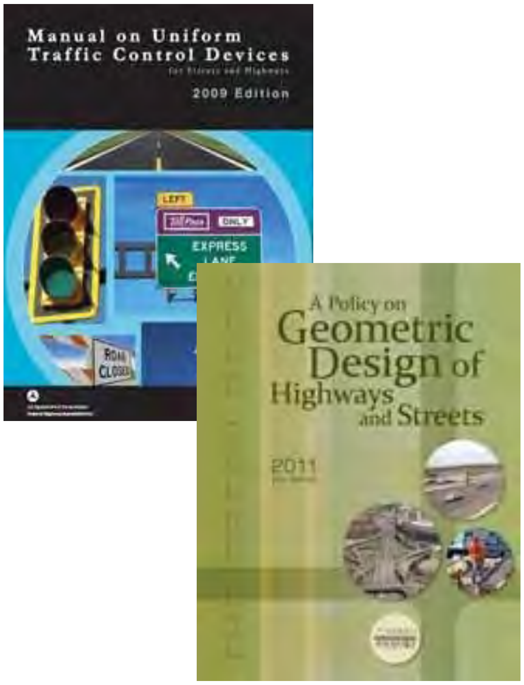
HSM Provides A Catalog of Crash Modification Factors (CMFs)

- Include a variety of geometric and operational treatment types
- Developed using high-quality before/after studies

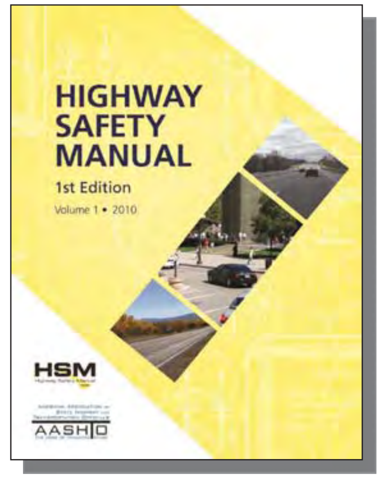
How is the HSM Applied?

- Identifying sites with the most potential for crash frequency or severity reduction
- Identifying factors contributing to crashes and associated potential countermeasures to address these issues
- Conducting economic appraisals of potential improvements and prioritizing projects
- Evaluating the crash reduction benefits of implemented treatments
- Estimating potential effects on crash frequency and severity of planning, design, operations, and policy decisions

The HSM and Other Documents



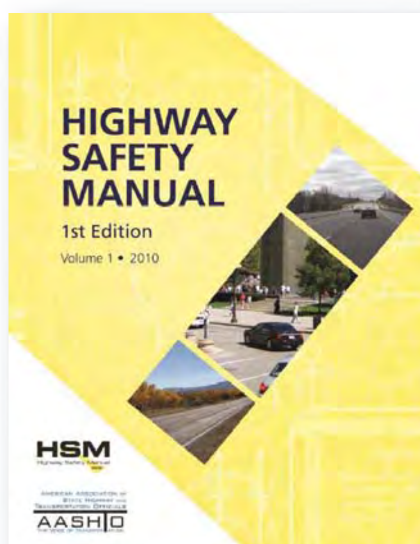
Versus



Learning Outcomes

HSM:

- Purpose
- Audience
- Structure
- Benefits



HSM Audiences

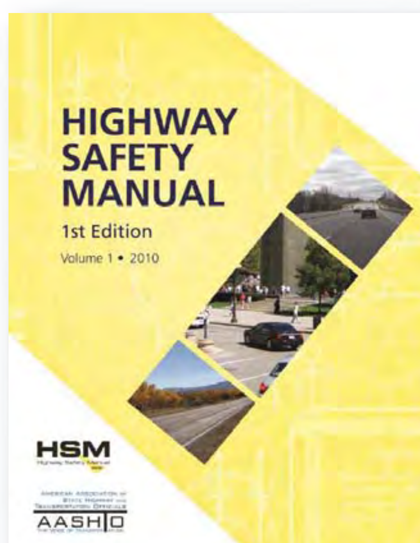
- Practitioners at the state, county, metropolitan planning organization (MPO), or local level
  - Such as?

ILLINOIS - RAILTEC

Learning Outcomes

HSM:

- Purpose
- Audience
- **Structure**
- Benefits



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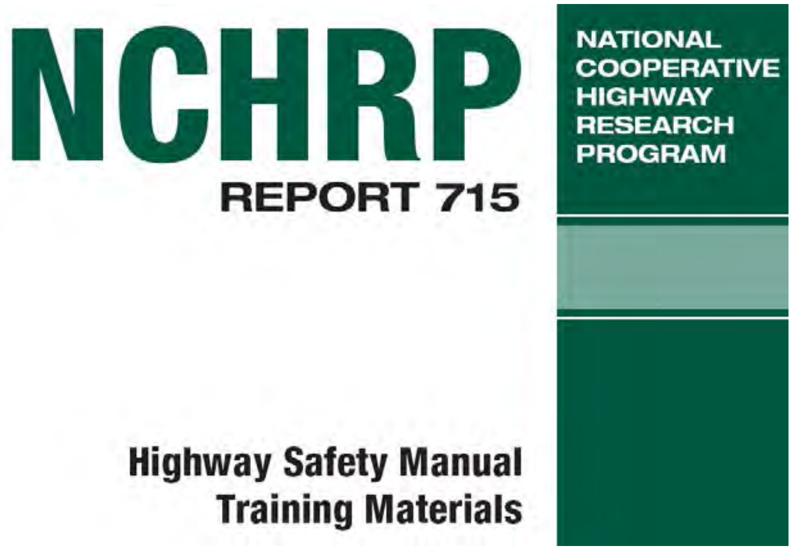
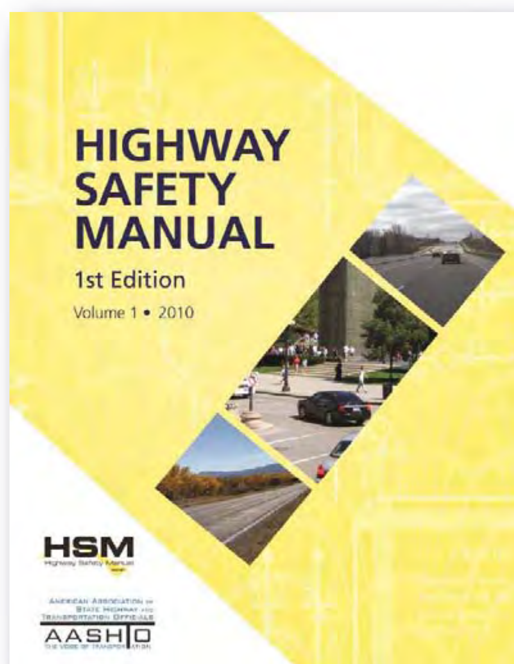
Key Educational Resource



http://www.trb.org/Main/Blurbs/167185.aspx

HSM

Content and Structure



HSM
Highway Safety Manual

Vol. 1 (Part A)
Introduction
Human Factors
Fundamentals

Vol. 3 (Part D)
Crash Modification Factors (CMFs)

Vol. 1 (Part B)
Roadway Safety Management Process

Vol. 2 (Part C)
Predictive Method

Part A | Part B | Part C | Part D

- Introduction and Overview (Ch. 1)
- Human Factors (Ch. 2)
- Fundamentals (Ch. 3)

HSM Vol. 1 (Part A) Knowledge Building

- Professional staff and consultants
- Safety partners (law enforcement, medical)
- External stakeholders
- General public
- Elected officials

HSM Highway Safety Manual

Vol. 1 (Part A) Valuable Safety Education

- Road Safety Audit expertise
- Design engineers and traffic engineers
- Public information programs for projects

- Vol. 1 (Part A) - Chapter 3
  - Highway and traffic safety fundamentals
  - Common definitions, terminology
- Vol. 1 (Part A) - Chapter 2
  - Human factors safety fundamentals

HSM Highway Safety Manual

Road Safety Management Process

- Part A
- **Part B**
- Part C
- Part D

1. Network Screening (Ch. 4)
2. Diagnosis and Countermeasure Selection (Ch. 5 & 6)
3. Economic Appraisal and Prioritization (Ch. 7 & 8)
4. Safety Effectiveness Evaluation (Ch. 9)

HSM Highway Safety Manual

Vol. 1 (Part B) Programming and Policy Implementation

- Identification of sites for potential crash reduction
- Crash pattern analysis
- Best solutions
- Resource allocation
- Measuring success
- Improvement over time

1. Network Screening
2. Diagnosis and Countermeasure Selection
3. Economic Appraisal and Prioritization
4. Safety Effectiveness Evaluation

HSM Highway Safety Manual

Part A
Part B
Part C
Part D

Predictive Methods

- Methodology
  - Safety Performance Functions
  - Crash Modification Factors
  - Calibration
- Applications
- Example problems
- References

HSM
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Part A
Part B
Part C
Part D

Part C Facilities

- Rural Two-lane Roads (Ch. 10)

- Rural Multi-lane Roads (Ch. 11)

- Urban Suburban Arterials (Ch. 12)

HSM
Highway Safety Manual

Part A

Part B

Part C

Part D

Predictive Methods

Common Procedures Appendix:

- Calibrating predictive methods
- Empirical Bayes -combining predicted with observed crashes

Part A

Part B

Part C

Part D

Crash Modification Factors

- Roadway segments (Ch. 13)
- Intersections (Ch. 14)
- Interchanges (Ch. 15)
- Special facilities and geometric situations (Ch. 16)

Vol. 2 (Part C) and Vol. 3 (Part D) Project Development



Two-Lane to Four-Lane Corridor Studies

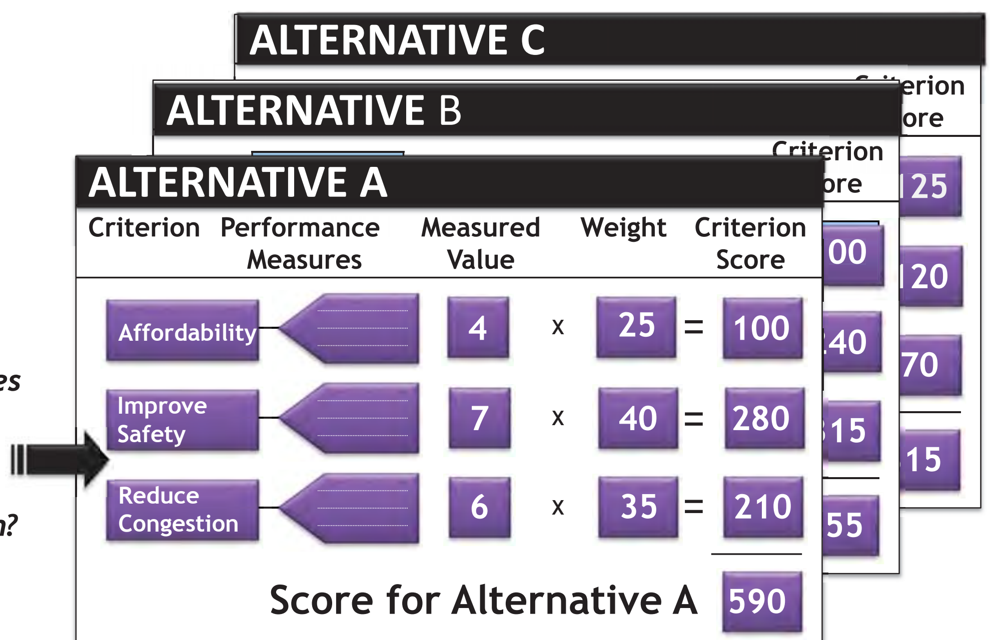
- Vol. 2 (Part C) -- Chapter 10
  - Establish purpose and need
  - Assess performance of 'no-build'
- Vol. 2 (Part C) – Chapter 11
  - Evaluate and compare safety performance of alignment and cross section alternatives
  - Estimate performance of the preferred 'build'
  - Calculate benefits (crash reductions) of preferred

Urban Arterial Corridor Studies

- Vol. 2 (Part C) -- Chapter 12
  - Establish purpose and need
  - Assess safety performance of 'no-build'
- Vol. 2 (Part C) - Chapter 12
  - Evaluate safety performance of cross section and access alternatives
  - Estimate safety performance of preferred 'build'
  - Calculate benefits (crash reductions) of preferred versus no-build

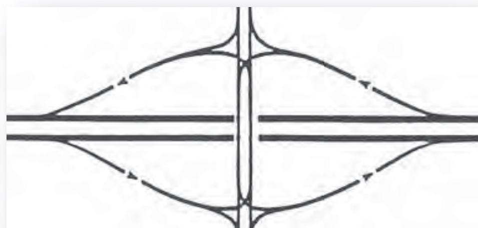
Multi-Objective Resource Allocation Decision Tool for Complex Projects

Where does the input for this criterion come from?

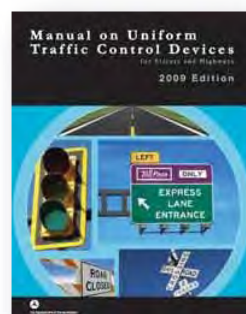


Interchange Warrant Studies (Rural Multilane Highways)

- Vol. 2 (Part C) - Chapter 11
  - Establish purpose and need
  - Assess performance of 'no-build'
- Vol. 3 (Part D) – Chapter 15
  - Estimate conversion performance
  - Estimate performance of preferred 'build'
  - Calculate conversion benefits (crash reductions)



Intersection Signal Warrant Program Implementation



- Vol. 1 (Part B)
  - Prioritize warranted signal implementation
- Vol. 2 (Part C) and Vol. 3 (Part D)
  - Confirm positive benefits of implemented signals; including alternative phasing plans
  - Compare signalization with roundabout implementation for warranted locations

Rural Highway Safety Program Development and Implementation

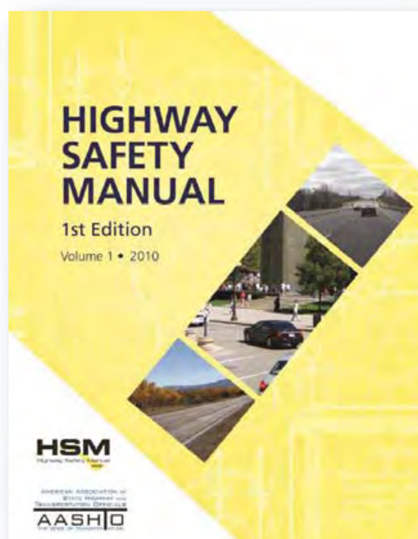
- Rumble strip applications
- Cable median barrier implementation
- Shoulder paving and improvement initiatives
- Guardrail upgrade programs

- Vol. 1 (Part B)
  - Chapter 4 - screen network (e.g., 5% locations) for candidate sites
  - Chapters 5 and 6 - estimate countermeasure effectiveness
  - Chapters 7 and 8 - program and prioritize
  - Chapter 9 - validate and improve program
- Vol. 3 (Part D)
  - Chapter 14 - effectiveness of Intersection-related programs
  - Chapter 15 - effectiveness of road segment related programs

Learning Outcomes

HSM:

- Purpose
- Audience
- Structure
- Benefits



The Value of the HSM

- Provides proven and vetted science-based approach to quantifying safety effects of decisions and actions we contemplate
- Provides common knowledge base, language and basis for reasoned safety judgments
- Allows incorporation of safety to same level of importance as other factors
- Does not increase risk of tort liability

It does not force or require you to do anything, it merely helps you do a better job

Companion Software and Websites

HSM Part	Supporting Tool
Part B: Roadway Safety Management Process	**SafetyAnalyst** www.safetyanalyst.org
Part C: Predictive Methods	**IHSDM** www.ihsdm.org
Part D: Crash Modification Factors	**FHWA CRF/CMF Clearinghouse** www.cmfclearinghouse.com

Resources and Contacts

- **HSM Website** www.highwaysafetymanual.org
- **AASHTO**
  - Kelly Hardy: khardy@aashto.org
- **AASHTO Joint Task Committee for the HSM**
  - Don Vaughn, ALDOT, vaughnd@dot.state.al.us
  - Priscilla Tobias, IDOT, Priscilla.Tobias@illinois.gov
- **FHWA**
  - Mike Griffith, mike.griffith@dot.gov
  - Ray Krammes, Ray.Krammes@dot.gov
- **TRB Highway Safety Performance Committee**
  - John Milton, WSDOT, miltonj@wsdot.wa.gov

HSM Vol. 1 (Part A): Chapters 2 & 3

MODULE 2.
HSM FUNDAMENTALS AND TERMS

Learning Outcomes

Overview of HSM key concepts:

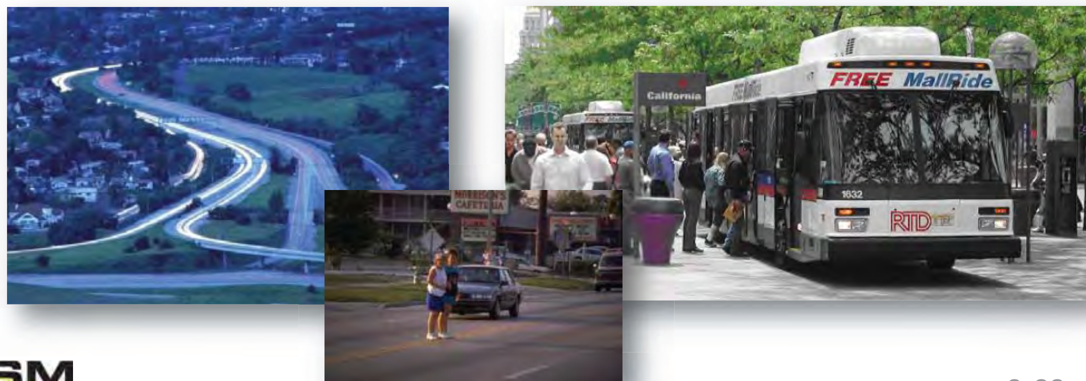
- Measuring safety by crashes
- Data needs
- Evolution of crash estimation methods
- Predictive methods
- Evaluating safety effectiveness

What is Safety?

The HSM uses crashes as a *measure of safety*

Measuring Safety

SUBJECTIVE SAFETY	OBJECTIVE SAFETY
• Perception • Values vary among observers	• Quantifiable • Independent of the observer



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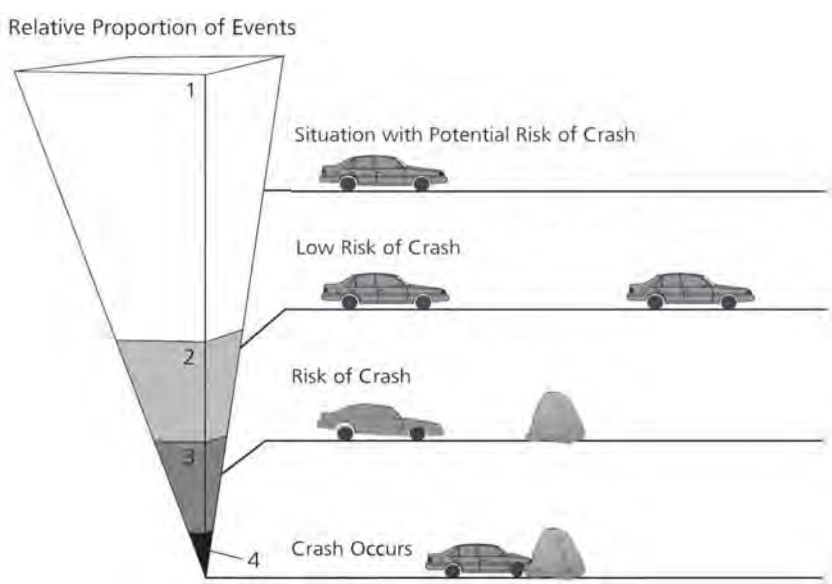
Crashes

Random Events

Rare Events

Relative Proportion of Crash Events



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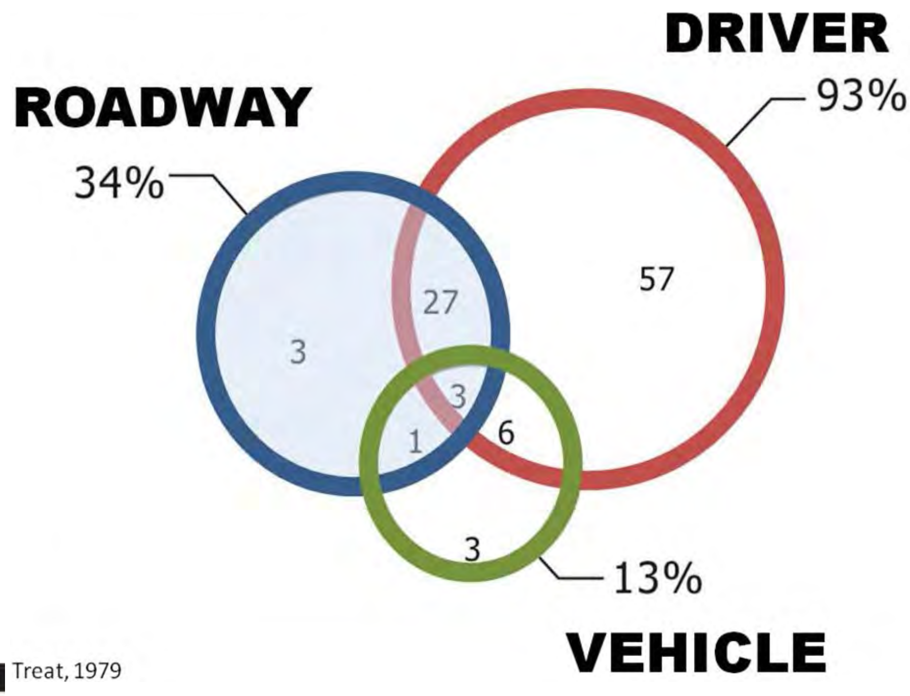
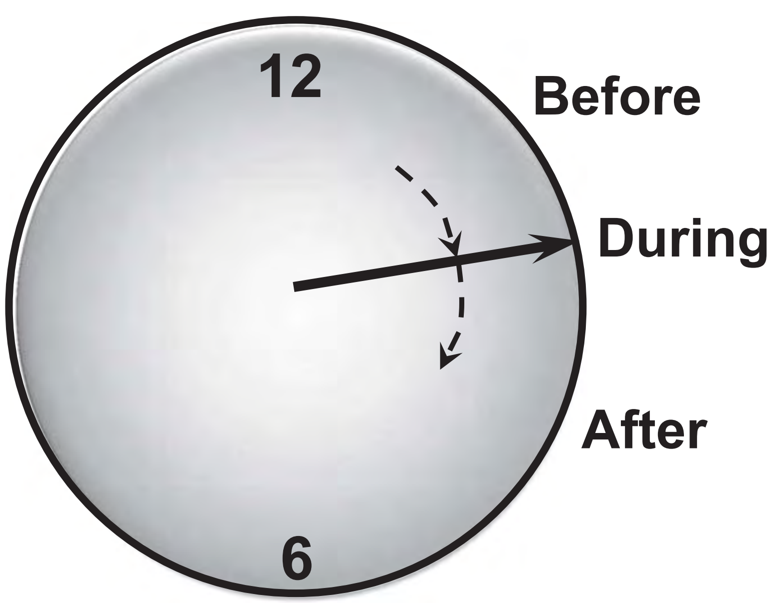
Contributing Factors



Treat, 1979

Crash Events



Haddon Matrix

PERIOD	Contributing Factor		
	Human	Vehicle	Environment
Before crash			
During crash			
After crash			

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K

A

B

C

O

Crash Severity Categories in the HSM

K
A
B
C
O

K crash

One or more persons died within 30 days of the crash

K
A
B
C
O

A crash

Incapacitating injury

K
A
B
C
O

B crash

Non-incapacitating evident injury

K
A
B
C
O

C crash

Possible injury

K
A
B
C
O

O crash

No injuries - reportable property damage resulted from crash

K
A
B
C
O

Crash Severity

Most severe injury controls level of crash severity

Crash Frequency

$$\frac{\text{Number of Crashes}}{\text{Number of Years}}$$

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Crash Estimation

Forecast / Predict Crash Frequency

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Predictive Methods - Part C

Estimate
"*expected average crash frequency*"

given

a specific geometric design, traffic volumes, and a given time period

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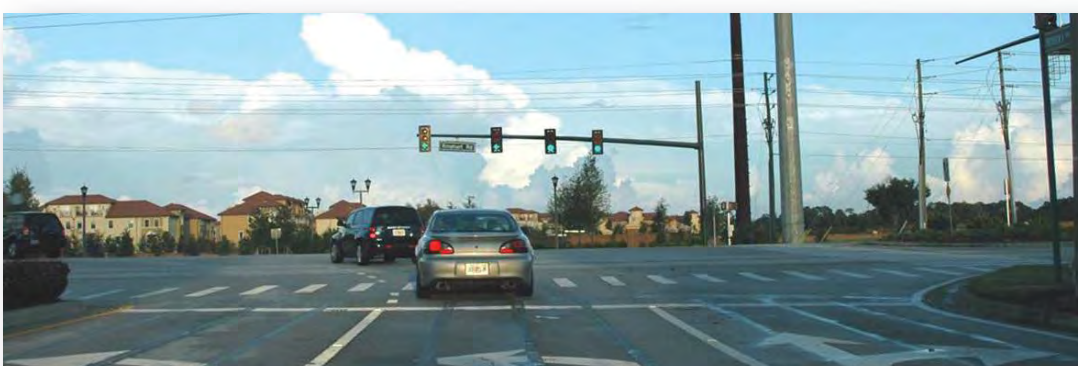
Expected Average Crash Frequency



Crash Frequency = Short Term Measure

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Crash Evaluation

Effectiveness After Implementation

Data Needs

1. Crash data
2. Facility data
3. Traffic volume data

Data Needs Guide

NCHRP Research Results Digest 329

June 2008

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Responsible Senior Program Officer: Charles W. Niessner

Research Results Digest 329

HIGHWAY SAFETY MANUAL DATA NEEDS GUIDE

This digest presents a summary of the data needed to use the methodologies in Part C of the 1st edition of the *Highway Safety Manual*. The TRB Task Force on Development of the Highway Safety Manual initiated and guided the work. Douglas W. Harwood, Midwest Research Institute, conducted the project.

SUMMARY

The purpose of this guide is to help potential users of the 1st edition of the *Highway Safety Manual* (HSM) anticipate the data needs for using the HSM. The guide focuses on the data needed to use the HSM Part C methodologies for rural two-lane highways, rural multilane highways, and urban and suburban arterials. The guide provides information for HSM users to assess whether their existing data sources contain the data needed to apply the HSM safety prediction methodologies to highways of interest.

HSM OVERVIEW

The HSM represents an effort to identify and assemble the best currently available information on safety and the provision of measures of performance, prediction, and evaluation of highway safety. The information in the HSM is intended to assist highway agencies in all aspects of safety decisionmaking during policymaking, planning, programming, project development, construction, maintenance, and operational activities.

Recent advancement in the science of safety analysis, safety impact prediction, and improved understanding of the statistical nature of crashes has led to significant gains in safety knowledge. Coupled with new analytical tools, these advancements make it possible to produce usable estimates of the impact of geometric design elements, safety-related planning, and traffic operations on the frequency and severity of crashes.

The HSM provides analytical tools that facilitate the inclusion of safety considerations in roadway planning, design, operational, and maintenance decisions based on intended safety performance. While highway safety information changes on a continual basis, the HSM is intended to provide accepted knowledge, methods, and processes usable by the highway safety community at the time of publication.

The HSM will consist of four parts:

- Part A: Introduction and fundamentals;
- Part B: Roadway safety management process;
- Part C: Predictive methods—tools for safety prediction of rural two-lane highways, rural multilane highways, and urban and suburban arterials; and
- Part D: Accident modification factors.

The HSM is designed for a wide audience of users and does not override or supersede state and local design manuals or any other related guidance documents in use by transportation authorities. Information, processes, and procedures contained

TRANSPORTATION RESEARCH BOARD

HSM Highway Safety Manual

National Programs

Crash Data	Roadway Data
MMUCC	**MIRE**
www.mmucc.us	www.mireinfo.org

HSM Highway Safety Manual

Observed Crash Data Limitations

1. Quality and accuracy
2. Reporting thresholds
3. Severity indeterminacy
4. Jurisdiction differences

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Limitation: Randomness and Change

1. Natural crash frequency variation
2. Roadway variations
3. Crash frequency variability and changing site conditions
4. Regression-to-the-mean and bias

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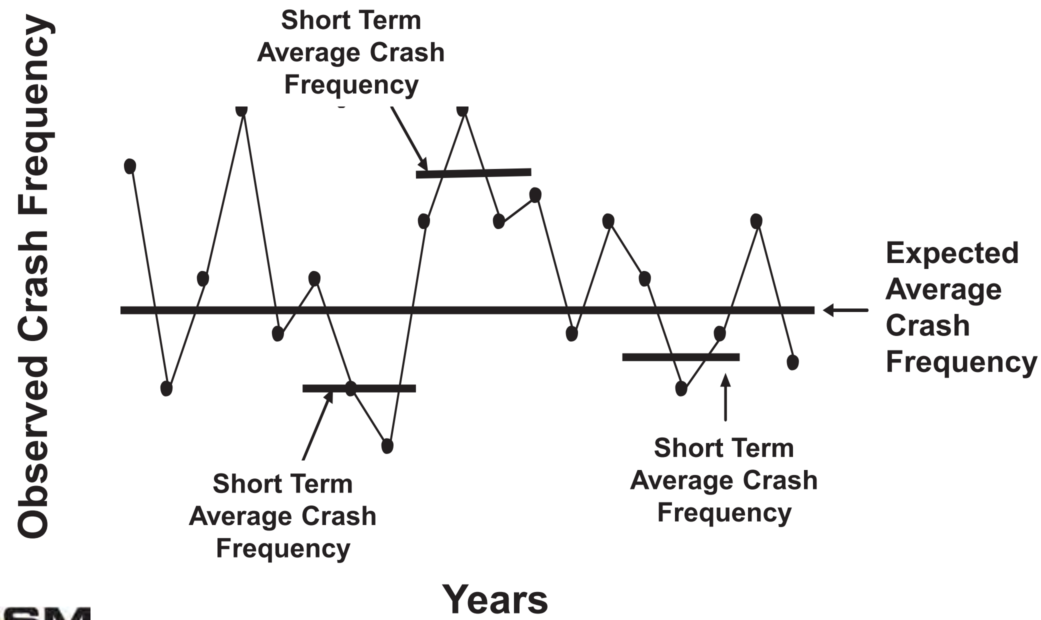
Natural Variability in Crash Frequency

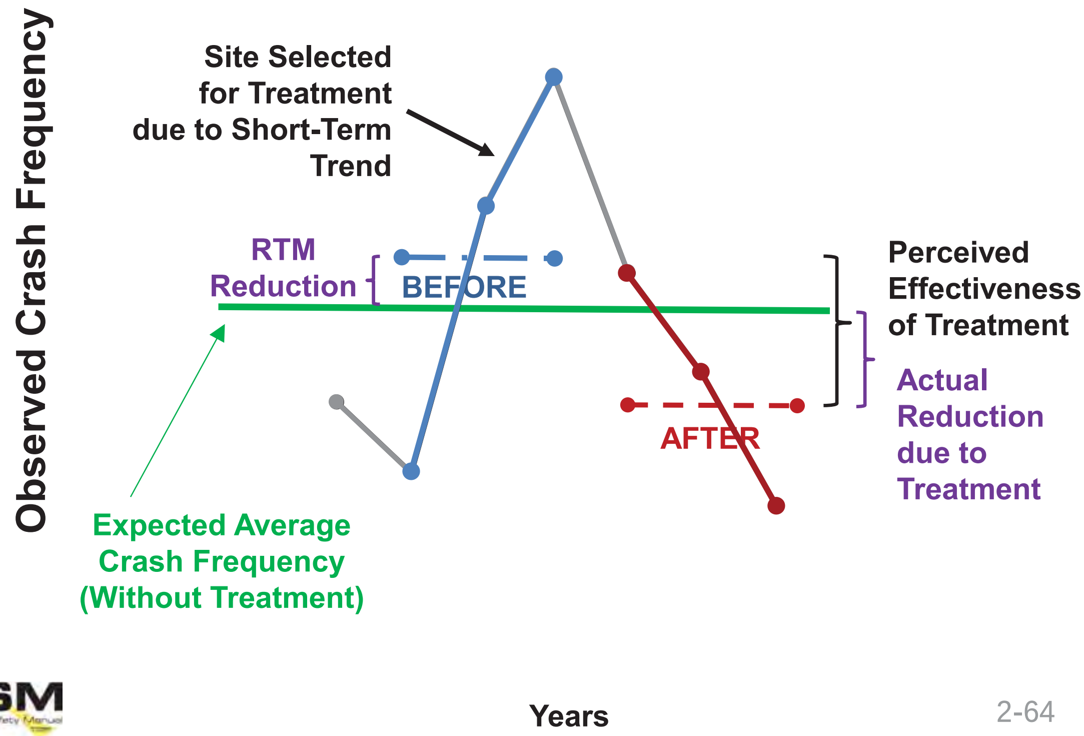


Regression-to-the-Mean (RTM)

RTM Bias

If we do not account for RTM, we cannot say the crash difference is due to the treatment

RTM Example



Roadway and Environment Variation

Consider Site Changes Over Time:

- Traffic volume
- Weather
- Traffic control
- Geometric design

Crash Frequency Variability

Conflicts with Changing Site Conditions:

Use predictive methods in Part C to estimate crash frequency

Evolution of Crash Estimation

Improvements in statistical sophistication and changes in thinking

Methods

1. Observed Crash Frequency and Crash Rate Methods

2. Indirect/ Surrogate Safety Measures

3. Statistical Methods

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1. Observed Crash Frequency and Crash Rate Methods

Crash Rate

$$\text{Crash Rate} = \frac{\text{Average Crash Frequency in a Period}}{\text{Exposure in the Same Period}}$$

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1. Observed Crash Frequency and Crash Rate Methods

- **Advantages**
  - Intuitive
  - Acceptance
  - Limited alternatives
- **Limitations**
  - Assumes a linear relationship between crash frequency and exposure
  - Inability to account for changes in geometric design and volumes and cannot compare design alternatives

HSM Highway Safety Manual

Example for Crash Rates

Before				After			
Year	No. Crashes	AADT	Rate	Year	No. Crashes	AADT	Rate
1988	13	2,900	2.11	1992	30	10,618	1.33
1989	11	2,900	1.79	1993	30	13,200	1.07
1990	13	3,050	2.01	1994	36	14,300	1.19
1991	23	3,400	3.19	1995	40	13,900	1.36
Average Rate = 2.28				Average Rate = 1.24			

Gambling Introduced in 1992

HSM Highway Safety Manual

Example Provided by Jake Kononov, Ph.D., P.E., Colorado DOT

Crash Rate Conclusion?

Before Gambling Average Rate = 2.28

Highway Alignment and Typical Cross-Section not Changed

After Gambling Average Rate = 1.24 but the Percent of Alcohol Related Crashes increased 500%

Possible Conclusion: Is Drinking and Driving in Concert with Gambling Good for Safety?

Probably Not but Crash Rates Say Otherwise

HSM Highway Safety Manual

Example Provided by Jake Kononov, P.E., Ph.D., Colorado DOT

2. Indirect/ Surrogate Safety Measures

- Based on events preceding crashes
- Presume causal link to expected crash frequency
- Conflict study
- Data are available but unproven relationship between surrogate measure and crash estimation

HSM Highway Safety Manual

3.

Statistical Methods

RTM Bias

3.

Statistical Methods

Reliably Estimate Expected Average Crash Frequency for:

- Existing projects
- Design projects

3.

Statistical Methods

Model Reliability - Function of:

- Original data “fit”
- Local data model calibration

3.

Statistical Methods

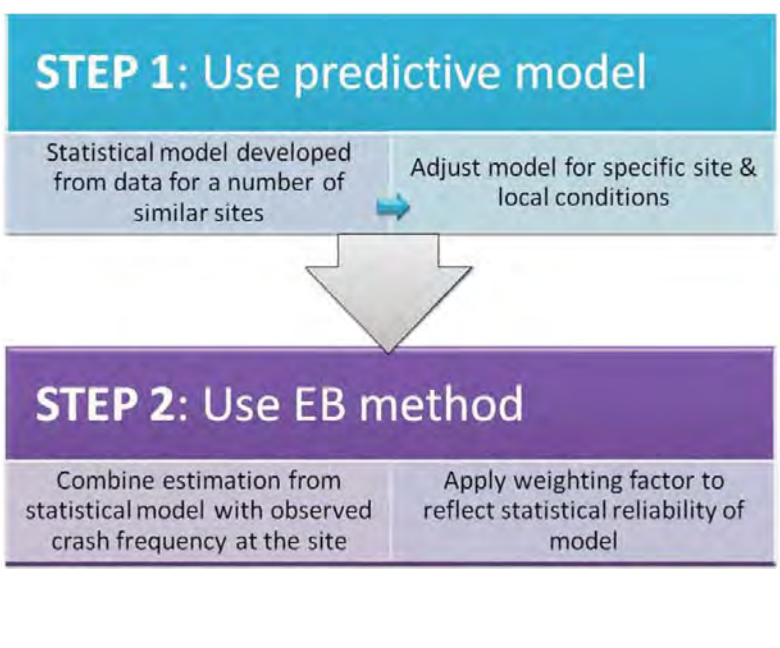
1. Empirical Bayes (EB)
2. Hierarchical Bayes
3. Full Bayes

Part C - Predictive Method

Content

- Overview
- SPFs
- CMFs and CRFs
- Calibration
- Weighting with EB
- Limitations

Predictive Method Elements



Predictive Method Advantages

- RTM bias
- Predictive relationships
- Non-linear relationship: crashes and exposure
- Negative binomial distribution

Base Condition

SPF Example Condition

- 2-lane rural highway
- 12-ft lanes
- 6-ft shoulders
- Level terrain
- Clear, level roadside

Safety Performance Function

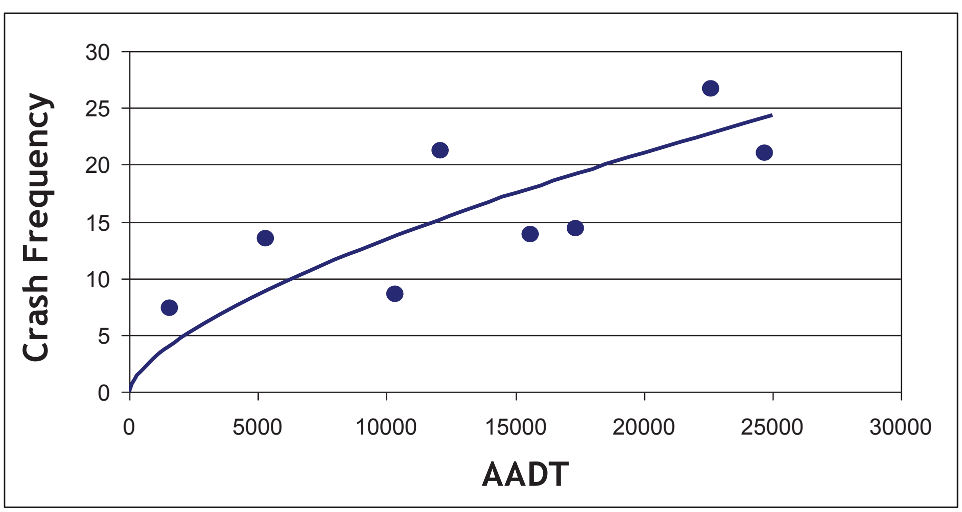
SPF

Product of Statistical Modeling Process

- Mathematical expression
- Used to estimate predicted average crash frequency for *base condition*

Crash-Volume Relationship

Can Be Non-Linear



SPFs

- Calibrate SPFs for LOCAL conditions
- Weight with EB Method

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Crash Modification Factor

CMF

Expected Crashes
= CMF x
(base condition crashes)

You can remember it as "M is for multiply"

$$CMF \cong \frac{Expected\ average\ crash\ frequency\ with\ condition\ 'b'}{Expected\ average\ crash\ frequency\ with\ condition\ 'a'}$$

HSM Highway Safety Manual

CMF Example

CMF = 0.90 Represents a 10% Reduction in Crashes

Expected crashes
= CMF x (base condition crashes)
= 0.9 x (base condition crash frequency)

HSM
Highway Safety Manual

CMF

Expressed as:

CMF ± SE

- SE = standard error
- Used to determine low, medium, and high confidence interval for CMF

HSM
Highway Safety Manual

CMF and Vol. 2 (Part C)

$$N_{predicted} \cong N_{SPF\ x} \partial (CMF_{1x} \partial CMF_{2x} \partial \ldots \partial CMF_{yx}) \partial C_x$$

- N_{SPF} = Estimated crash frequency from SPF for base condition
- CMF_{ix} = Crash modification factors
- C_X = Calibration factor

Apply CMF ONLY if:

- Known base conditions
- Setting and road type
- AADT range
- Crash type and severity

Crash Reduction Factor

CRF

- Portion crash frequency will reduce
- CRF=0.20 represents a 20% reduction in crashes
- For an initial crash count of 100, the average estimated crash count is 80 after installation

HSM
Statistical Methods Application

- Expected average crash frequency
- Calibration need
- Engineering judgment
- Crash data errors and limitations
- Development of SPFs and CMFs requires skill / knowledge

Effectiveness Evaluation

1. Observational before-after studies
2. Observational cross-sectional studies
3. Experimental before-after studies

Effectiveness Evaluation → Policy Development → Future Decision Making

Observational Before-After Study

Estimate expected average crash frequency for 'before' period

↓

Adjust for change in conditions in the 'after' period if the treatment had not been applied

↓

Result: Estimate the safety of the treatment

Observational Cross-Sectional Study

Compare sites with and without treatment over same time period

HSM
Highway Safety Manual

Key Takeaways

INTRODUCTION TO PIPELINE TRANSPORTATION SAFETY AND RISK

CEE498 TSR -Transportation Safety and Risk

Dr. Rapik Saat, Ph.D.

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Department of Civil & Environmental Engineering

University of Illinois at Urbana-Champaign, U.S.A.

Learning Outcomes

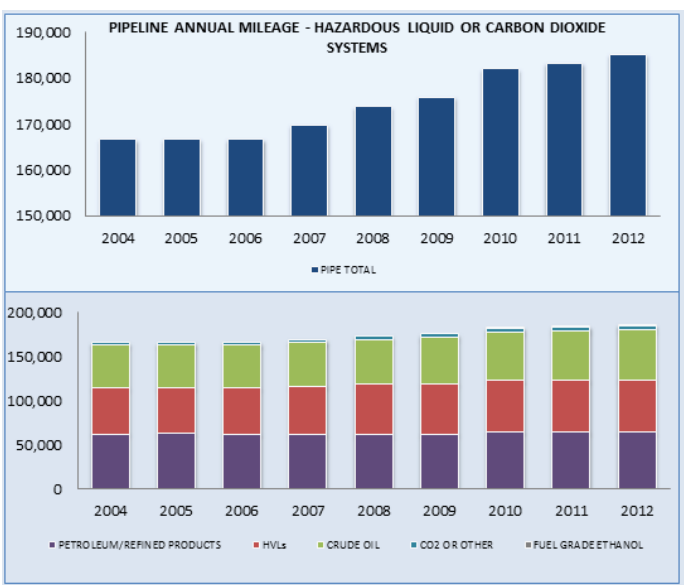
At the end of this lecture students will be able to:

1. Recognize the extent of pipeline transportation infrastructure in the U.S.
2. Identify pipeline release incident risk factors
3. Understand recent U.S. pipeline safety statistics

U.S. Pipeline Transportation Infrastructure

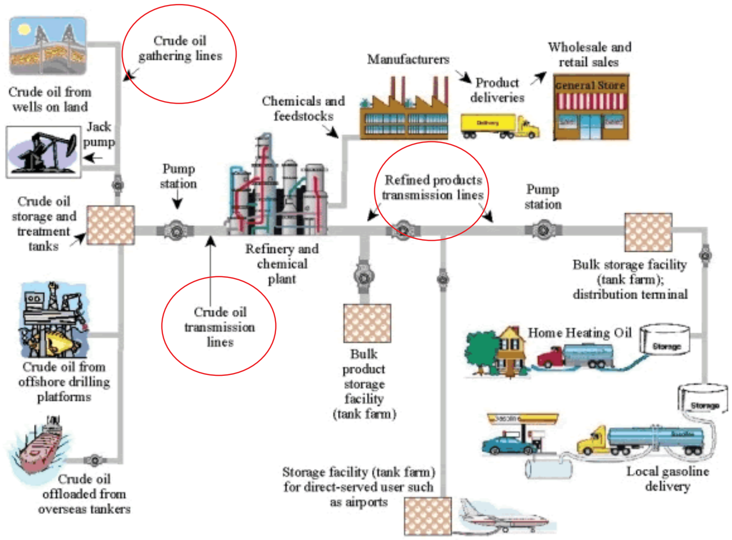
- The energy transportation network of the United States consists of over 2.5 million miles of pipelines
- Operated by approximately 3,000 companies, large and small.
- Based on data generated from annual reports to PHMSA from pipeline operators, the network includes approximately:
  - 182,000 miles of Hazardous Liquid and Carbon Dioxide pipelines
  - 325,000 miles of onshore and offshore Gas Transmission and Gathering Systems pipelines
  - 2,145,000 miles of Gas Distribution mains and services pipelines
  - 129 LNG Facilities connected to our gas transmission and distribution systems
  - Propane Distribution System pipelines.

Annual Report Mileage for Hazardous Liquid or Carbon Dioxide Systems



Source: PHMSA

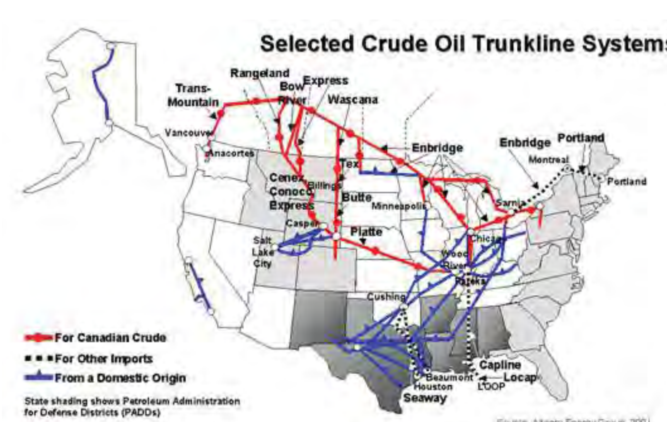
Petroleum Pipeline Systems

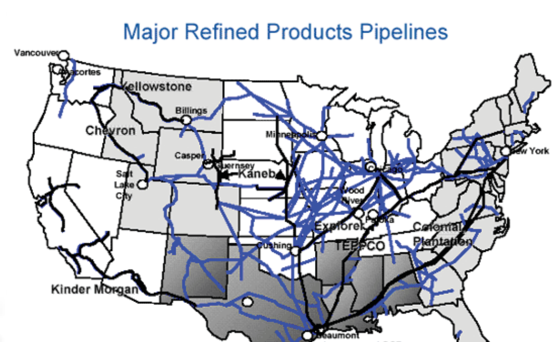


Source: PHMSA

U.S. Petroleum Pipeline Systems

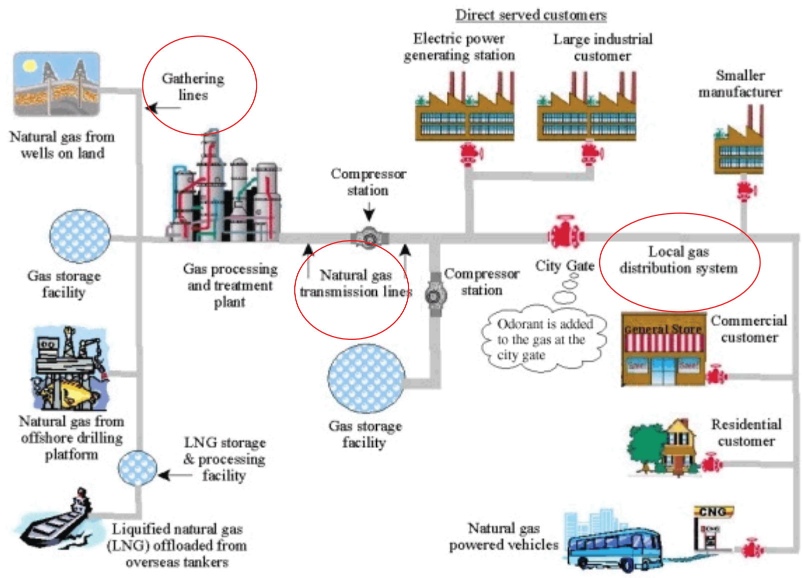
- The U.S. has 30,000 to 40,000 miles of small gathering lines (usually 2 to 6 inches in diameter) located primarily in Texas, Oklahoma, Louisiana, and Wyoming with small systems in a number of other oil producing states
- These small lines gather the oil from many wells, both onshore and offshore, and connect to larger trunk lines measuring from 8 to 24 inches in diameter
- There are approximately 95,000 miles nationwide of refined products pipelines (8 to 12 inch diameter lines up to 42 inches in diameter)





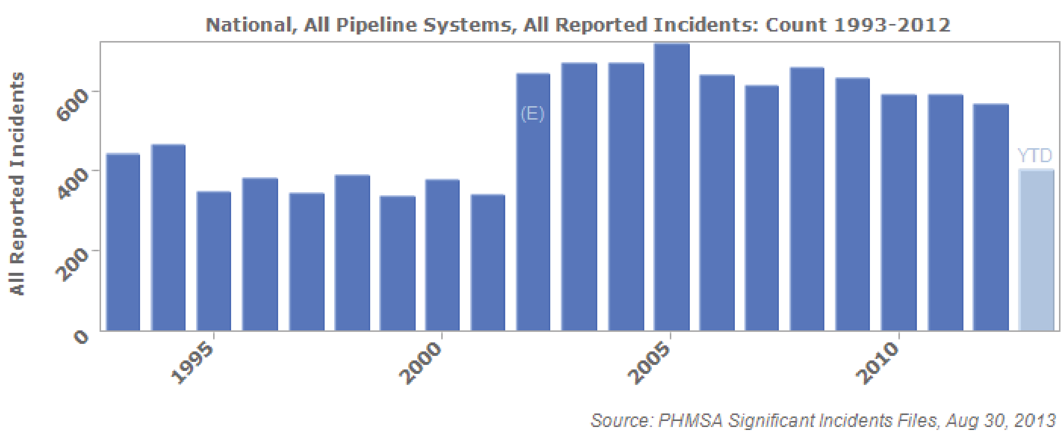
Source: Allegro Energy Group, 2001

Natural Gas Pipeline Systems



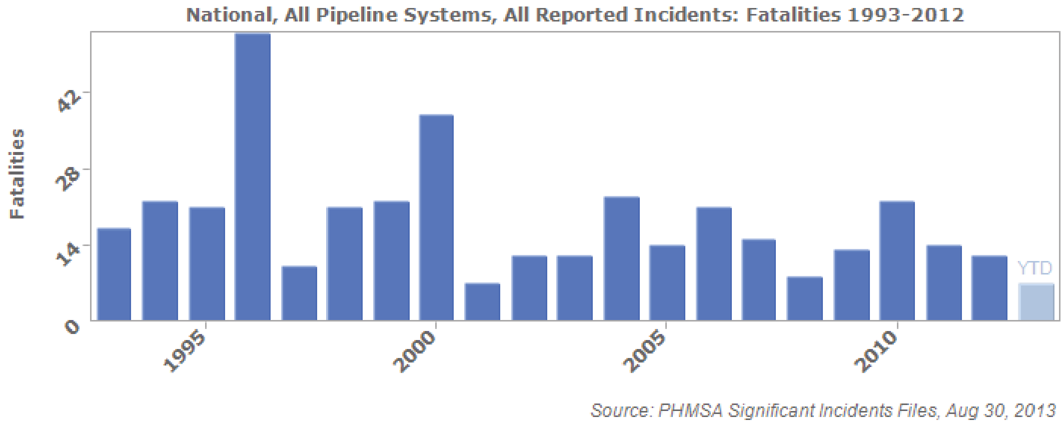
Source: PHMSA

U.S. Pipeline Reported Incidents



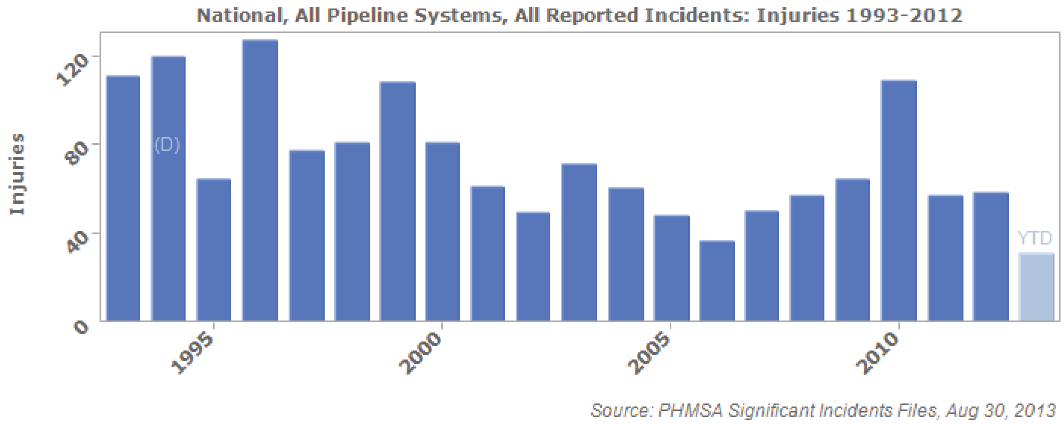
Source: PHMSA

U.S. Pipeline Reported Fatalities

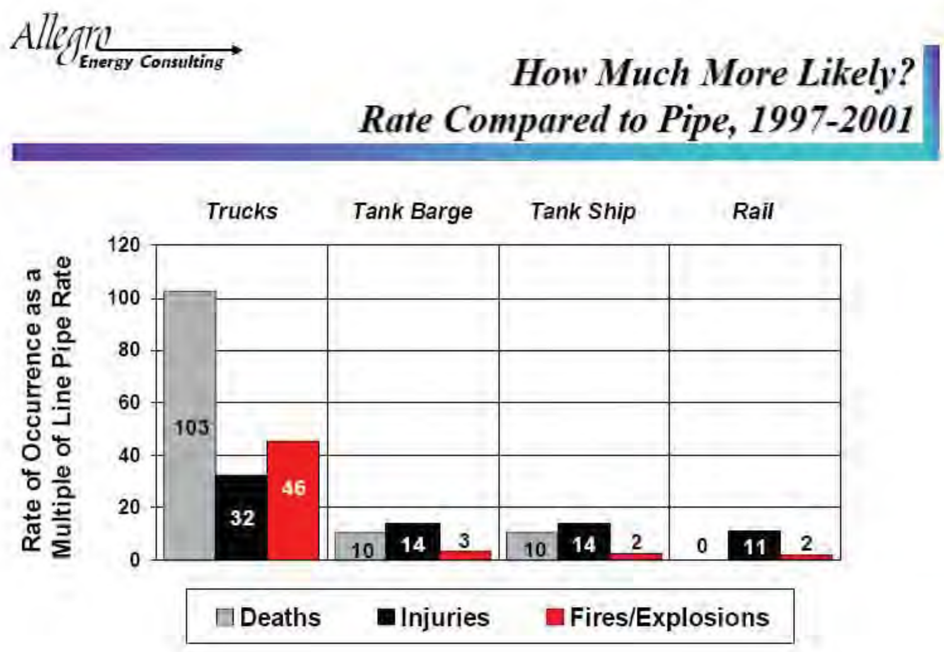


Source: PHMSA

U.S. Pipeline Reported Injuries



Source: PHMSA



Source: http://www.pipeline101.com/reports/Safety03.pdf

Pipeline Transportation Risk Analysis

CCPS 1995 – Chemical Transportation Risk Analysis

Pipeline Incidents - Initiating and Contributing Causes

Human errors	*Equipment failures*	*System or procedural failures*	*External events*
Pigging operations	Thermal expansion	Inspection	Accidental excavation
Hot tapping	Internal corrosion	Operation	Post digging
Slug operation	External corrosion	Startup/shutdown	Wind (above-ground lines)
Repair/replacement of a section of line	Bad welds	Communication	Earthquake
Startup	Fatigue	Maintenance	Subsidence
Changing operating conditions	Failure of cathodic protection	Leak detection	Avalanche
Shutdown	Cyclic stress	Emergency temporary repair	Flood/scouring
Preparation for maintenance	Galvanic corrosion	Material specification and testing	Lightning
Valve operation	Internal erosion	Modifications	Fire
	Control system failure		Vandalism/sabotage
	Brittle fracture		Freezing/thawing
	Support failure		Rail/road crossing (pipebridge or sleeved casing)
	Construction defects		Railroad derailment
	Overpressure		Mining
	Polymerization		Anchor dragging
	Plugging or fouling		Mooring pole

Pipeline Incidents – General Categories

- External mechanical interference
- Corrosion defects
- Material failure/construction defect
- Miscellaneous causes

Cause	*Rate Per 1000 Mile-Years* US[1]	Europe[2]
External mechanical interference	0.68	0.67
Corrosion	0.20	0.17
Material failure/construction defect	0.26	0.20
Other	0.10	0.08
Total	**1.25**	**1.12**

[1] Jones, 1986 (excluding 1983 data); Transportation Data Source 4-9
[2] European Gas Pipeline Incident Data Group, 1988; Transportation Data Source 4-14

Pipeline External Mechanical Interference

- Being damaged by excavators or other equipment in use by other utility or construction companies
- Damage following derailments on railroads
- Hot tap in error by other utilities
- Damage during deep plowing by farmers
- Damage during construction of land drainage
- Damage at river crossings by dragging of ships anchors
- Damage during the construction of barge pole moorings

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Pipeline Corrosion Defects

- External corrosion due to moisture in the ground
  - Small pinhole failures caused by pitting (localized galvanic corrosion) leads to small leaks that are often difficult to detect but that gradually grow in size over a period of time
  - More generalized corrosion leading to a reduction in pipe wall thickness over a plane area that can eventually fail catastrophically under pressure, leading to a large scale release
- Internal corrosion due to the corrosive nature of the products being transported
  - Leads to similar failure mechanisms as external corrosion
  - Failures are generally caused by the formation of acids resulting from the presence of water, carbon dioxide or sulphur compounds in the substances being transported

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Pipeline Material Failure/Construction Defect

- Pipe material defects usually result from inadequate specification and testing of materials
  - Failures can be of any type such as ruptures following brittle fracture or leaks due to longitudinal seam defects in pipe
- Construction defects are most frequently the type in which mechanical damage to the pipe is caused by machinery during the backfilling or land restoration activity
  - Often discovered shortly after pressurization.
  - Inadequate welding or joint corrosion protection and corrosion coating damage during laying will only be identified some time later

Pipeline Incident Miscellaneous Causes

- Operator errors
- Equipment failures
- Ground forces (e.g. during ground slips, mining activities or earthquakes)
- Internal erosion (e.g. very high gas velocities in gas pipelines or the presence of abrasive particulate matter in slurry pipelines)

Parameters Influencing Accident Rates

- Pipeline age
- Pipeline design and standards
- Corrosion
- Maintenance
- Fatigue loading
- Third party activities near pipelines
- Other miscellaneous factors

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Example Pipeline Incident Data Analysis

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Data Source

- Data was collected from the U.S. Department of Transportation Pipeline and Hazardous Materials Safety Administration (PHMSA) Pipeline Safety Incidents Database
- The database contains all pipeline incidents, without a minimum release size, that occurred within the United States as well as in offshore pipeline

Data Scope

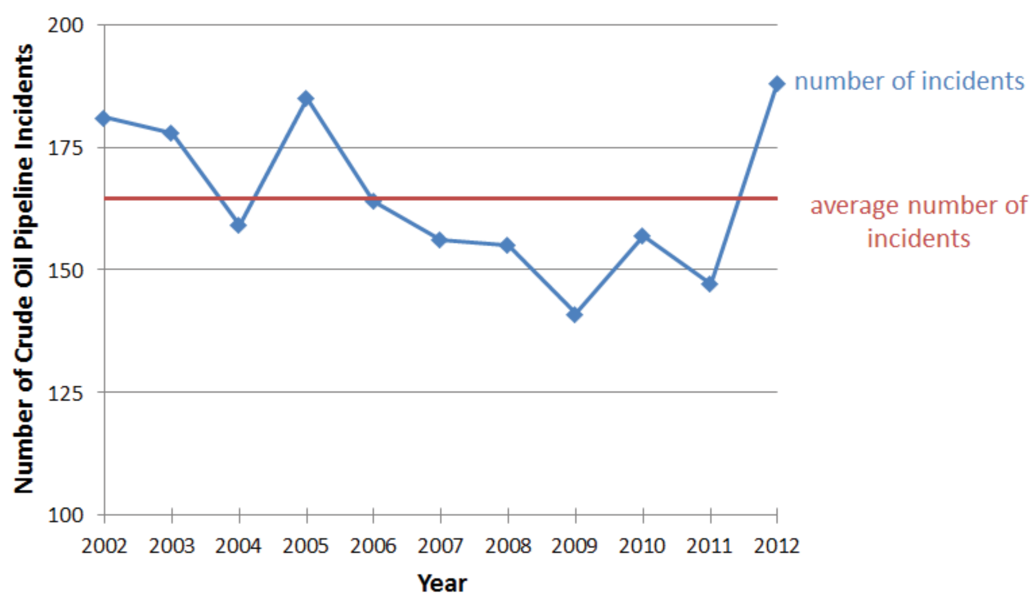
- The data used was from January 1, 2002 through April 30, 2013
- All onshore, crude oil pipeline incidents that fell within the above dates and that had valid latitude and longitude coordinates were considered
- Any commodity other than crude oil was ignored since this analysis focused specifically on crude oil incidents
- Offshore incidents were ignored since they experience different failure mechanisms than onshore pipeline
- Incidents without latitude and longitude coordinates were ignored since they would be incompatible with the analysis method

Data Used for the Analysis

- 1,865 crude oil pipeline incidents occurred during the time period being analyzed
  - 1,637 incidents were considered in this analysis
  - Due to invalid/missing latitude and longitude coordinates, the remaining 228 incidents were not used
  - On average, 165 crude oil pipeline incidents occurred per year

Quantity	Mean	Minimum	Maximum
Release size (barrels)	79.56	0	31,322
Total cost (US $)	1.12 million	0	810 million
Exposure radius (miles)	0.108	0	10.71

Crude Oil Pipeline Incidents by Year

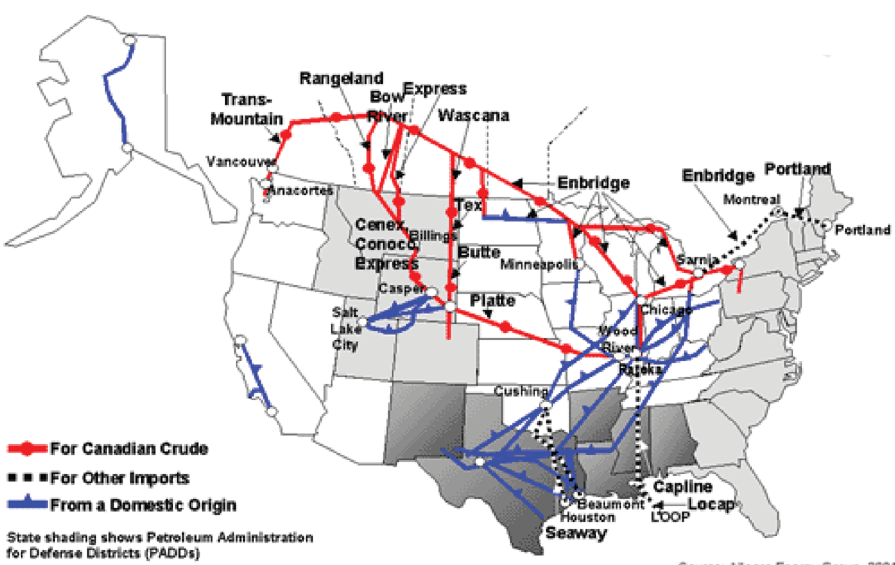


Note: all 1,865 incidents were used in this figure.

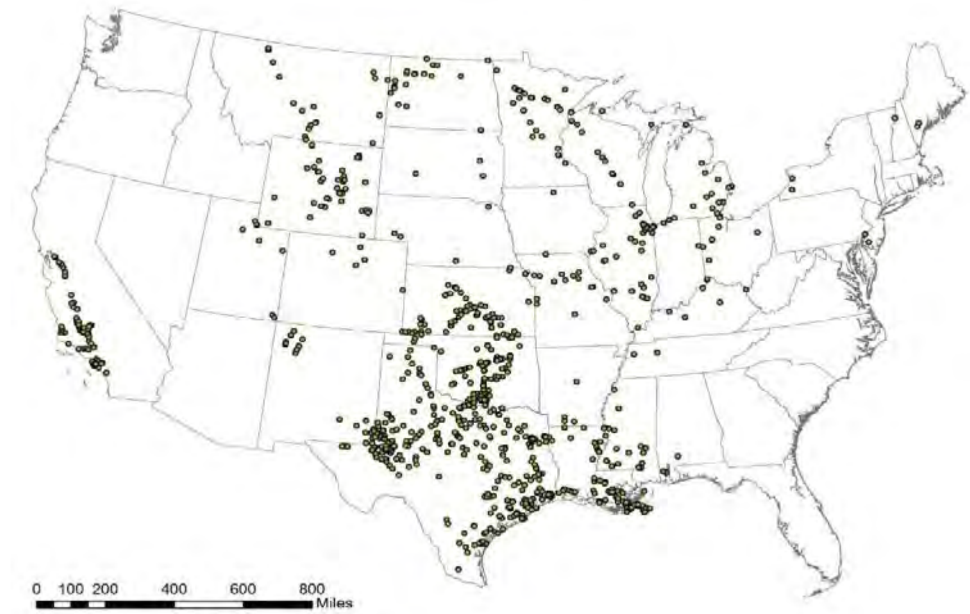
Incident Causes

- The database was split into seven incident cause categories:
  - Corrosion failure
  - Equipment failure
  - Incorrect operation
  - Material failure
  - External impact
  - Excavation damage
  - Other

Selected Crude Oil Pipelines

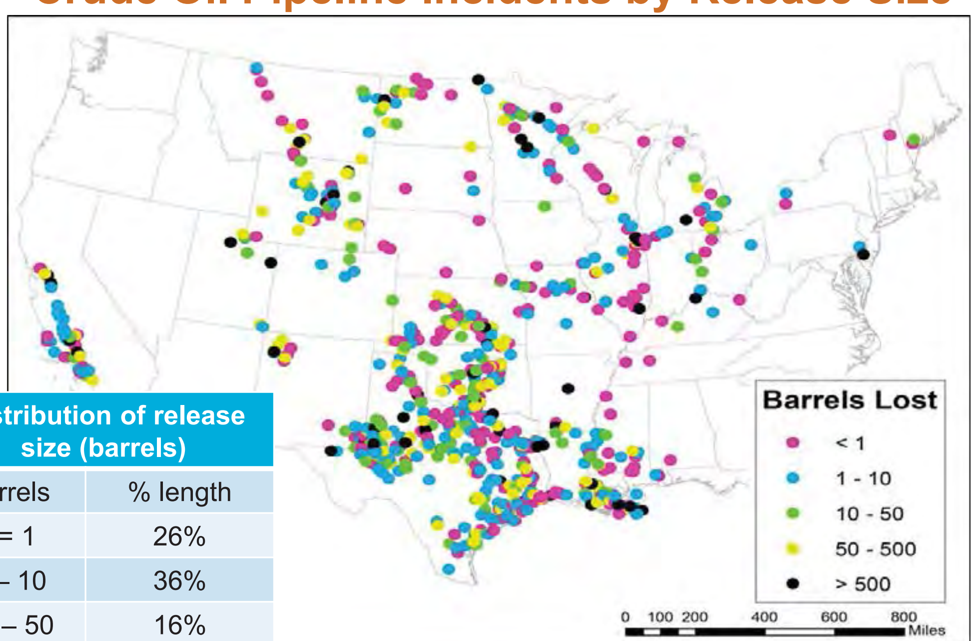


Crude Oil Pipeline Incidents



Note: incidents range from January 2002 through April 2013; 1,637 incidents are represented in the figure.

Crude Oil Pipeline Incidents by Release Size

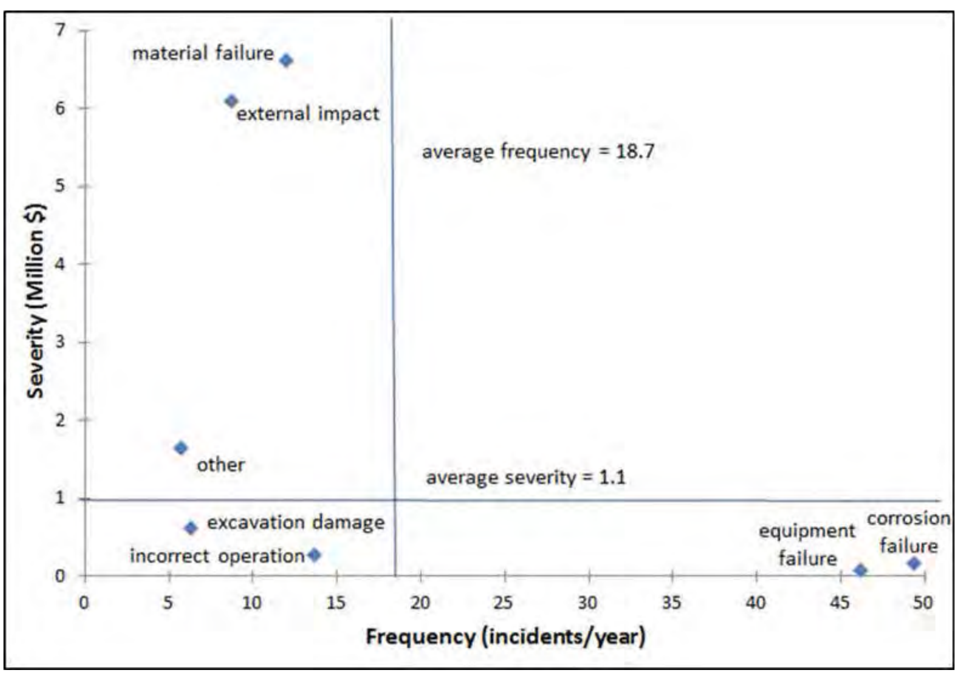


Distribution of release size (barrels)	
barrels	% length
<= 1	26%
1 – 10	36%
10 – 50	16%
50 – 500	15%
> 500	7%

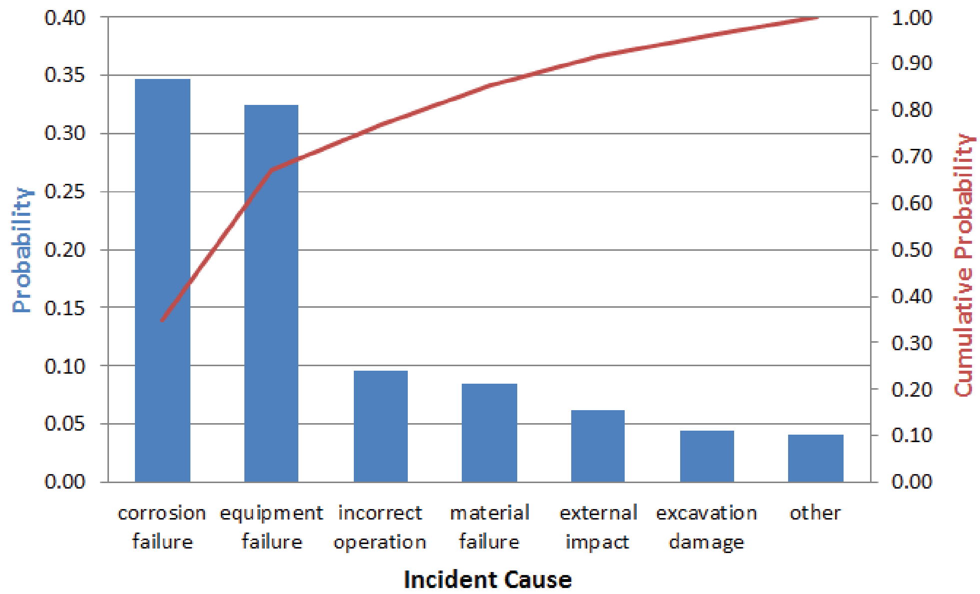
Frequency/Severity Analysis of Incident Causes

- A severity vs. frequency analysis was done in order to obtain a basic intuition of the comparative risk of each incident cause
  - Frequency is the number of incidents per year
  - Severity is the average cost per incident (U.S. $)
- Costs included in severity:
  - operator costs
  - socioeconomic costs
  - cleanup costs
  - cost of released crude oil
  - environmental damage costs.
- The average frequency and severity are weighted averages

Severity vs. Frequency Analysis of Crude Oil Pipeline Incident Causes



Incident Cause Probability



Example Pipeline Transportation Qualitative Risk Analysis

Han & Weng 2011 - Comparison study on qualitative and quantitative risk assessment methods for urban natural gas pipeline network

The Framework of Qualitative Risk Assessment Index System

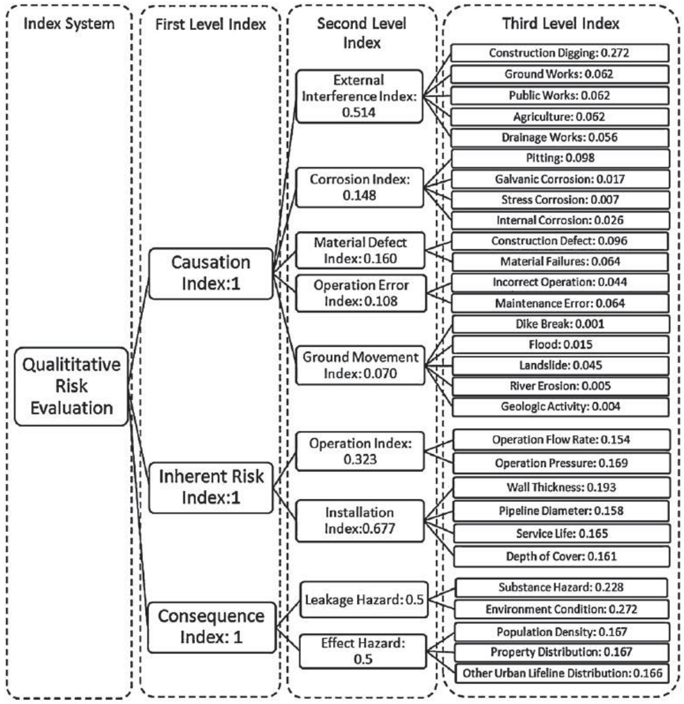


Table 1
Causation index evaluation for pipeline 1 of small urban natural gas pipeline network.

Third level index	Weights	Characteristic information	Value
Construction digging	0.272	Frequent	7
Ground works	0.062	Extraordinary frequent	10
Public works	0.062	Not frequent	4
Agriculture	0.062	Scarcely	1
Drainage works	0.056	Frequent	7
Pitting	0.098	Corrosion resistant	5
Galvanic corrosion	0.017	Electric potential: −100	5
Stress corrosion	0.007	Pressure drop: 1.728 kPa	10
Internal corrosion	0.026	Without H_2S	1
Construction defect	0.096	Duration of service: 20 year	10
Material failures	0.064	Pipeline length: 113.44 m	4
Incorrect operation	0.044	Possible	5
Maintenance error	0.064	Possible	5
Dike break	0.001	None	0
Flood	0.015	None	0
Landslide	0.045	None	0
River erosion	0.005	None	0
Geologic activity	0.004	None	0
Risk value	5.662		

Table 2
Inherent risk index evaluation for pipeline 1 of small urban natural gas pipeline network.

Third level index	Weights	Characteristic information	Value
Operation flow rate	0.154	10.05 kg/s	0.99
Operation pressure	0.169	9 kPa	10
Wall thickness	0.193	2.2 cm	2.34
Pipeline diameter	0.158	100 cm	2.50
Service life	0.165	20 year	10
Depth of cover	0.161	0.4 m	2.35
Risk value	4.687		

Table 3
Consequence index evaluation for pipeline 1 of small urban natural gas pipeline network.

Third level index	Weights	Characteristic information	Value
Substance hazard	0.228	Comparative denseness	7
Environment condition	0.272	Windy	7
Population density	0.167	Extraordinary denseness	10
Property distribution	0.167	Extraordinary denseness	10
Other urban lifeline distribution	0.166	Extraordinary denseness	10
Risk value	8.500		

Key Takeaways

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INTRODUCTION TO MARITIME TRANSPORTATION SAFETY AND RISK

CEE498 TSR -Transportation Safety and Risk

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Department of Civil & Environmental Engineering

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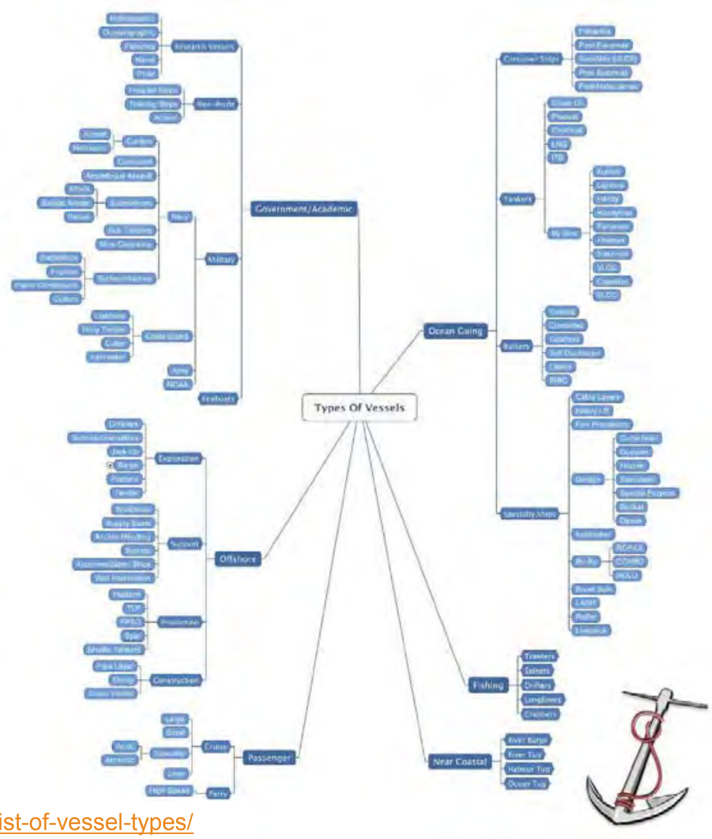
Learning Outcomes

At the end of this lecture students will be able to:

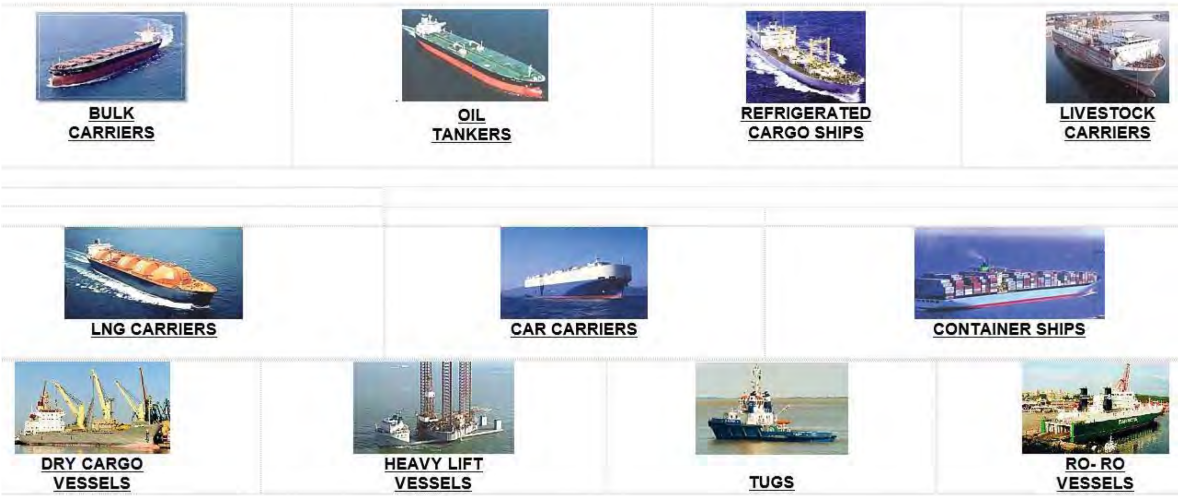
1. Understand different types of maritime ship accidents
2. Identify maritime hazmat release incident risk factors
3. Develop simple maritime hazmat risk model

Master List of Vessel Types



http://gcaptain.com/types-of-ships-a-master-list-of-vessel-types/

Types of Cargo Ships



http://stevesmaritime.com/mships.html

Intermodal Tank Containers

Slide 6

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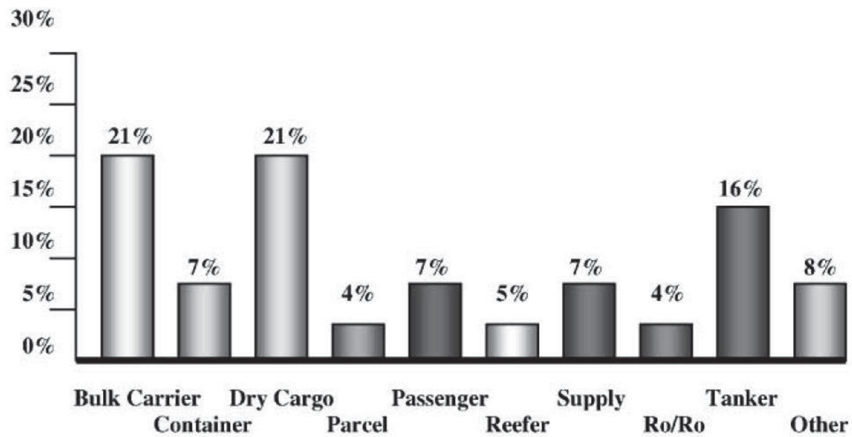
Distribution of Incidents by Ship Type (1989-1999 by the UK P&I Club)



Wang & Foinikis (2001) – Formal safety assessment of containerships

Slide 7

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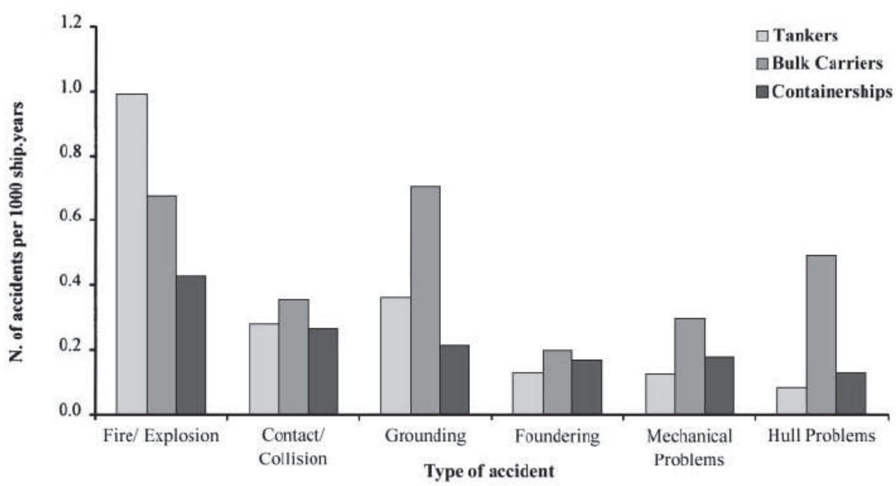
Example Maritime Ship Accidents

http://youtu.be/aSJmT2TfzbA

Maritime Ship Accident Types

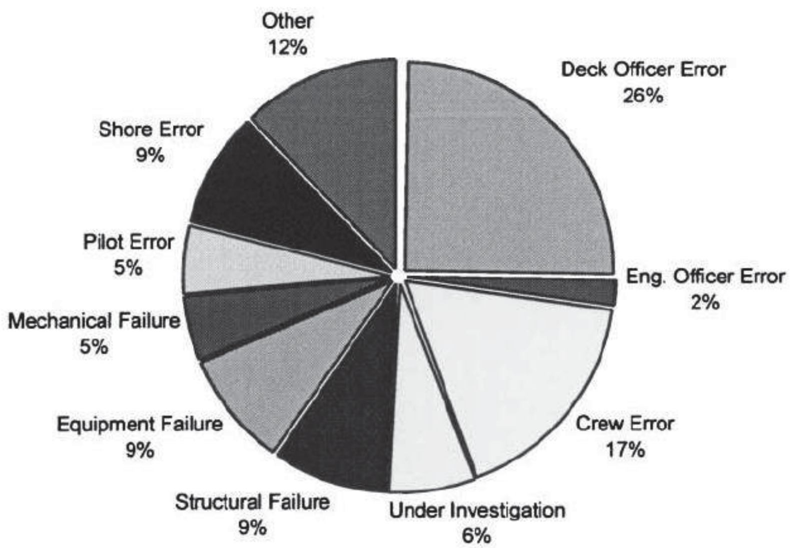
- Fire/Explosion
- Collision - Striking or being struck by another ship, whether under way, anchored or moored (excludes striking underwater wrecks)
- Contact - Striking or being struck by an external object, but not another ship or the sea bottom (includes striking offshore rigs/platforms)
- Grounding - Striking the sea bottom, shore or underwater wrecks (also termed Wrecked or Stranded)
- Foundering - Sinking due to rough weather, leaks, breaking in two, etc.
- Mechanical Problems
- Hull Problems – Structural failures

Maritime Ship Accident Type Annual Average Rate by Ship Type



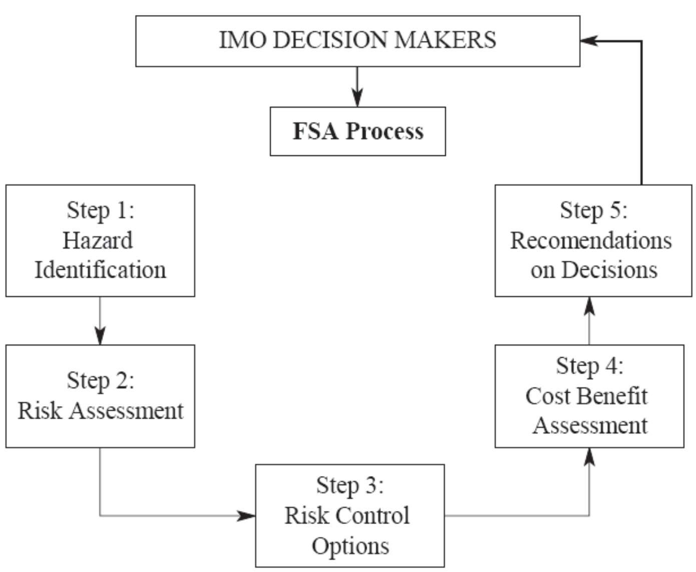
Guedes Soares & Teixeira (2001) – Risk assessment in maritime transportation

Principal Causes of Ship Accidents



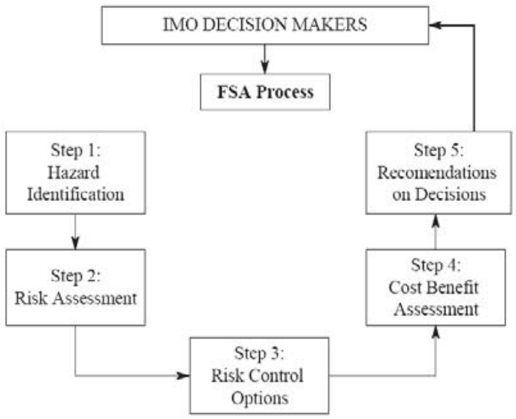
Guedes Soares & Teixeira (2001) – Risk assessment in maritime transportation

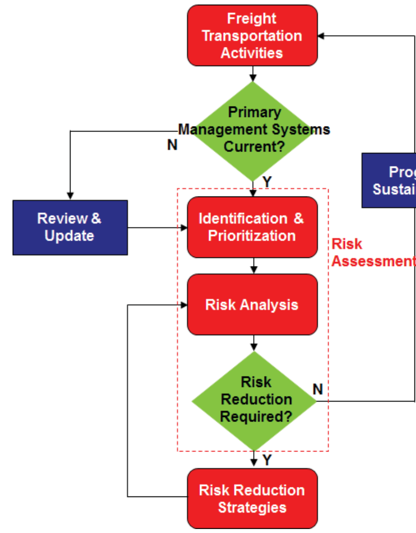
International Maritime Organisation (IMO) Formal Safety Approach (FSA)



Guedes Soares & Teixeira (2001) – Risk assessment in maritime transportation

IMO FSA vs. General Freight Transportation Risk Management Process





IMO FSA Individual & Societal Risks

Maximum tolerable risk for crew members	10^{-3} annually
Maximum tolerable risk for passengers	10^{-4} annually
Maximum tolerable risk for public ashore	10^{-4} annually
Negligible risk	10^{-6} annually

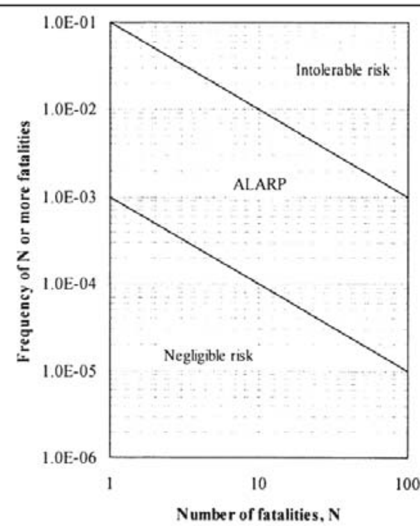
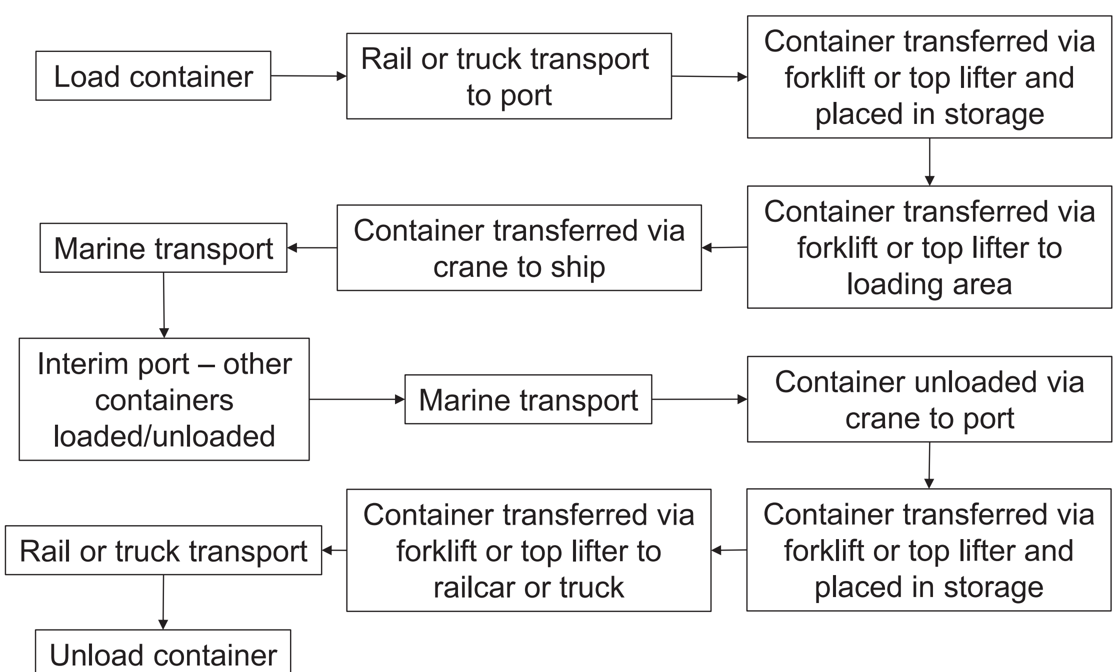


Fig. 8. Example of a F–N acceptance criterion ($F < AN^{-K}$ curve for $A =$ 0.1 and $A = 0.001$ with $K = 1$).

Guedes Soares & Teixeira (2001) – Risk assessment in maritime transportation

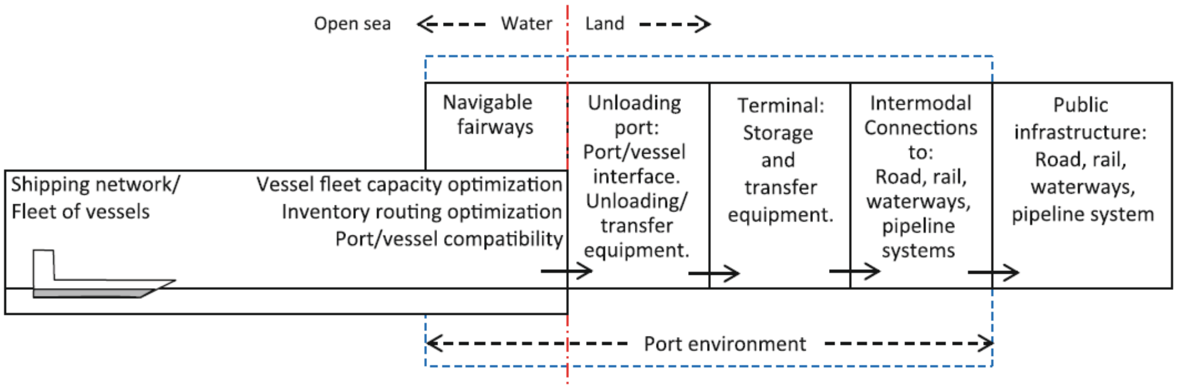
Maritime Hazmat Release Risk Identification

Typical Intermodal Transport Operation



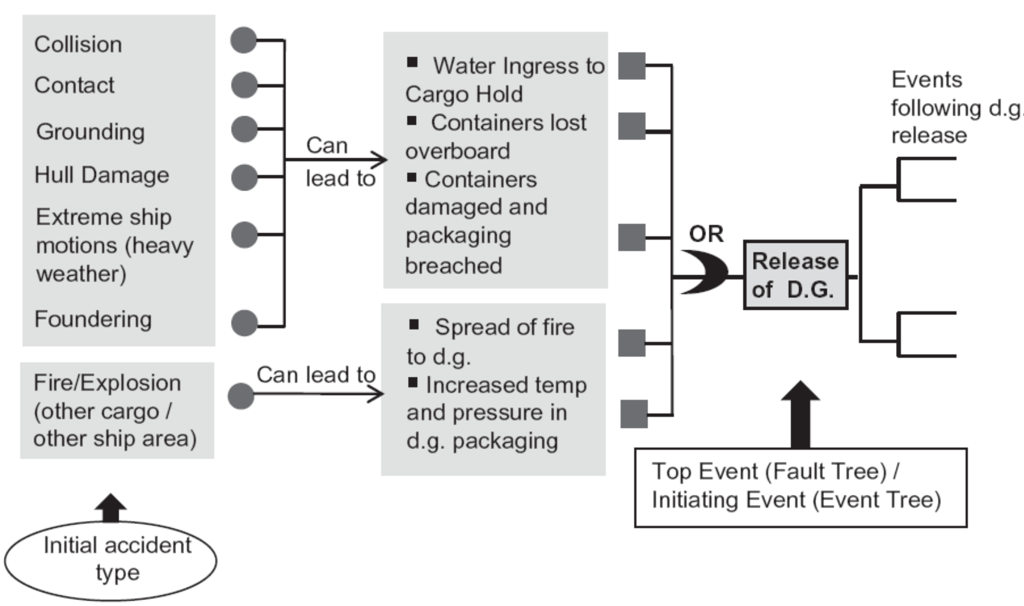
Modified from CCPS (1995)

General Port-Vessel Logistical Interfaces



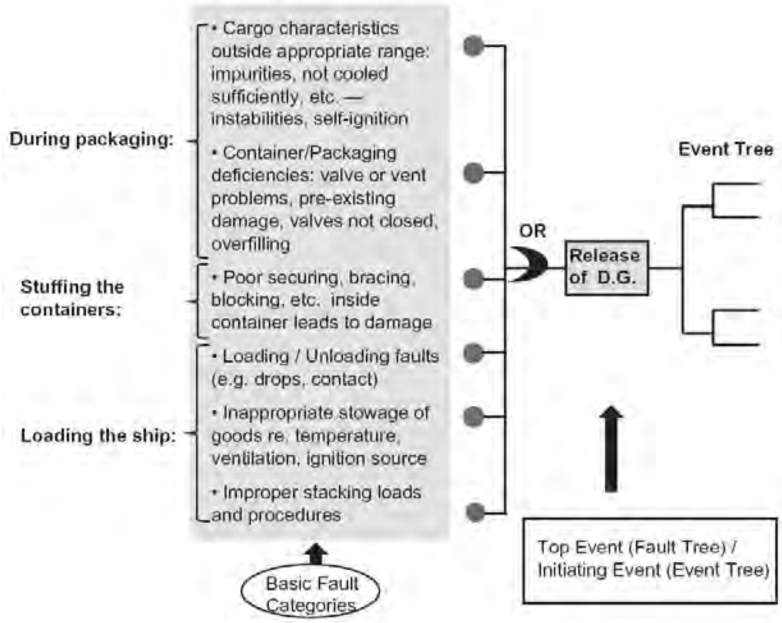
Egil et al. (2012) – Risk based design of maritime transport systems

Simplified Event Sequence Where Hazmat Release is Due to Another Primary Accident Type



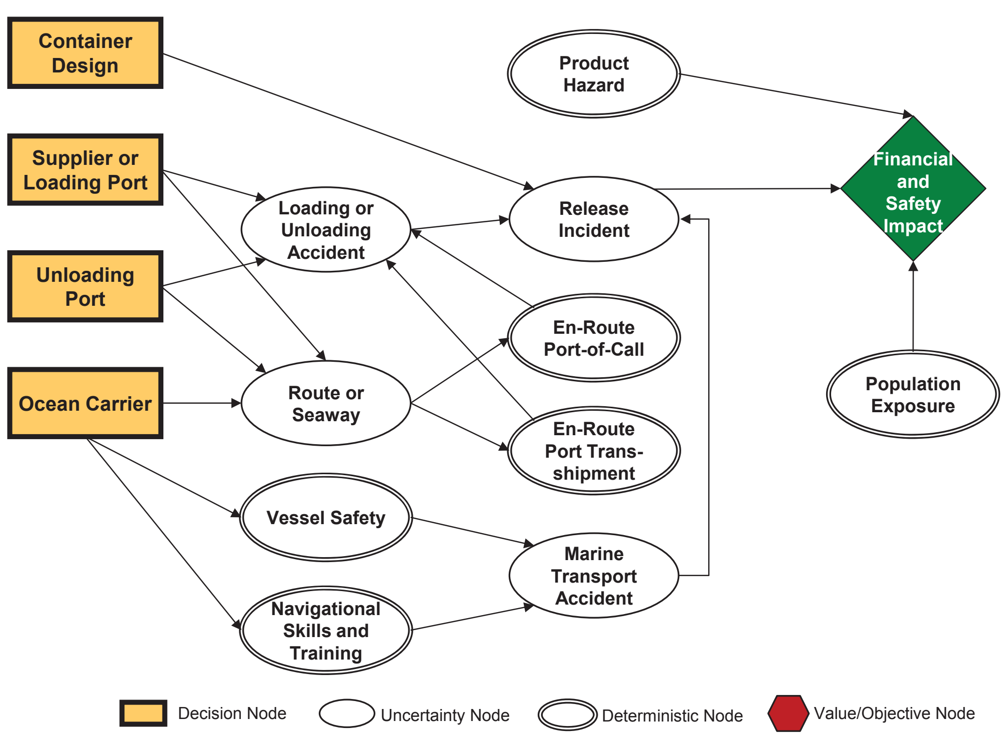
Ellis (2011) – Analysis of accidents and incidents occurring during transport of packaged dangerous goods by sea

Simplified Event Sequence Where Hazmat Release is The Primary Accident Type

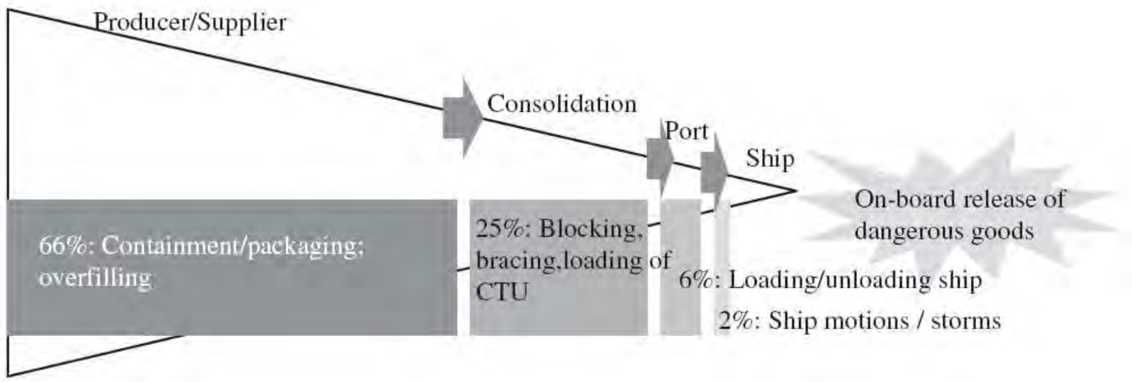


Ellis (2011) – Analysis of accidents and incidents occurring during transport of packaged dangerous goods by sea

Maritime Hazmat Transportation Risk Influence Diagram



Generalized Causes Contributing to Release of Hazmat in HMIRS Maritime Incidents (1998-2008, n=83)



97% of risk is before the marine transportation

Ellis (2011) – Analysis of accidents and incidents occurring during transport of packaged dangerous goods by sea

General Maritime Hazmat Release Frequency Estimation

Release Frequency

= Release probability during container movement × number of lifts

+ Release probability during loading

+ Release probability during port of call × number of port calls

+ Release probability during transshipment × number of transshipment ports

+ Release probability during ocean transit

+ Release probability during unloading

Simplified Maritime Hazmat Release Frequency Estimation

Release Frequency

= Release probability during container movement × number of lifts

+ Release probability during loading[1]

+ Release probability during port of call[2] × number of port calls

+ Release probability during transshipment[3] × number of transshipment ports

+ Release probability during ocean transit

+ Release probability during unloading[1]

Notes:

1. Loading/unloading refers to the risk of dropping the container (Probability of dropped object onto fixed installation = 1.4×10^{-5} per lift)
2. Port of call refers to the risk of dropping other containers onto the container of interest at en-route ports (Probability of dropped object onto vessel = 1.6×10^{-6} per lift)
3. Transshipment refers to transferring the container to another ship at en-route ports (assumed similar probability to loading/unloading accident = 1.4×10^{-5} per lift)

Probability source: International Association of Oil and Gas Producers' Risk Assessment Data Directory

Maritime Hazmat Release Risk Screening Model

$$\mathrm{R}_{a,b} = \sum_{i,j} \mathrm{P}(A_j) \times \mathrm{P}(\mathrm{R}|\mathrm{A}) \times \mathrm{Pop}_i$$

where:

$R_{a,b}$ = hazmat release risk index due to transport by sea between port of origin *a* to port of destination *b*

$P(A_j)$ = probability of accident impact involving hazmat container due to shore activity *j* (e.g. loading, unloading, transshipment, port-of-call)

Shore Activity *j*	Probability
Loading/Unloading	1.4×10^{-5}
Transshipment	1.4×10^{-5}
Port-of-Call	1.6×10^{-6}

[data source: International Association of Oil and Gas Producers' Risk Assessment Data Directory]

P(R|A) = conditional probability of release of a damaged hazmat container = *0.0305*
[data source: previous U of I study]

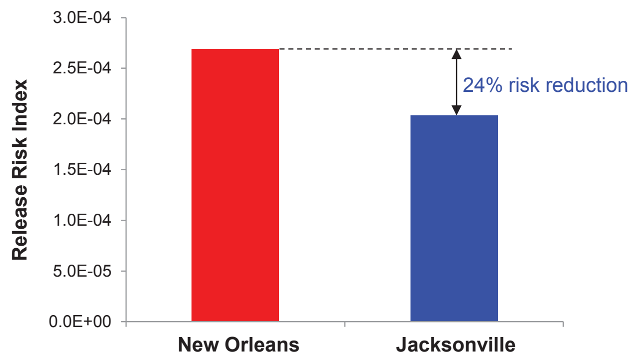
Pop_i = population class index near port *i*

= 7 (5 million or greater), 6 (less than 5 million to 1 million), 5 (less than 1 million to 500,000), 4 (less than 500,000 to 250,000), 3 (less than 250,000 to 100,000), 2 (less than 100,000 to 50,000), 1 (less than 50,000)

[data source: ESRI's World Cities or local census]

Example Maritime Hazmat Release Risk Screening

	PORT OF NEW ORLEANS					PORT OF JACKSONVILLE			
	Port	Shore Activity	Population Class	Risk Index		Port	Shore Activity	Population Class	Risk Index
1	New Orleans	Loading	4	5.60E-05	1	Jacksonville	Loading	5	7.00E-05
2	Caucedo, Dominican Republic	Transshipment	6	8.40E-05	2	Port Everglades	Port of Call	4	6.40E-06
3	Santos, Brazil	Port of Call	4	6.40E-06	3	Suape	Port of Call	6	9.60E-06
4	Buenos Aires, Argentina	Port of Call	7	1.12E-05	4	Santos, Brazil	Port of Call	4	6.40E-06
5	Montevideo, Uruguay	Port of Call	6	9.60E-06	5	Buenos Aires, Argentina	Port of Call	7	1.12E-05
6	Rio Grande, Brazil	Port of Call	2	3.20E-06	6	Rio Grande, Brazil	Port of Call	2	3.20E-06
7	Navegantes, Brazil	Port of Call	2	3.20E-06	7	Itapoá	Port of Call	1	1.60E-06
8	Santos, Brazil	Port of Call	4	6.40E-06	8	Rio de Janeiro, Brazil	Port of Call	7	1.12E-05
9	Itaguai, Brazil	Port of Call	3	4.80E-06	9	Salvador, Brazil	Unloading	6	8.40E-05
10	Salvador, Brazil	Unloading	6	8.40E-05					
			Total Risk	2.69E-04				Total Risk	2.04E-04



Key Takeaways