Railroad Safety & Risk Analysis Using North American Accident Database Systems

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UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

Thank you for the invitation! 謝謝

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- and various petroleum, chemical and refining companies

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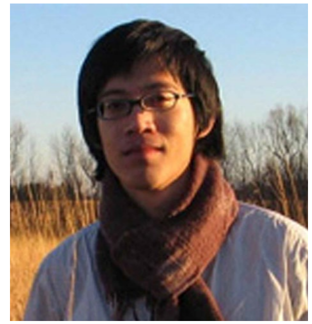
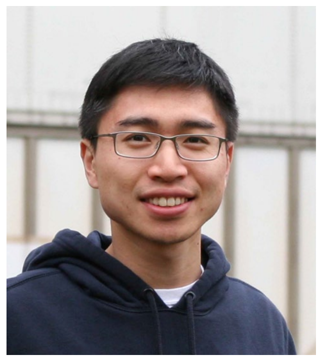
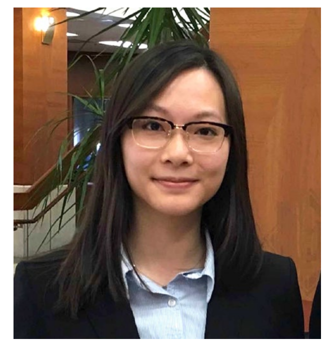
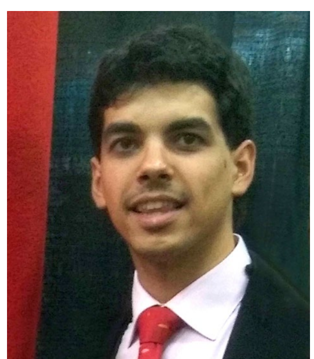
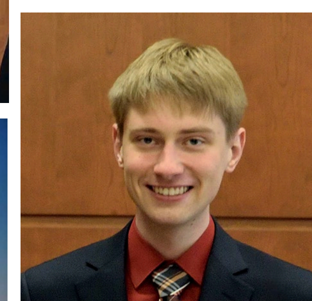




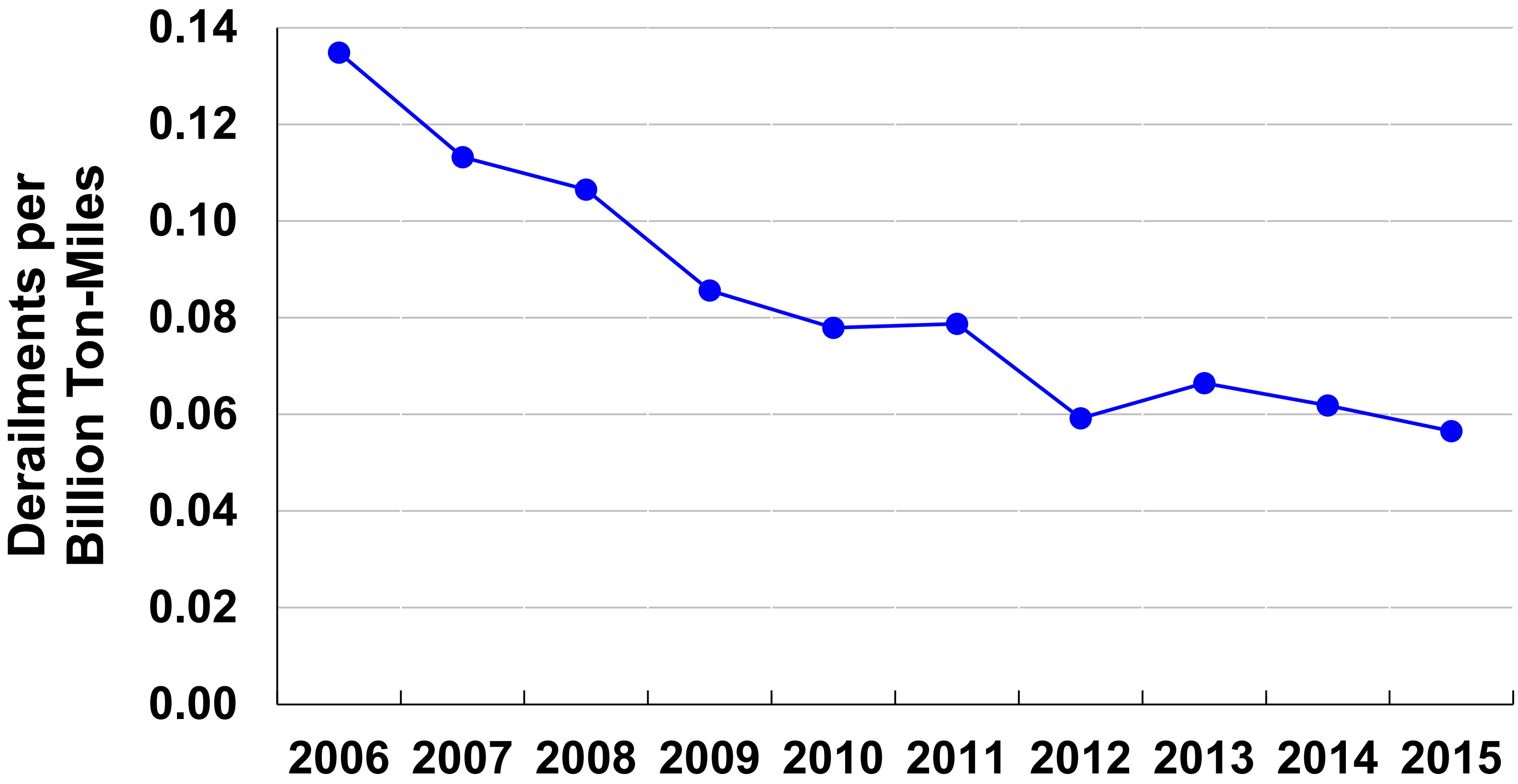


Outline of Presentation

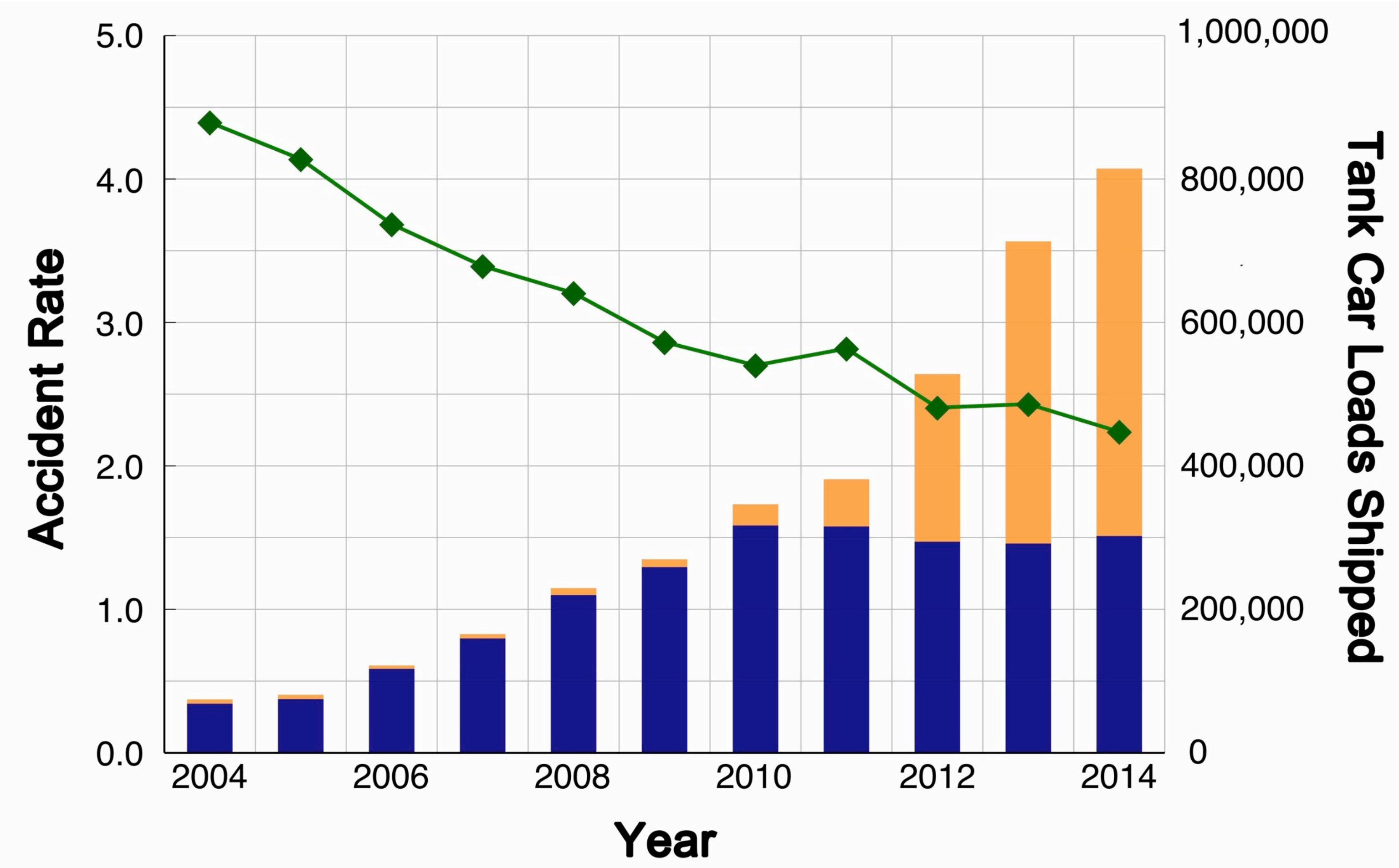
- Introduction to North American rail safety trends
- Types of data needed for railroad safety and risk analysis
- Review several projects:
    - Optimizing Tank Car Safety Design
    - Multiple Tank Car Release Risk
    - Analysis of Train Derailment Rates, Causes, and Changes
    - Loaded versus Empty Unit Train Derailment Cause Analysis
    - Adjacent Track Accident Risk Model Development

Substantial decline in major North American railroads' mainline derailment rate: 2006 - 2015



- 50% reduction in mainline derailment rate in this time period
- However, this improvement occurred at the same time as an even more dramatic increase in hazardous dangerous goods traffic

Decline in railroad derailment rate coincided with increase in flammable liquid traffic



- Beginning in the mid-2000s flammable liquid traffic, notably ethanol and petroleum crude oil grew more than 10-fold
- Most of this traffic was moving in large unit trains rather than single carload shipments

Safety paradox, derailments were declining but serious incidents were increasing

- Substantial increase in rail transport of ethanol and petroleum crude oil led to a corresponding increase in derailments involving these products

New Brighton, PA

Cherry Valley, IL

Lac-Mégantic, QC

Casselton, ND

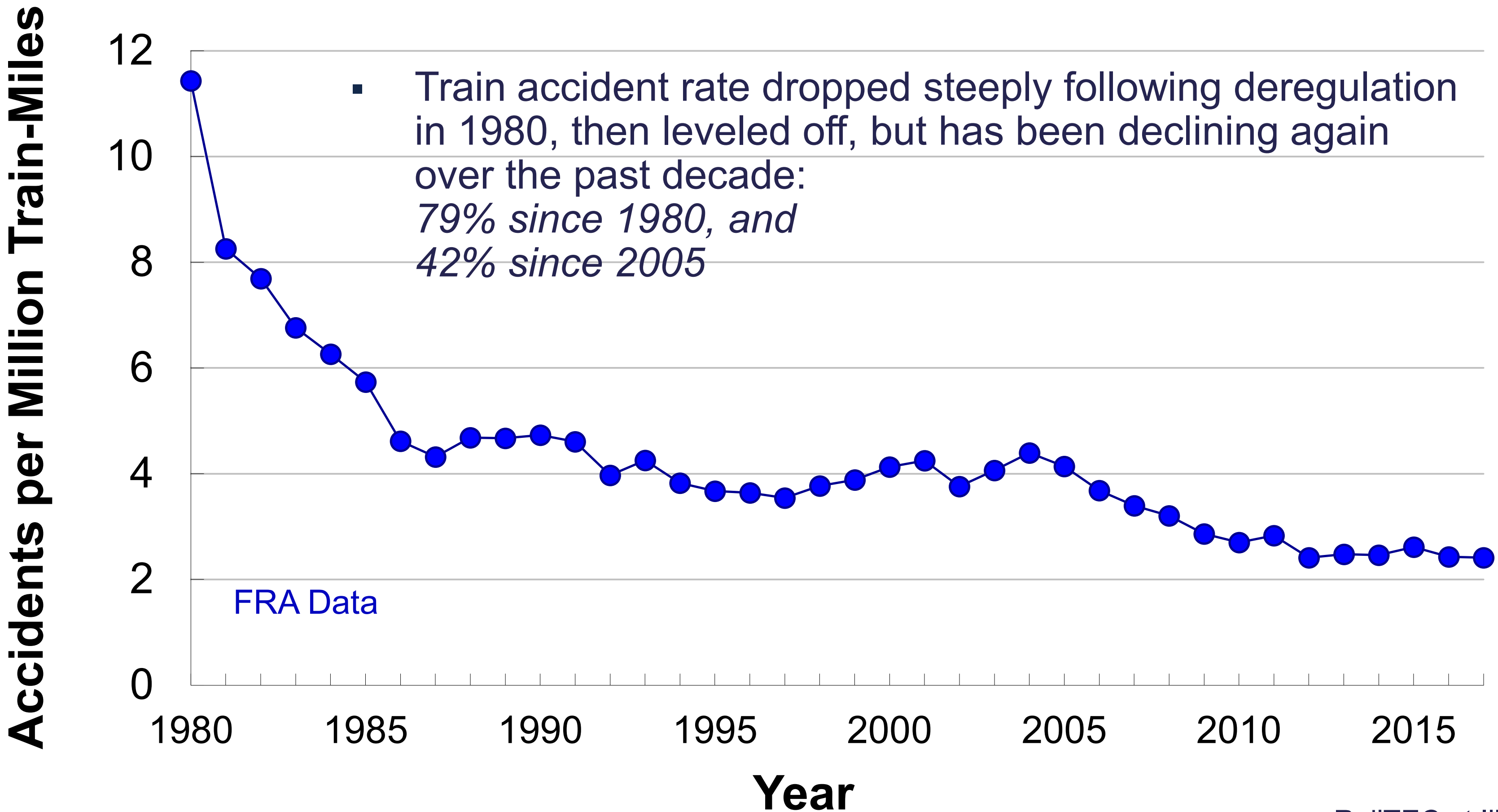
Aliceville, AL

Mt. Carbon, WV

… and a number of others

Decline in accidents part of a longer-term trend, but shows evidence of diminishing returns

- Eliminating the remaining accident causes is an increasingly stubborn problem
- Requires more sophisticated data and analytical techniques to prioritize investment in most effective risk reduction strategies



Railroad freight train risk reduction strategies

Infrastructure

e.g. Track upgrade

Reduce accident occurrence

Operational

e.g. Speed reduction

Reduce accident severity

Railcar/Container

e.g. Tank car safety design

Reduce incidence and severity of releases

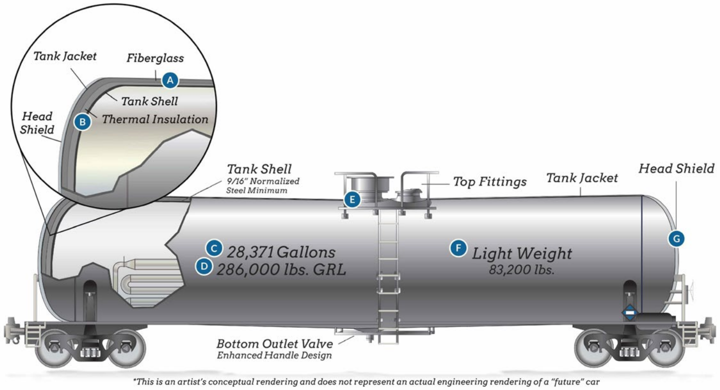
Routing

e.g. Alternative routings

Reduce impact of releases

Railroad data systems needed for safety and risk analysis

- Accidents and incidents – what, when, where, why & how occurred
- Operations and traffic – type, routing and exposure
- Infrastructure – routes and characteristics
- Rolling stock – safety design characteristics



Railroad accident and incident data

- **US DOT Federal Railroad Administration**
  - Highway-rail grade crossing accident/incident (58 variables + narrative)
  - Rail equipment accident/incident (80 variables + narrative)
  - Death, injury, or occupational illness (>40 variables + narrative)
- **US DOT Pipeline and Hazardous Materials Administration**
  - Hazardous materials incident report (90 variables + narrative)
- **RSI-AAR Railroad Tank Car Safety Research and Test Project**
  - Railroad tank car accident database
    - Train accident characteristics (37 variables and >30,000 records)
    - Damage and performance of tank cars involved in accidents (34 variables and >48,000 records)

Railroad operations and traffic

- **Association of American Railroads**
  - TRAIN II – Detailed records of railcars, lading transported, and routing of most rail shipments in North America
  - Analysis of Class 1 Railroads – Detailed annual summary of railroad operating statistics
- **US Surface Transportation Board**
  - Waybill Sample – Statistically robust sample of rail shipment movements over US rail network
- **Major North American railroads**
  - Operating data – Detailed data on train makeup, movements, routing, schedules, traffic composition and volume, railcars, and commodities transported (proprietary)

Railroad infrastructure route characteristics

- **Association of American Railroads**
  - Analysis of Class 1 Railroads – Annual summary of certain railroad infrastructure characteristics
- **US DOT Federal Railroad Administration**
  - Grade crossing inventory file – Data on all US grade crossings
- **Major North American railroads**
  - Detailed data on track characteristics, train control systems, and numerous other characteristics (proprietary)
- **Geographic Information System (GIS) databases**
  - US Bureau of Transportation Statistics: National Transportation Atlas Database – GIS database of US rail network
  - US Census Service: TIGER* data – GIS database of US population distribution
  - Various other GIS databases on numerous features of interest including environmental characteristics, waterways, etc.

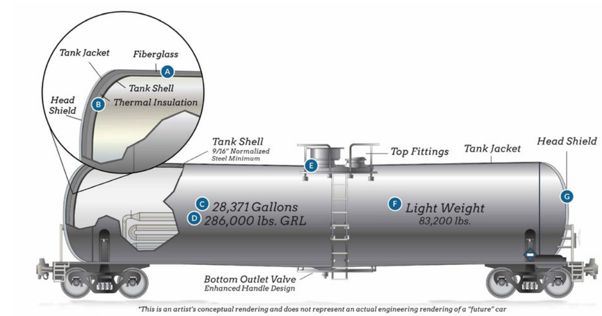
* Topologically Integrated Geographic Encoding and Referencing

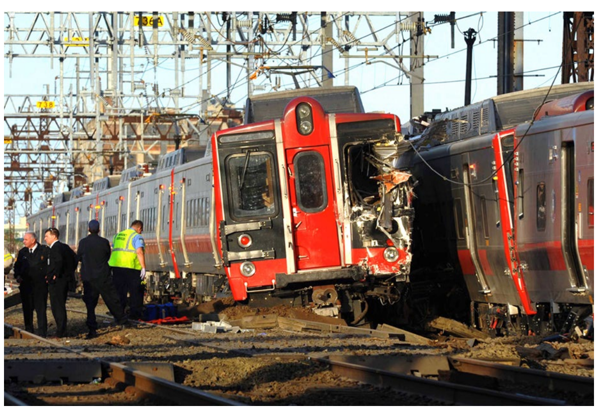
Railroad rolling stock design characteristics

- **Association of American Railroads**
  - UMLER (Universal Machine Language Equipment Register) Detailed data on nearly all rail rolling stock operating in North America
- **RSI-AAR Railroad Tank Car Safety Research and Test Project**
  - Car design properties and lading transported for tank cars involved in accidents (40 variables)

Examples of recent and current research

- Optimizing Tank Car Safety Design
- Multiple Tank Car Release Risk
- Analysis of Train Derailment Rates, Causes, and Changes
- Loaded versus Empty Unit Train Derailment Cause Analysis
- Adjacent Track Accident Risk Model Development





Optimizing Tank Car Safety Design

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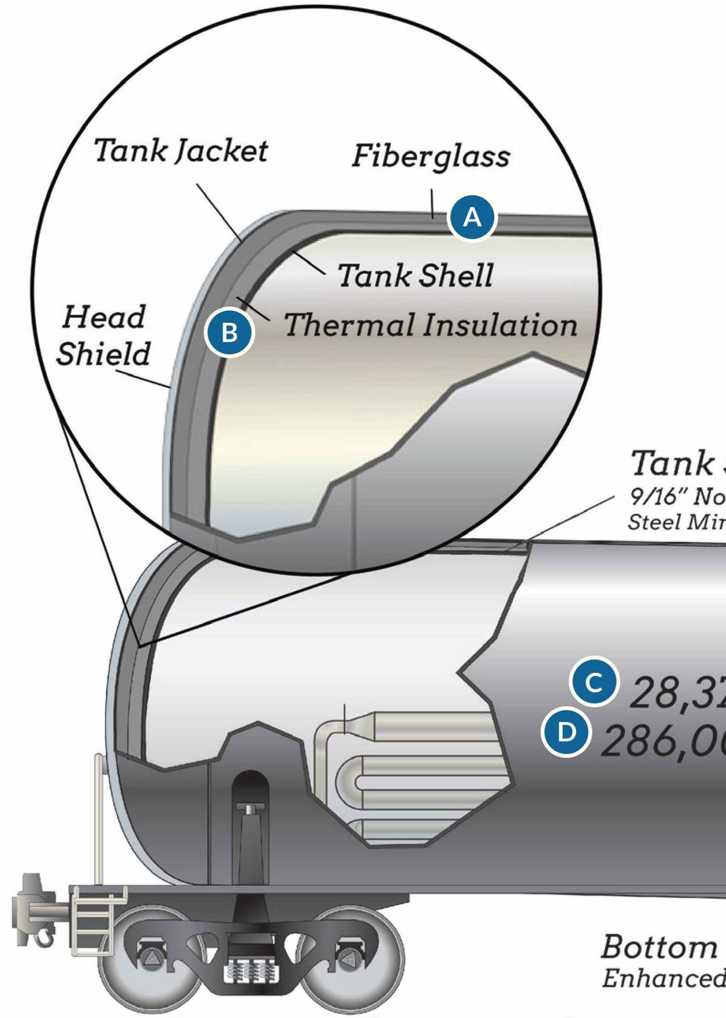

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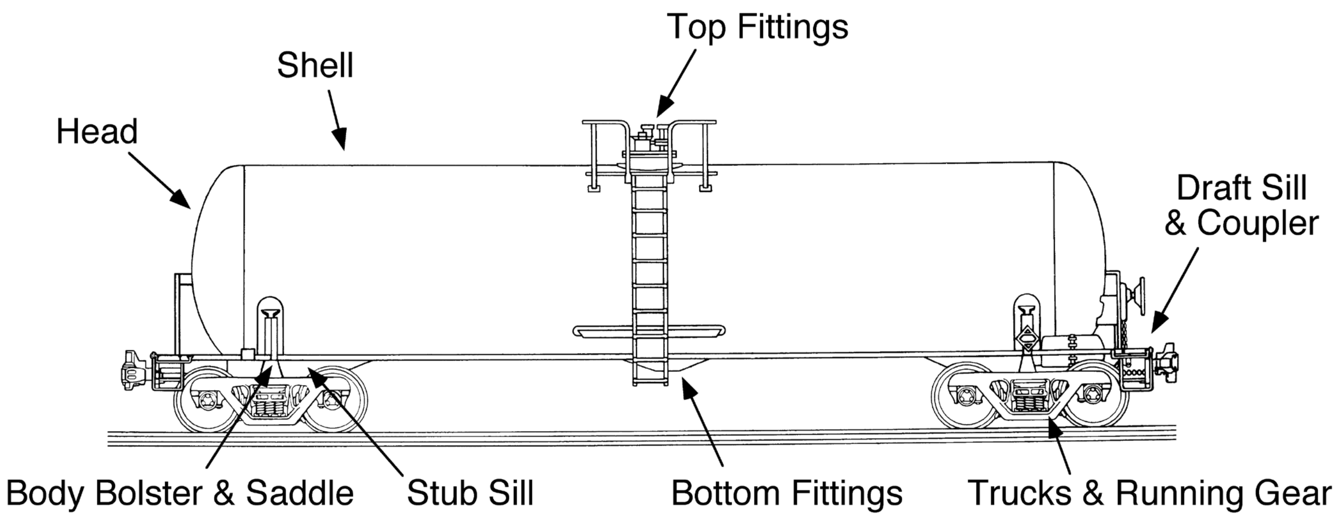
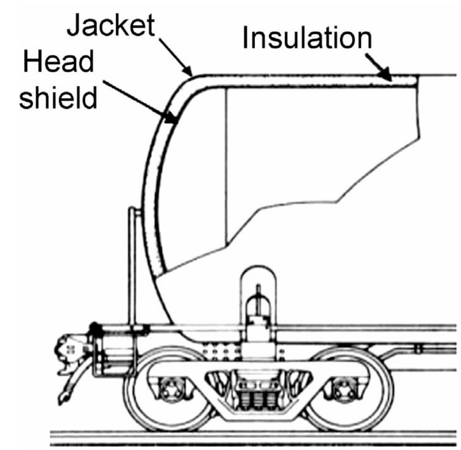
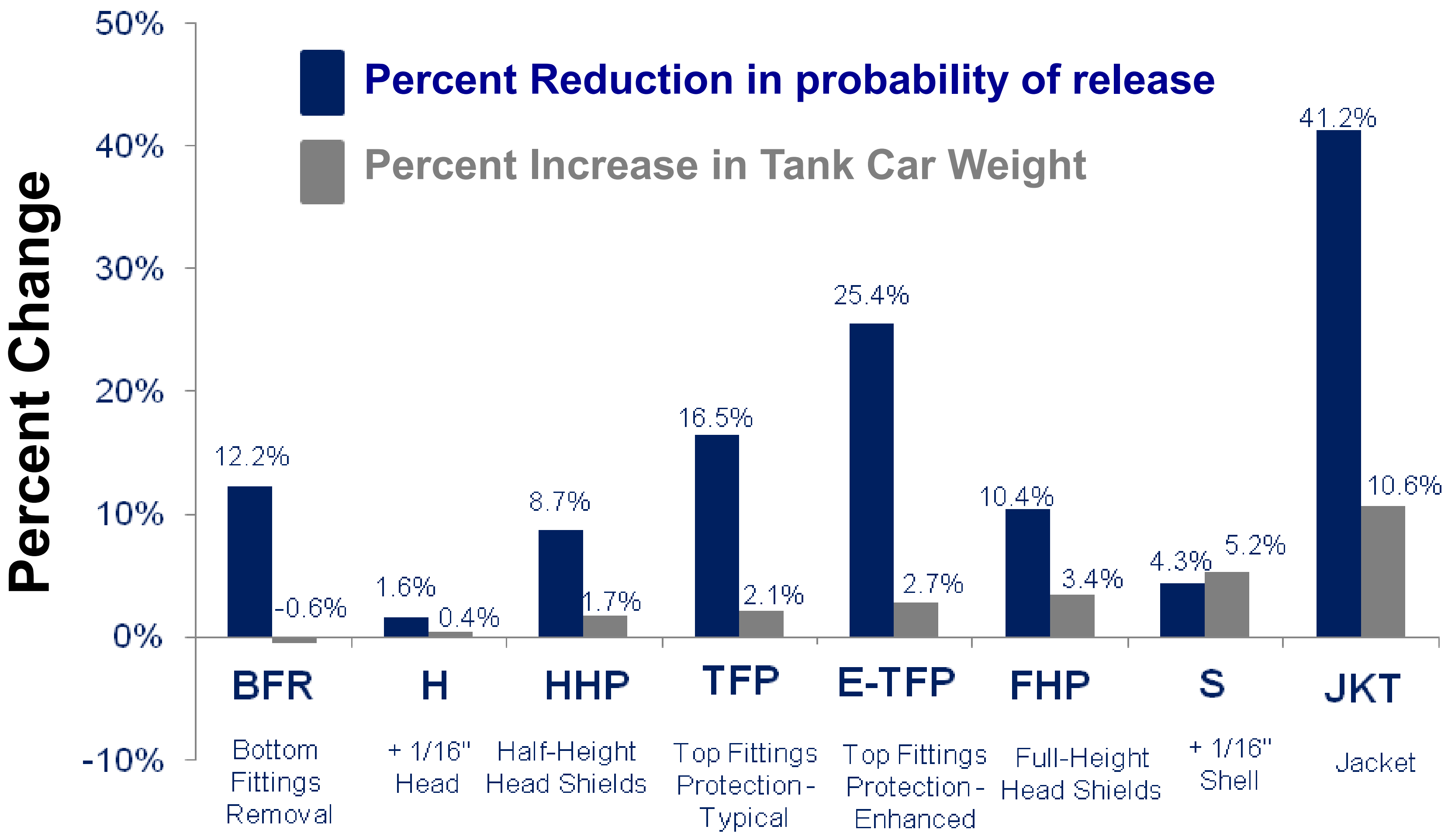
Fundamental tradeoff in tank car design: Safety versus efficiency





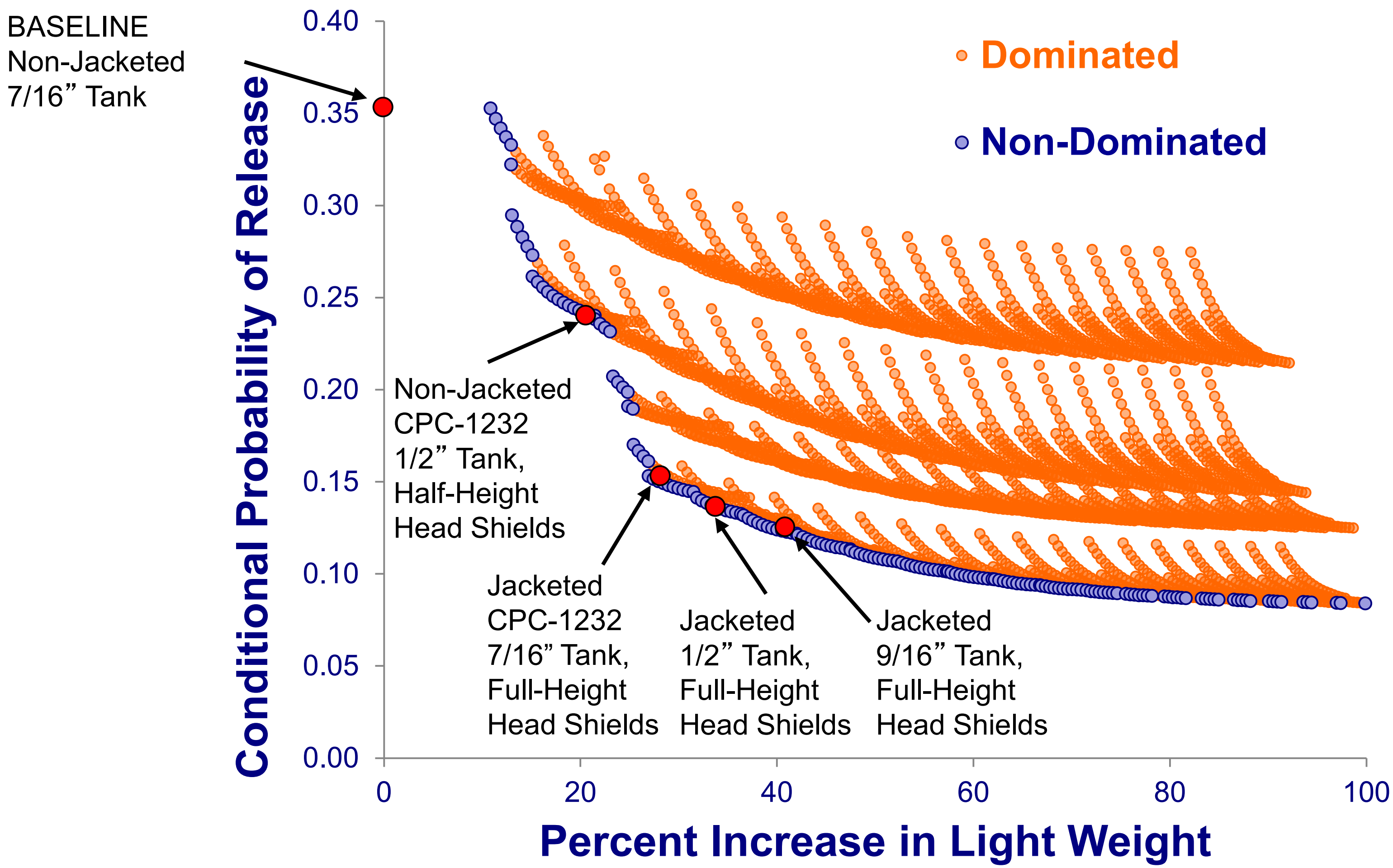
- Principal approaches to enhance tank car safety design:
  - Thicker/stronger head and/or head shield
  - Thicker/stronger shell
  - Adding top fittings protection
  - Removing bottom fittings
- Stronger tank and better-protected fittings ***improve accident performance***
- *Also* increase weight and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

Change in light weight and probability of release for each tank car safety design modification



Example: 263,000-lb maximum GRL for 30,000-gallon baseline 111 tank car

Pareto optimal set of flammable liquid tank car design options



Multiple Tank Car Release Risk

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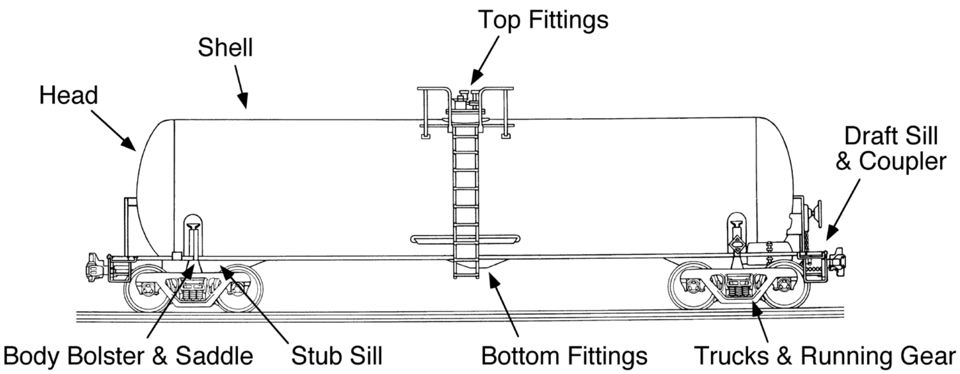
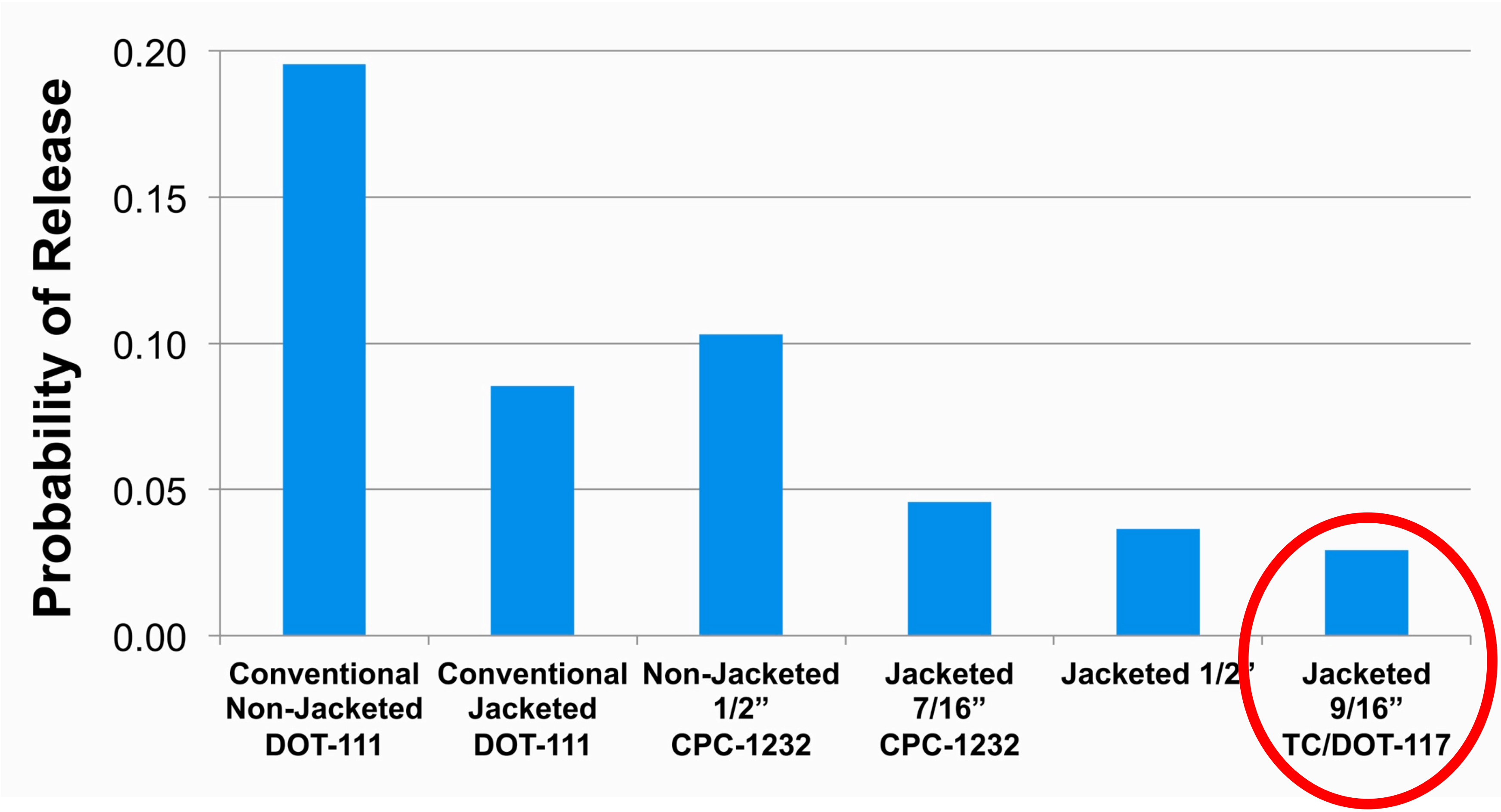
Previous tank car safety research focused on single car performance

- Optimization techniques and tank car data used to quantitatively identify combinations of design features that maximized tank car safety performance*
- This approach alone was successful when focused on single-car release incidents such as environmentally sensitive chemicals (ESC) or toxic inhalation hazard materials (TIH)
- Substantial growth in unit-trains transporting petroleum and alcohol suggested need to consider probability of multiple-car release events†

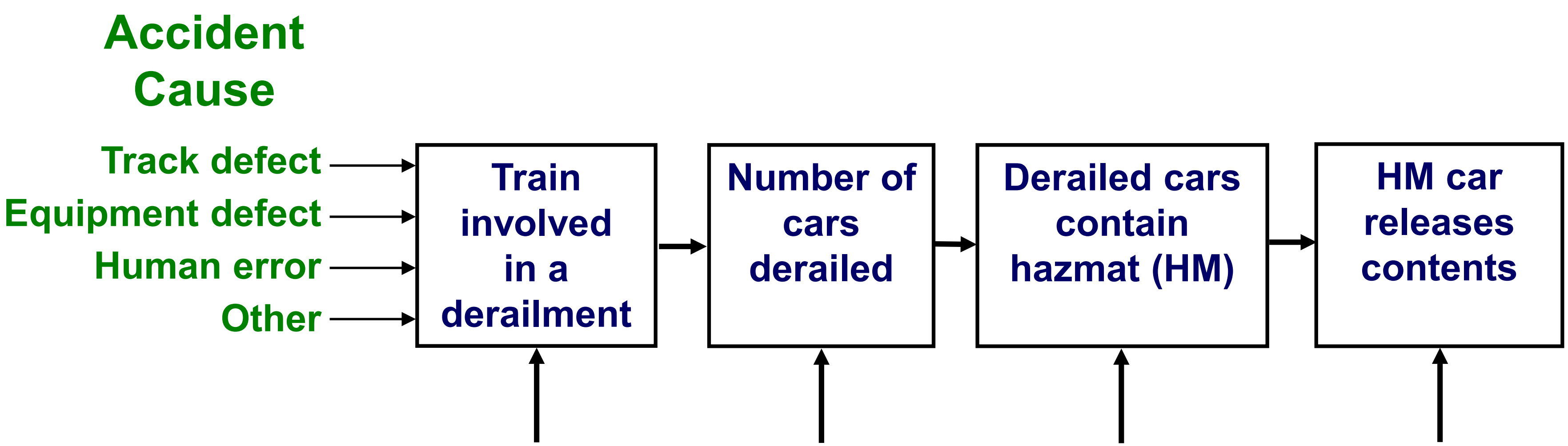


Safety performance of flammable liquid tank cars derailed in accidents



* CPR(100) = Probability that a tank car derailed in an FRA-reportable accident releases ≥100 gallons due to the impacts it receives in the derailment

Events leading to a release incident



Influencing Factors

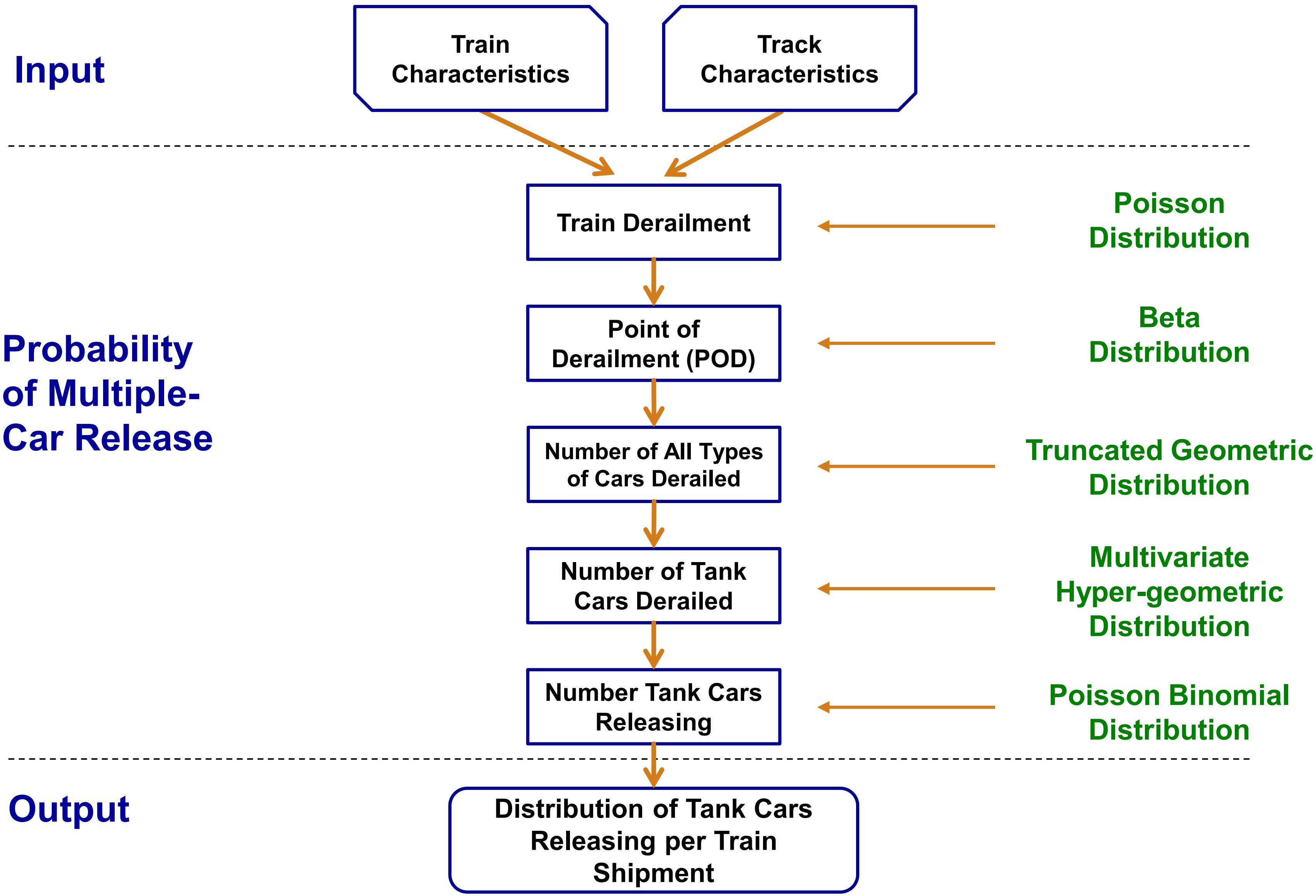
Train involved in a derailment:
- track quality
- method of operation
- track type
- human factors
- equipment design
- railroad type
- traffic exposure

Number of cars derailed:
- speed
- accident cause
- train length

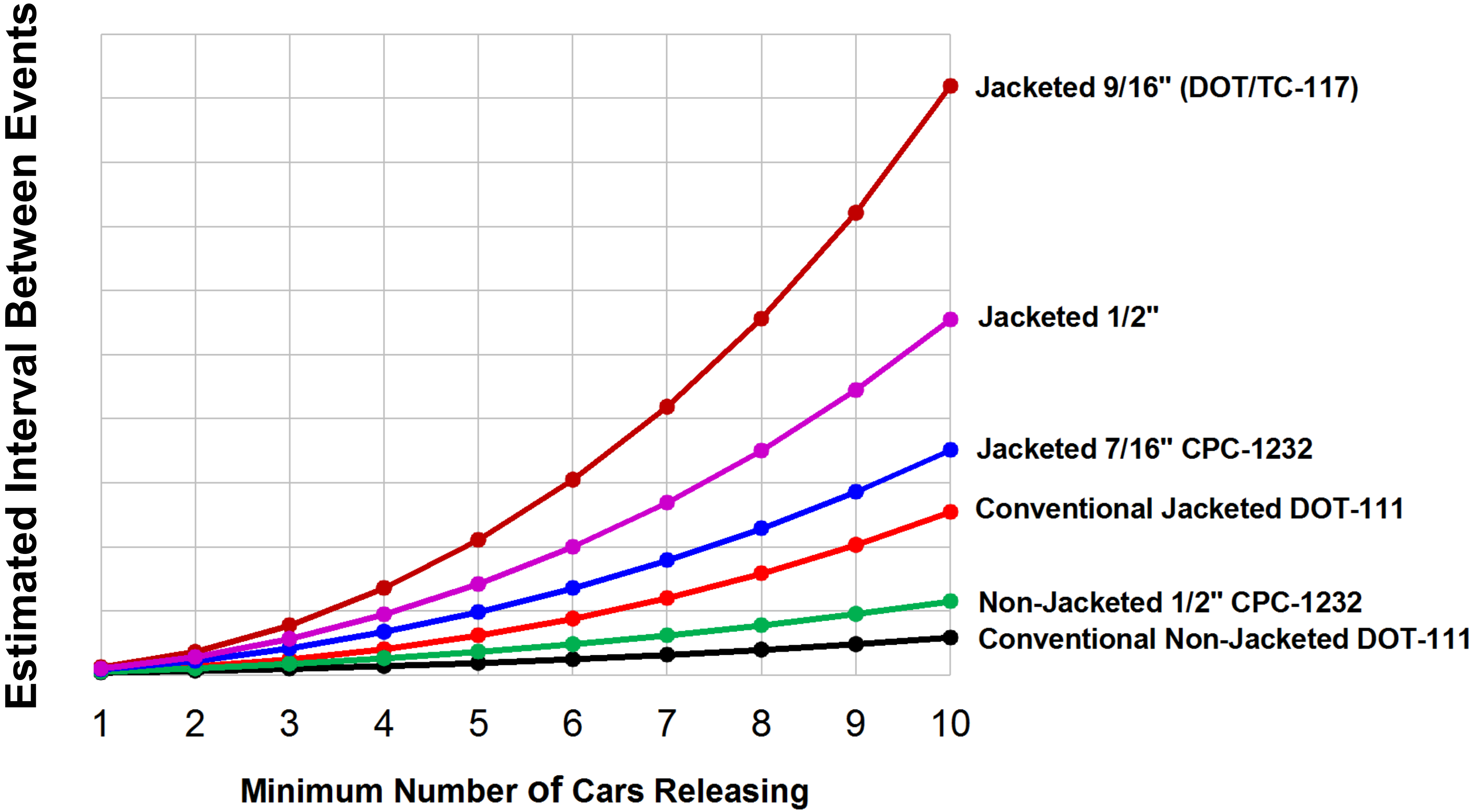
Derailed cars contain hazmat (HM):
- number of HM cars in the train
- train length
- placement of HM cars in the train

HM car releases contents:
- HM car safety design
- operating speed
- accident characteristics

Analytical framework for estimating probability distribution of number of tank cars releasing



Effect of tank car safety design on estimated interval* between multiple-car release incidents



* Assuming 2012 levels of crude oil and alcohol tank car traffic (ca. 550,000 carloads)
Ceteris paribus, the estimated intervals will be reduced in proportion to increases in traffic

Analysis of Train Derailment Rates, Causes, and Changes

Brandon Wang

Graduate Research Assistant

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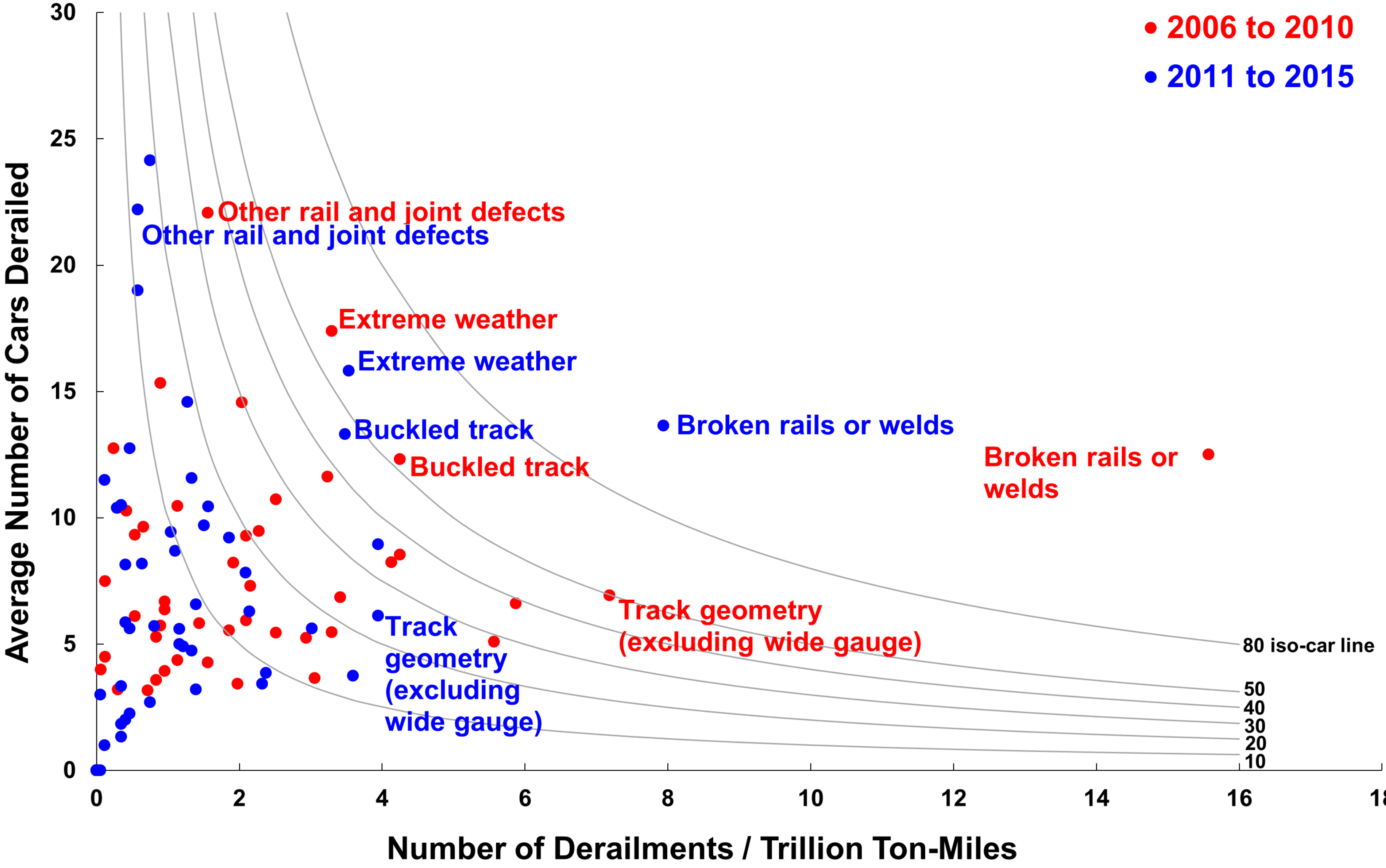
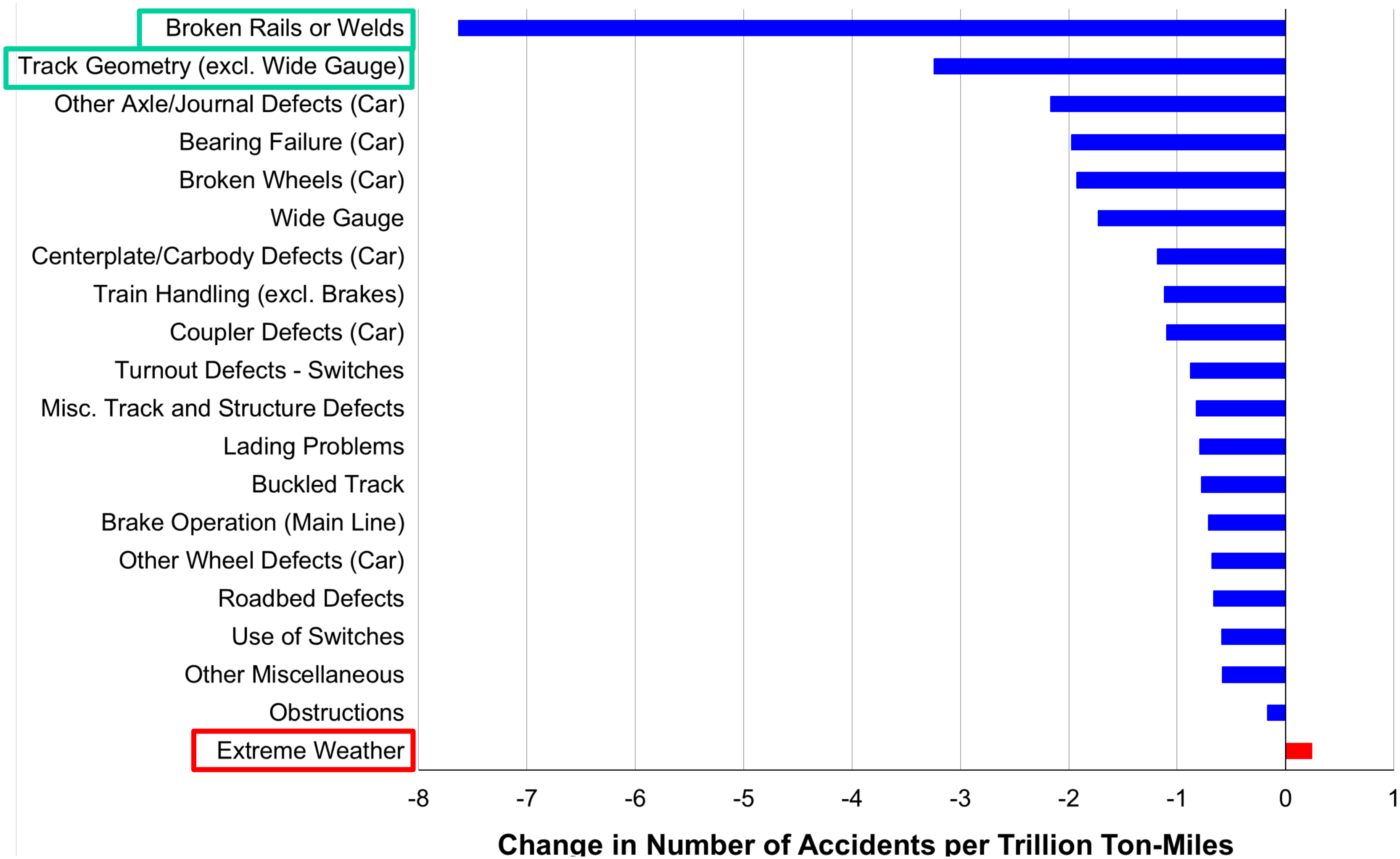
Frequency vs Severity of Mainline Derailments



Changes in Derailment Rate by Cause Group: 2006 – 2010 vs 2011 - 2015

- Broken rails or welds showed the most reduction, followed by track geometry
- Derailments due to extreme weather increased



Loaded versus Empty Unit Train Derailment Cause Analysis

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Undergraduate Research Assistant

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Summary statistics for loaded vs. empty unit train derailments

Loading Condition	Number of Accidents	Tons (1,000s)	Train Length†	Average Speed†	Average Number of Cars Derailed*	Average POD*
Loaded	1,536	14.2	106.9	25.1	11.5	54.4
Empty	303	3.0	106.8	24.8	8.9	41.8
Other	4,180	7.1	77.9	22.5	8.3	34.2

* Denotes that significant difference for loaded and empty train derailments

† Denotes no significant difference between loaded and empty train derailments

- Loaded unit trains were five times more frequent than empty unit trains
- Loaded unit trains weighed over four times more than empty trains
- Similar train length and speed for both loading conditions
- Loaded trains tended to derail more cars
- Position of first derailed (POD) car was farther back in loaded trains than empty

Substantial difference in most frequent causes for loaded & empty unit train derailments

Rank	Loaded Train Causes	Number	Empty Train Causes	Number
1	Broken Rails or Welds	288	Severe Weather	33
2	Broken Wheels (Car)	175	Broken Rails or Welds	31
3	Other Axle/Journal Defects (Car)	127	Track Geometry (excl. Wide Gauge)	25
4	Bearing Failure (Car)	122	Other Wheel Defects (Car)	24
5	Buckled Track	93	Buckled Track	15
6	Track Geometry (excl. Wide Gauge)	80	Lading Problems	13
7	Wide Gauge	74	Other Brake Defect (Car)	10
8	Roadbed Defects	44	All Other Car Defects	10
9	Turnout Defects - Switches	41	Train Handling (excl. Brakes)	9
10	Other Rail and Joint Defects	36	Non-Traffic, Weather Causes	8

Causes in **red are unique** to loaded unit trains, causes in **blue are unique** to empty unit trains and causes in **black are shared** by the two loading conditions

Adjacent Track Accident Risk Model Development

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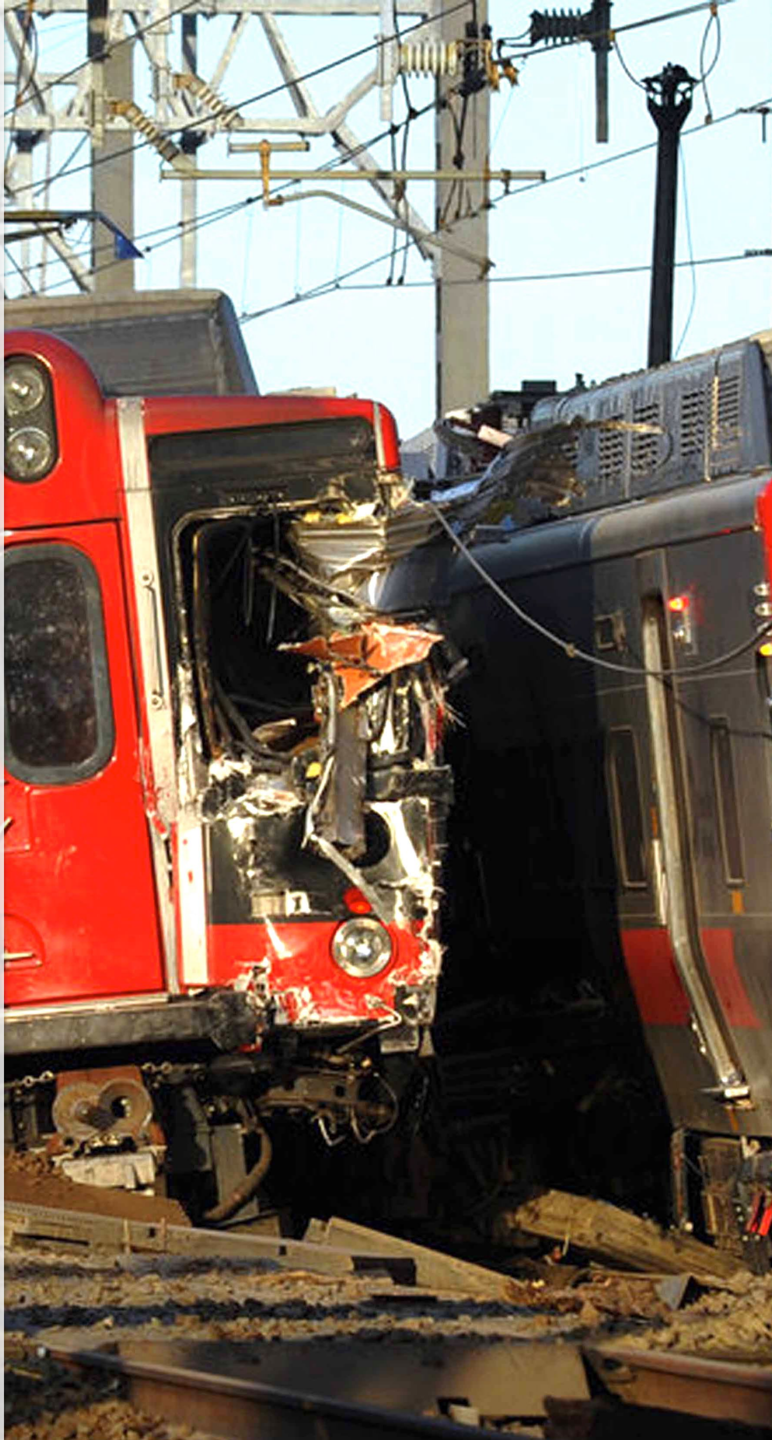
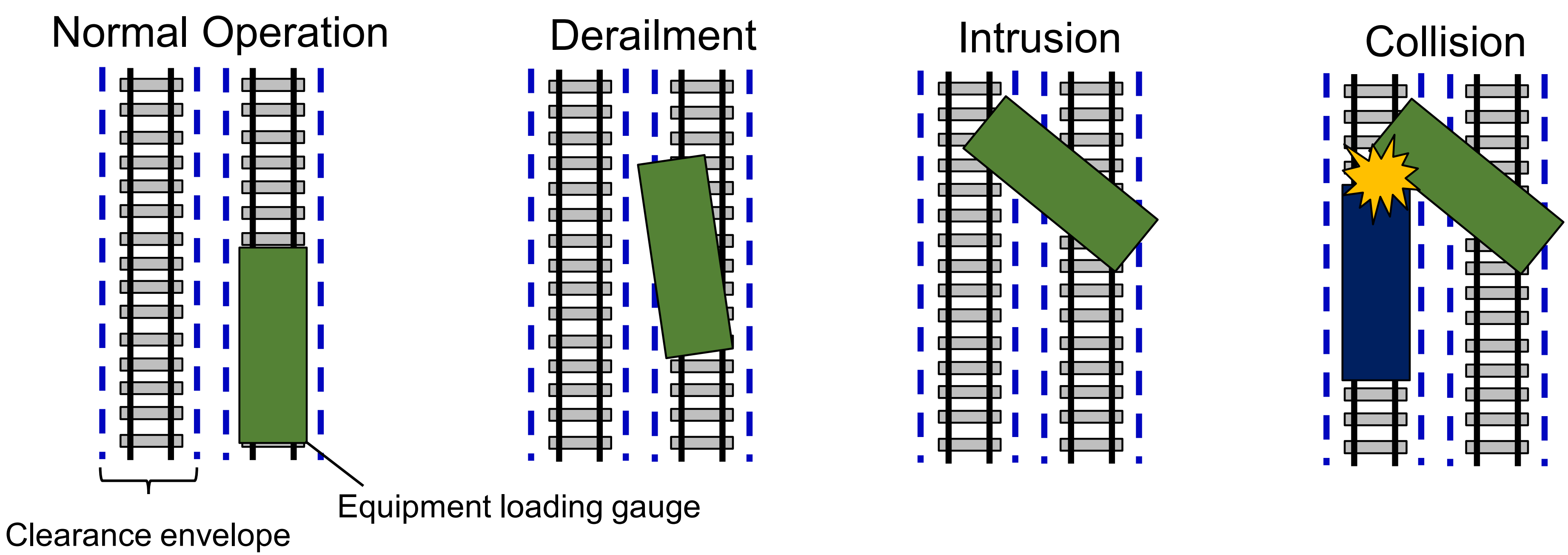


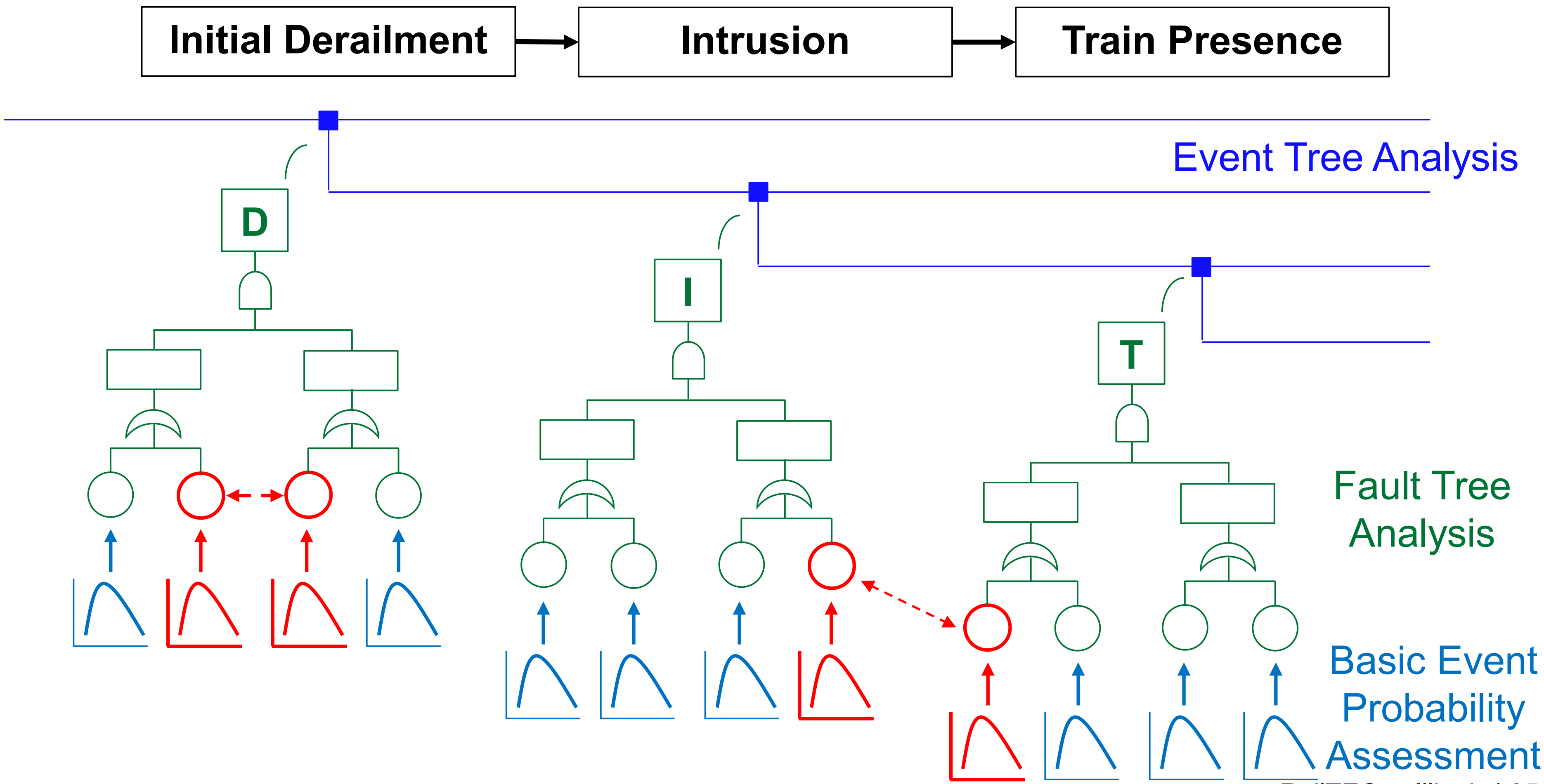
Adjacent track accidents (ATA)

- ATAs refer to train accident scenarios where derailed railroad equipment intrudes upon adjacent tracks, causing operational disruptions and potential subsequent collisions on the adjacent track(s)
- Other ATA scenarios include collisions between trains on adjacent tracks (raking collisions), turnouts, and railroad crossings (side collisions)
- A typical adjacent track accident scenario:



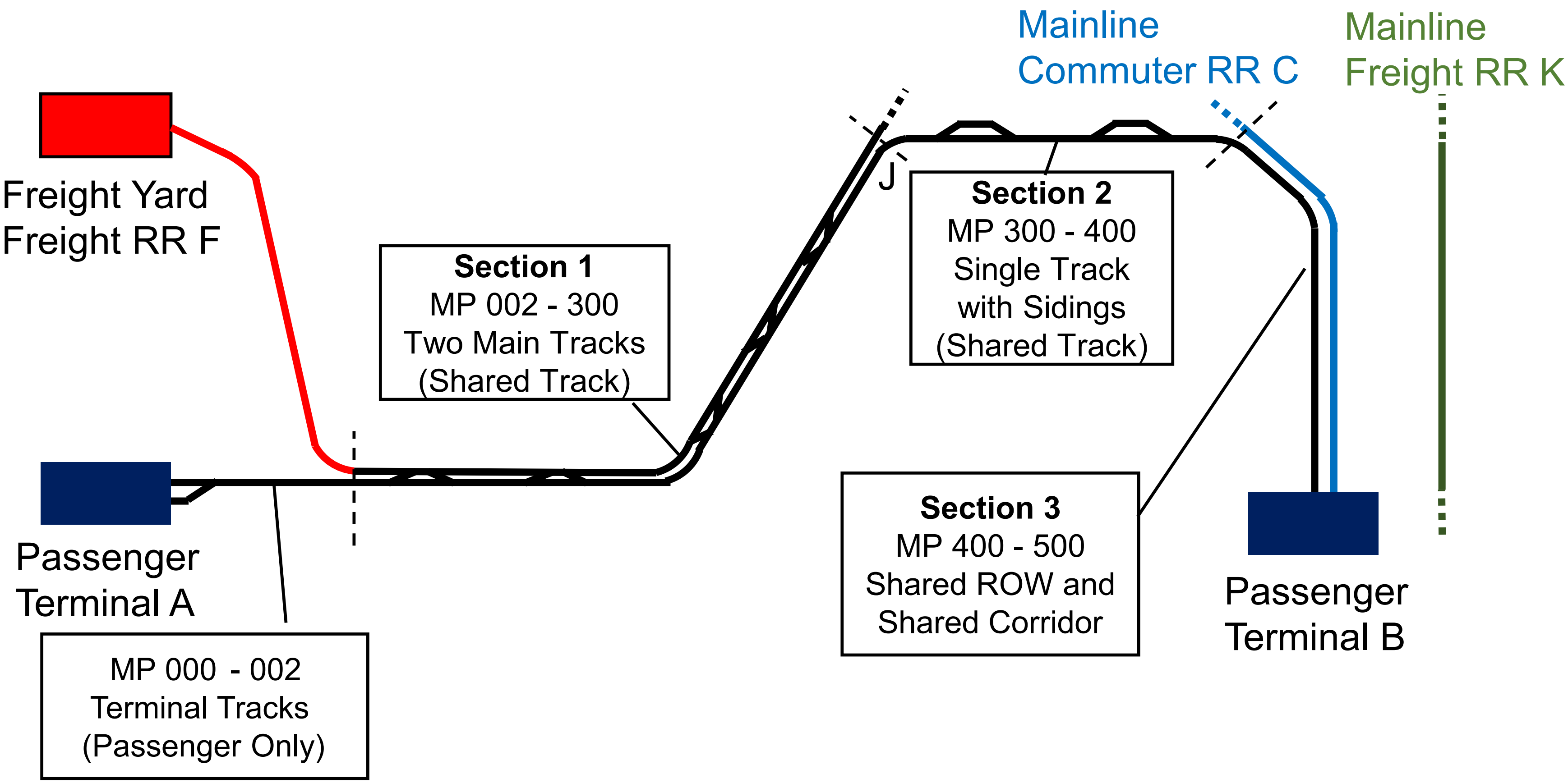
Integrated ATA risk assessment model

- Combine probability models for initial accident, intrusion and train presence on adjacent tracks to develop a holistic risk assessment model for ATA
- Account for common affecting factors in different probability models



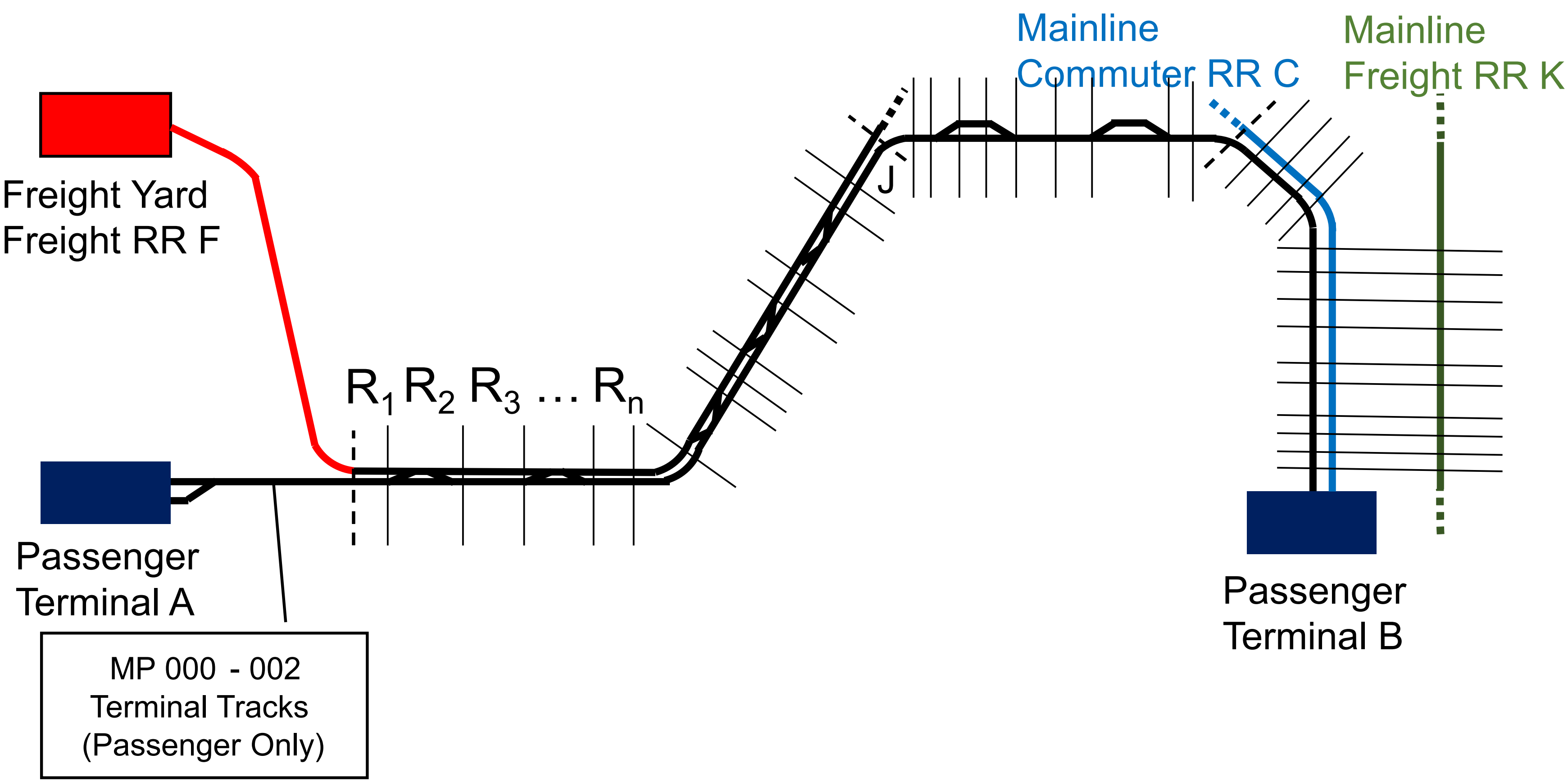
ATA model application: hypothetical shared rail corridor

$$R = P(D) \times P(I|D) \times P(T|I|D) \times C$$

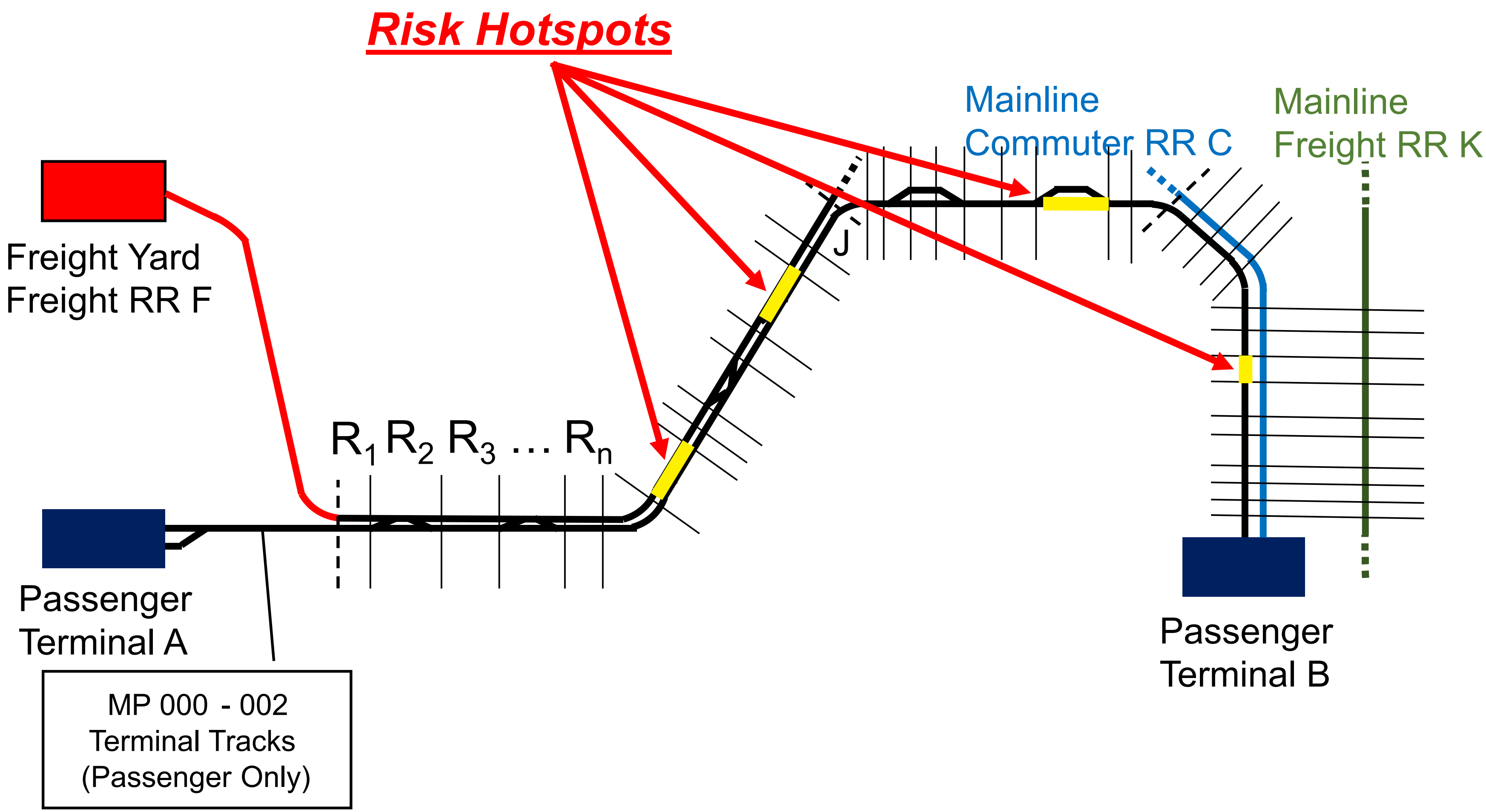


Calculate segment-specific ATA risk

$$R_i = P(D)_i \times P(I|D)_i \times P(T|I|D)_i \times C_i$$



Identify high ATA risk segments



Conclusion: Efficient investment in train safety is essential

- Continued decline in derailment rates benefits the rail industry and the public
- Continued pressure, both internally and externally, for further improvement
- Most effective means of improving train safety becomes less obvious (and often more costly) as incident rate declines
- Industry (and government) must stay focused on identifying the most effective means for improvement
- Increasingly sophisticated data and analytical methods can be used to understand the most efficient ways to invest in safety improvements

Thank you very much!   Questions?

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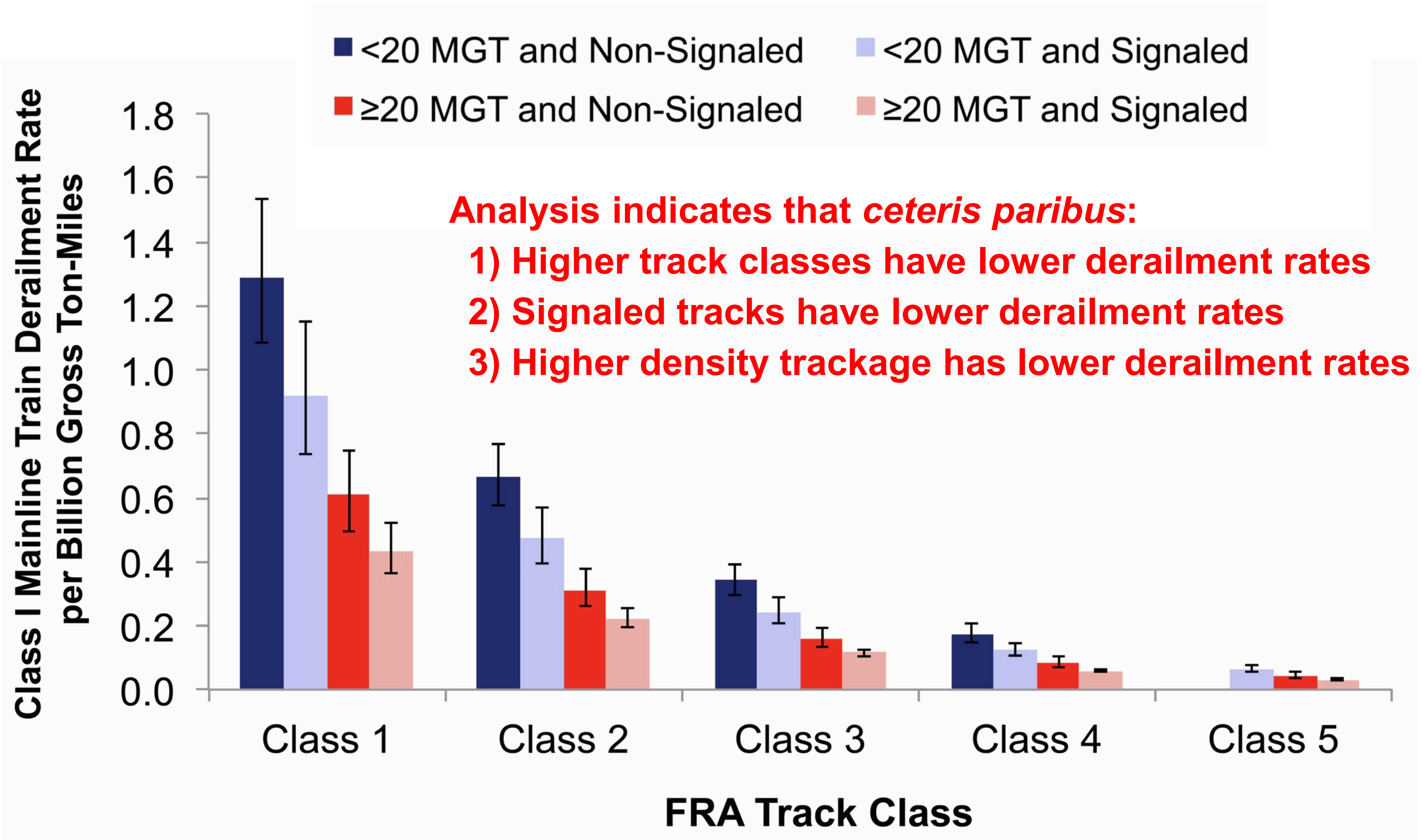
APPENDICES

Current RailTEC Safety and Risk Research Topics

- **Derailment analysis**
  - Factors affecting downward trend and rate
  - Effect of train length on derailment occurrence
  - Quantitative assessment of impact of speed restrictions
  - Early detection of changes in derailment rate
  - Loaded vs empty train unit-train derailment occurrence and causes
- **Hazardous materials transportation safety and risk**
  - Unit vs manifest train risk of hazardous materials transport
  - Risk assessment tools for multiple railroad tank car releases
  - Risk analysis of toxic inhalation hazard tank car implementation
- **Grade crossing risk to railroads**
  - Derailment probability due to grade crossing incidents
  - Consequences of grade crossing incidents
- **Passenger train derailments**
  - Causal analysis and comparison to freight trains
  - Quantitative risk analysis of adjacent-track train accident risk

Three-factor model of mainline freight train derailment rate: track class, method of operation & traffic density



Analysis indicates that *ceteris paribus*:

1. **Higher track classes have lower derailment rates**
2. **Signaled tracks have lower derailment rates**
3. **Higher density trackage has lower derailment rates**

*Liu et al 2017 Freight-train derailment rates for railroad safety and risk analysis. Accident Analysis and Prevention

How did the distribution of derailments change between 2006-2010 and 2011-2015?

Number of Derailments: 2006 - 2010

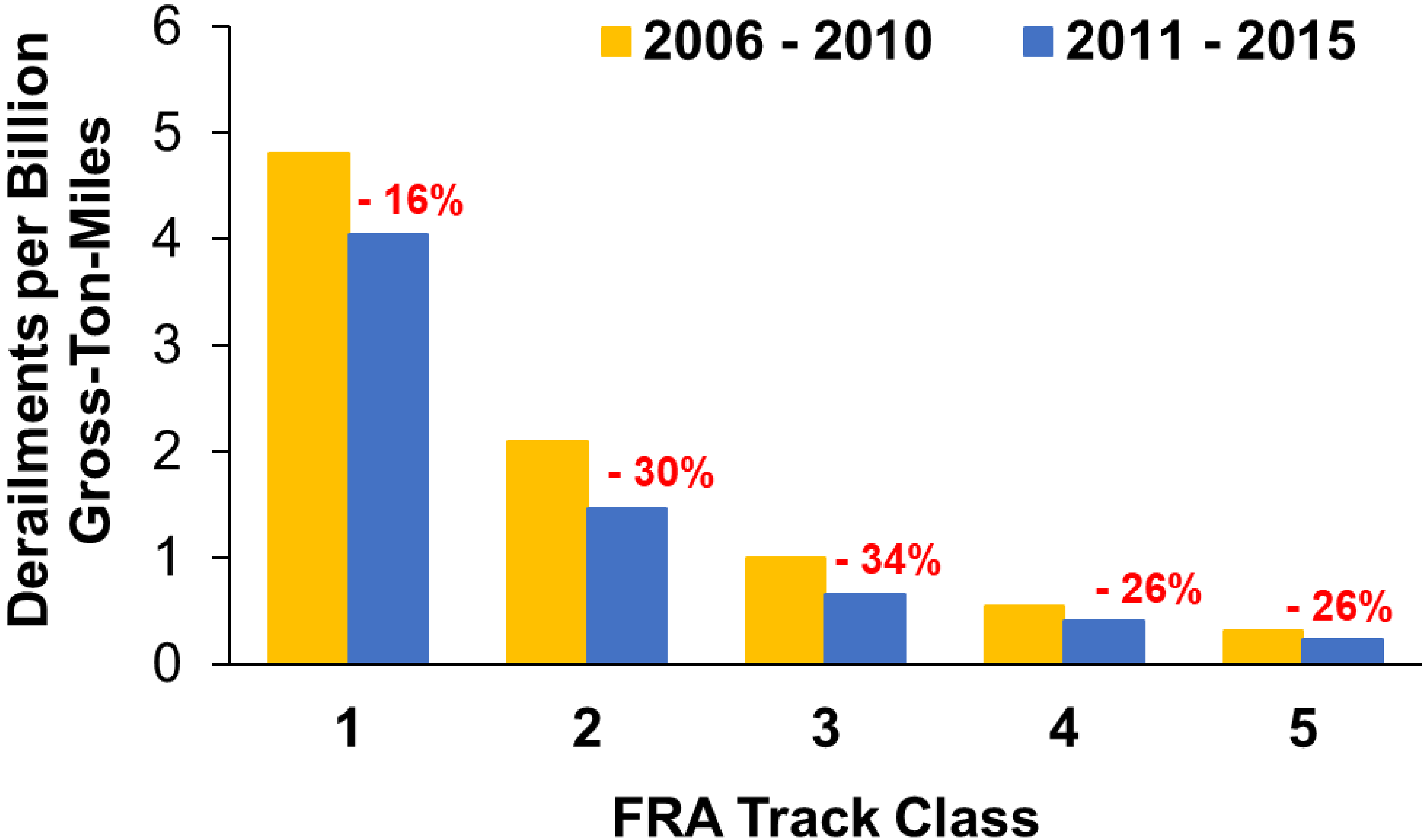
Traffic Density (MGT)	Method of Operation (MO)	FRA Track Class 1	2	3	4	5	Total
<20	Non-Signaled	49	91	73	55	3	271
	Signaled	17	31	49	52	8	157
≥20	Non-Signaled	8	22	30	77	5	142
	Signaled	31	94	130	387	141	783
		105	238	282	571	157	1,353

Number of Derailments: 2011 - 2015

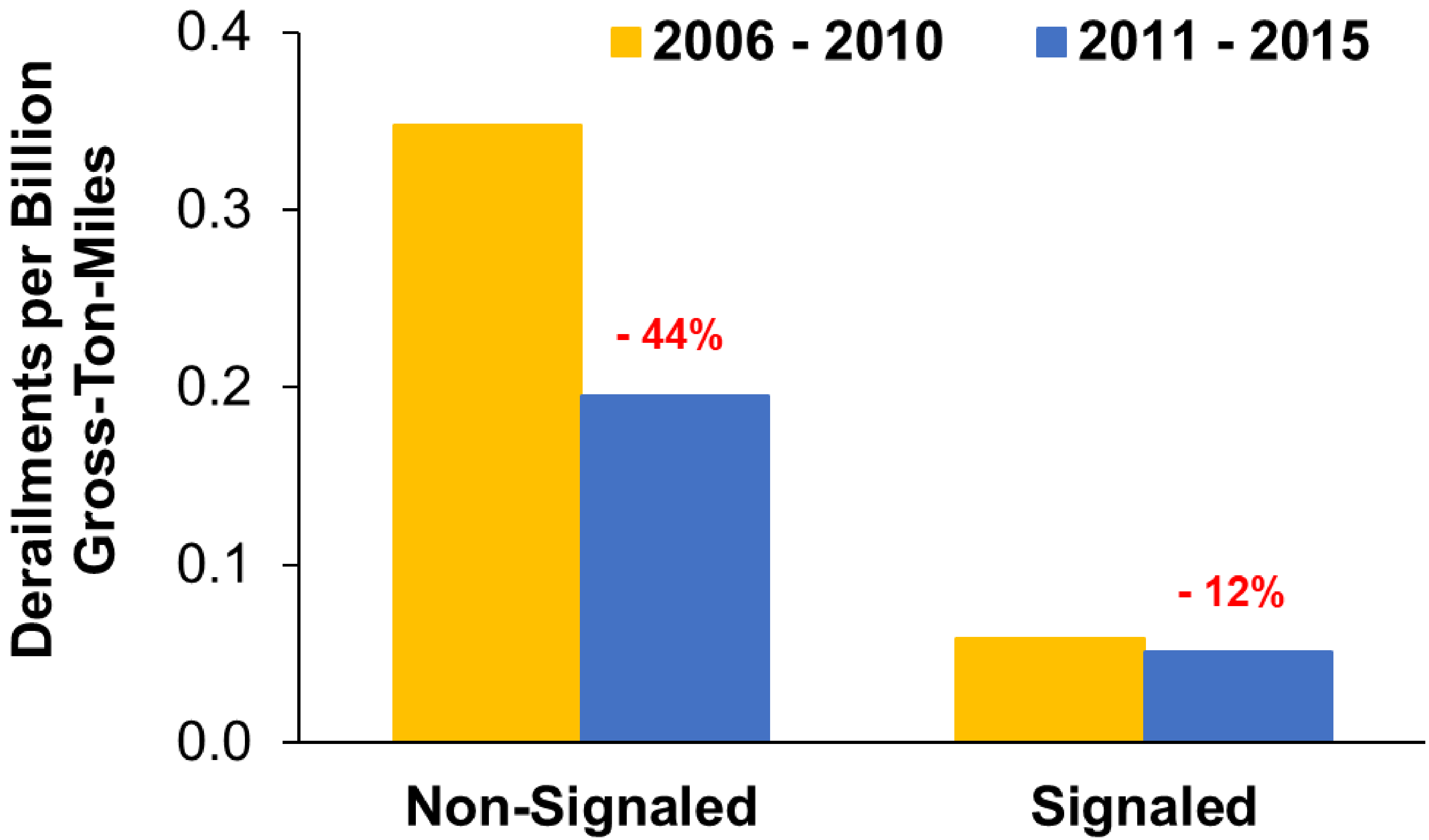
Traffic Density (MGT)	Method of Operation (MO)	FRA Track Class 1	2	3	4	5	Total
<20	Non-Signaled	28	48	43	43	0	162
	Signaled	17	31	44	62	10	164
≥20	Non-Signaled	7	10	8	27	0	52
	Signaled	25	61	97	312	102	597
		77	150	192	444	112	975

*Gross Ton-Miles: 2006 to 2010 = 16.7 trillion, 2011 to 2015 = 17.2 trillion

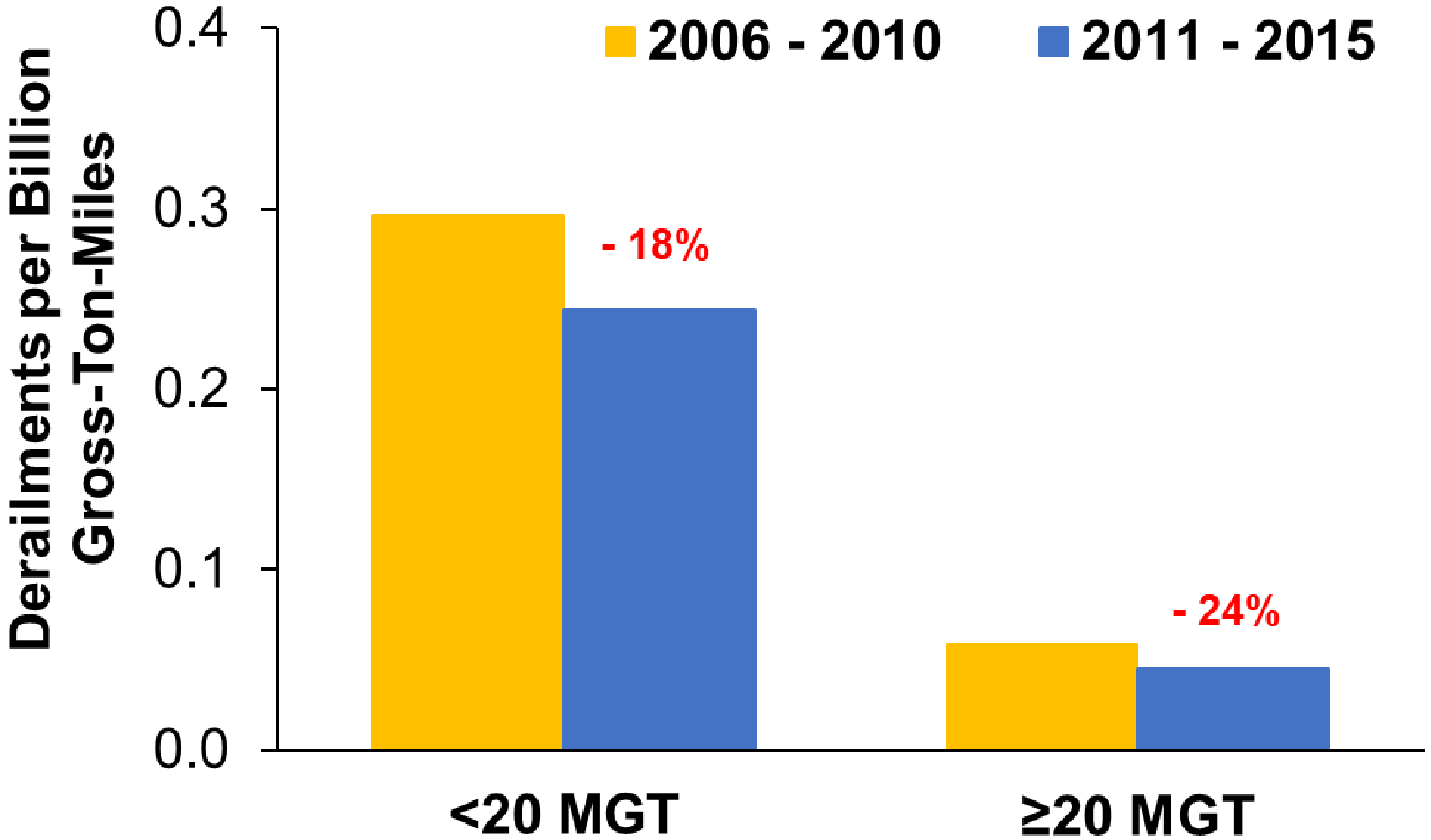
Change in Estimated Derailment Rate by FRA Track Class



Change in Estimated Derailment Rate by Method of Operation

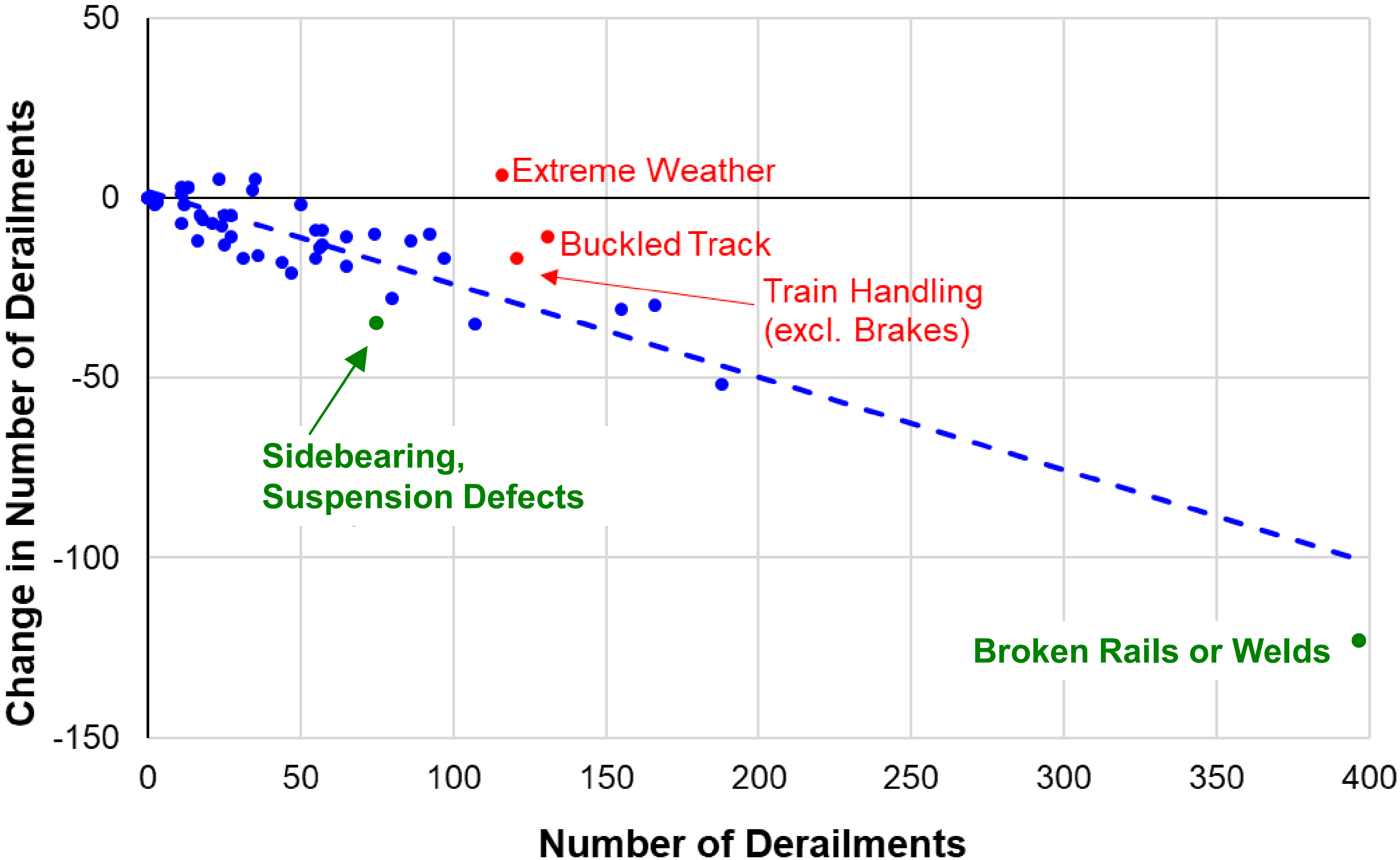


Change in Estimated Derailment Rate by Traffic Density

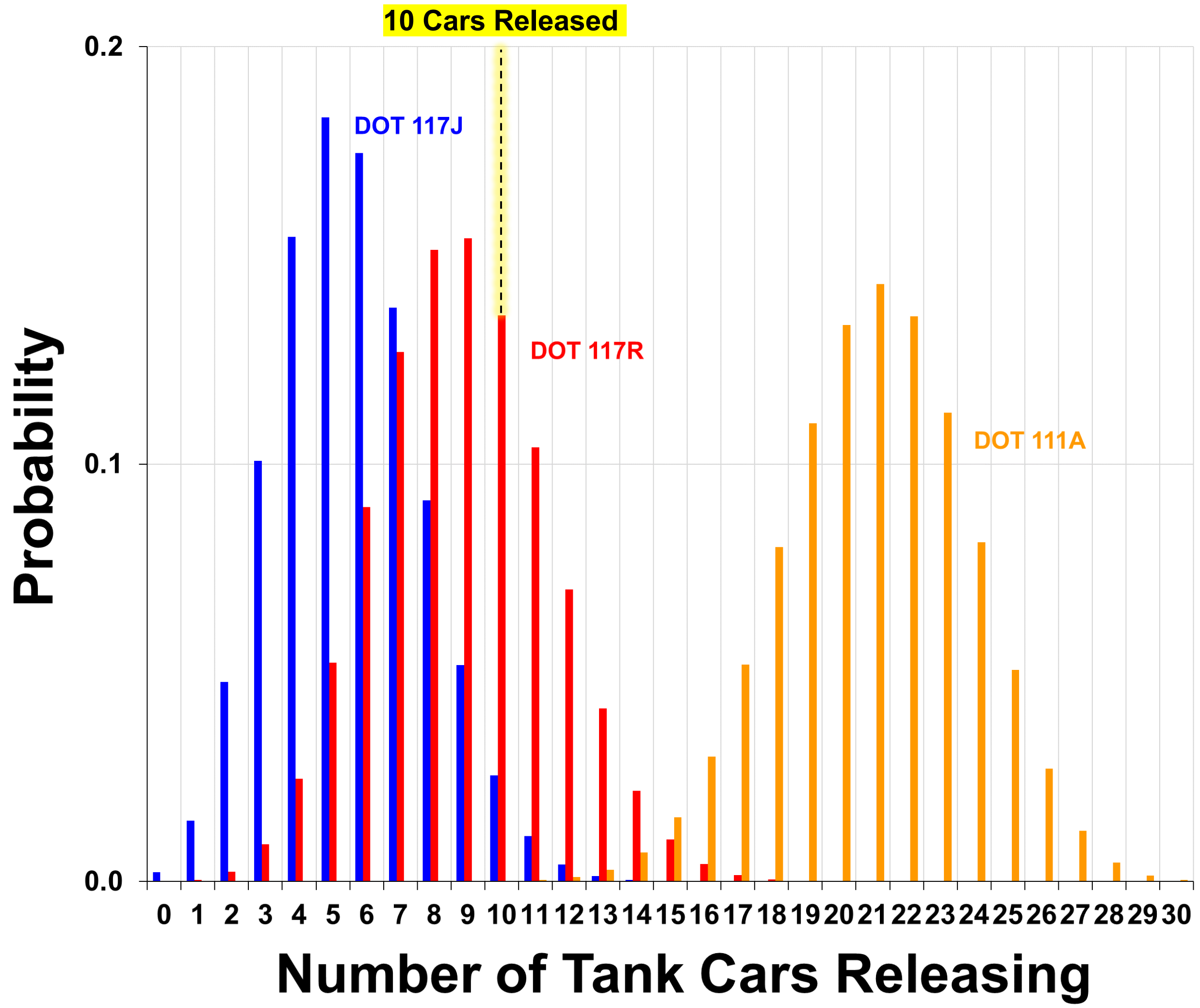


Did Derailment Causes Show Uniform Rates of Change?

- Was the decline in accident causes proportional to their frequency or did some decline at a rate greater (or less) than average?
- Statistical analysis of the change in cause-specific derailment frequency



Estimated Probability Distribution and Actual Number of Cars Releasing



Cumulative Frequency Distribution of Loaded, Empty and Other Type Train Derailments