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Risk Analysis in LNG by Rail

Safe Transportation of Liquefied Natural Gas by Railroad Tank Car - Phase II: Public Meeting 3

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Overview – and Author Bios

- Methods for Assessing Risk in LNG Transportation
- Uncertainty in Transportation Risk Analysis - LNG by Rail
- Assessing the Risk Calculations

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LNG Initiatives

- Dual Fuel Locomotives
- Commodity Transport
  - ISO containers
  - DOT-113 tank cars

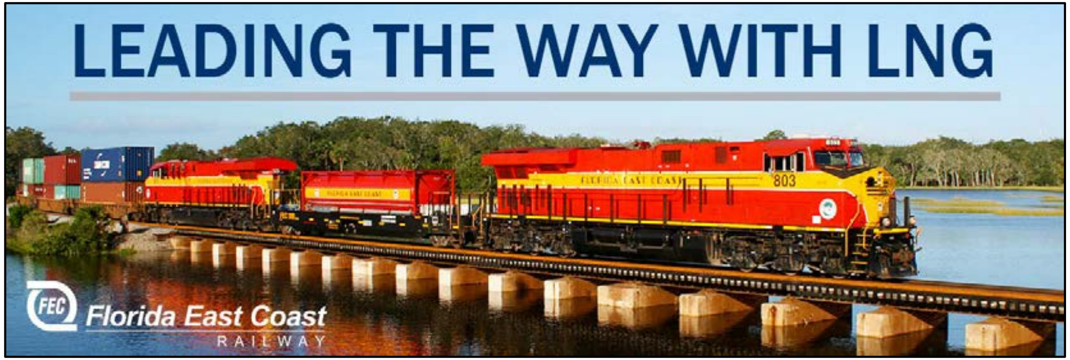
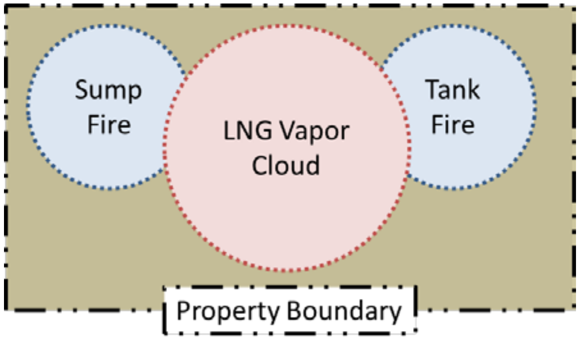


Chart Industries

Methods for Assessing LNG Transportation Risk

Assessing LNG Risks

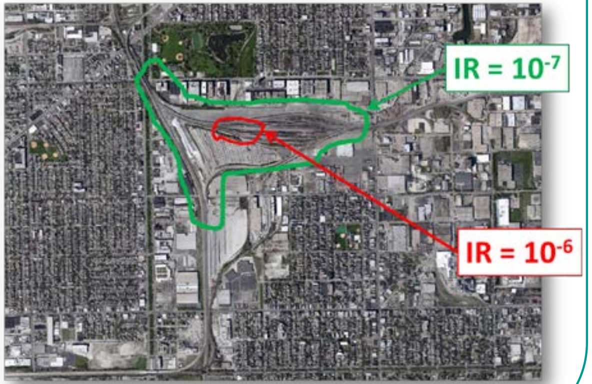
Regulatory – Prescriptive



Qualitative Risk

	Descriptions		Likelihood			
			So unlikely …	Unlikely but possible	Likely …in life of an item, several times in the fleet.	…several times in life of an item, frequently in the fleet.
			1	2	3	4
Severity	More than 3 fatalities to crew and public	1	4	8	12	16
	Up to 3 fatalities injuries to crew and public	3	3	6	9	12
	No fatalities, non-life threatening injuries to crew or public	2	2	4	6	8
	No injury or health impacts to crew	1	1	2	3	4

Quantitative Risk



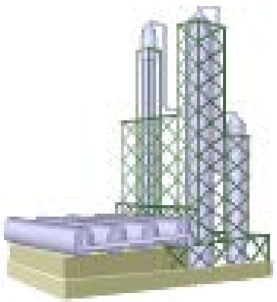
Increasing Complexity and Level of Effort

Analyzing the Risk - QRA

Quantitative Risk Calculations

Train Accident Model
- Frequency
- Leak cause
- Hole size
- Hole orientation

Source Model
- Temp, Pres
- Inventory
- Discharge effects



Fence line

Consequence Model
- Evaporation
- Cloud dispersion
- Pool fire
- Jet fire
- Flash fire
- Explosion

Probabilistic Outcomes Model
- Combinations of consequences
- Populations

Quantitative Risk Assessment

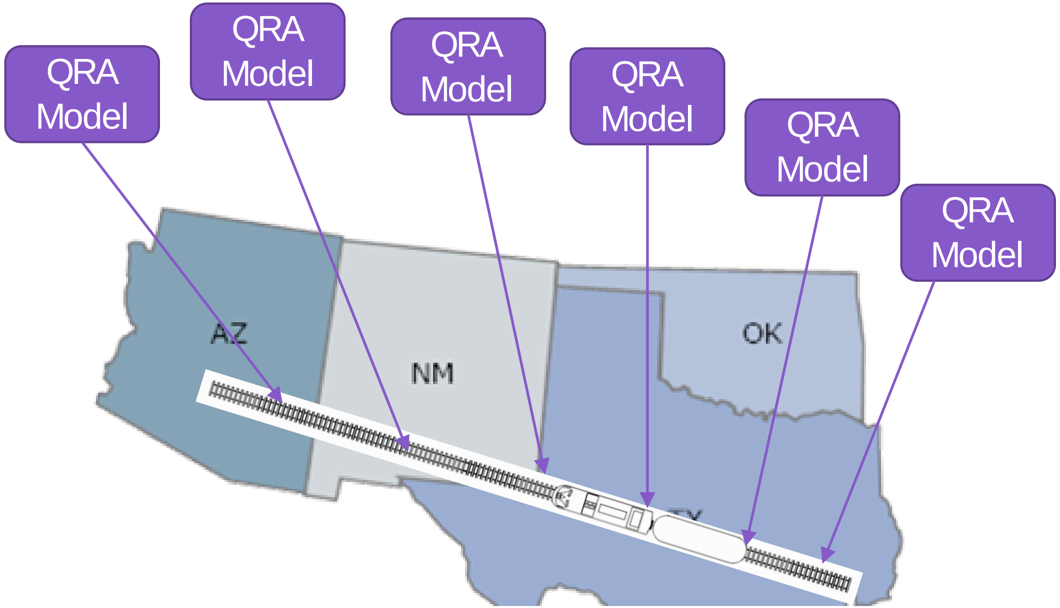
Risk Drivers

Risk Tolerability Thresholds

Risk Mitigation

Fixed Site QRA Differs from a TRA

Risk Must Be Analyzed Along a Route



Quantitative Risk Assessment

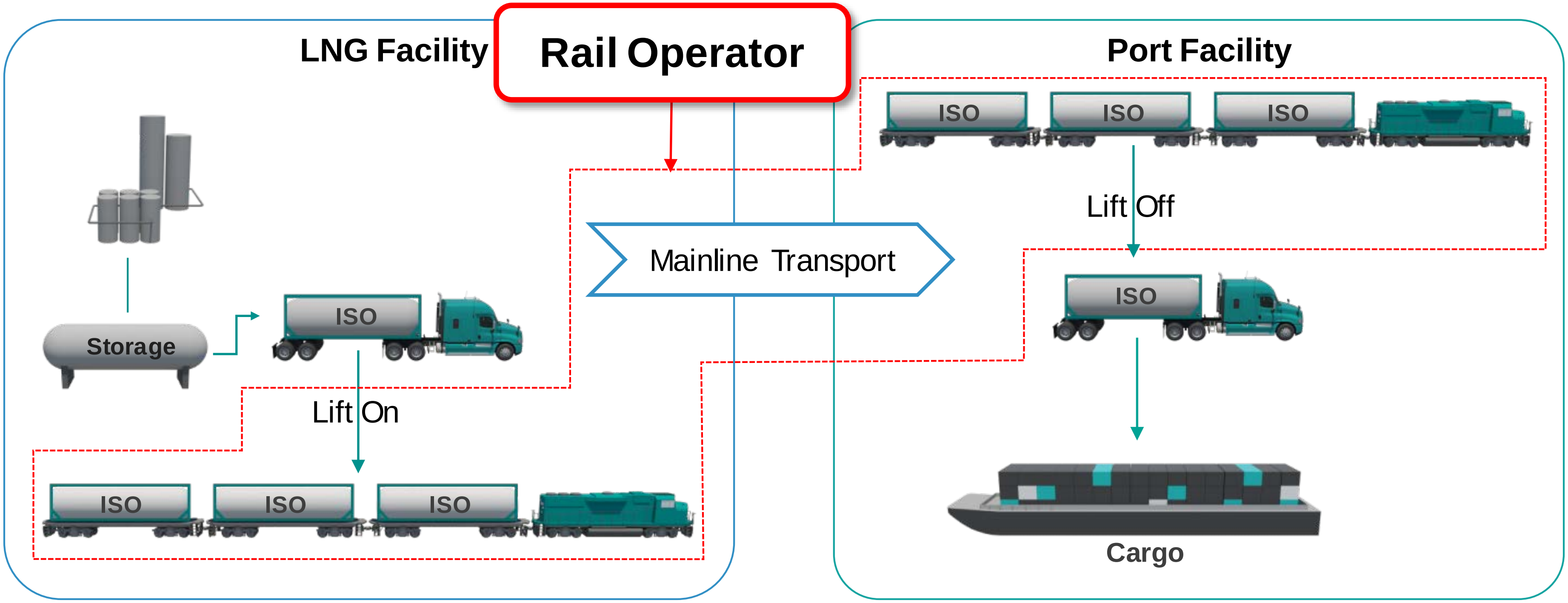
Risk Drivers

Risk Tolerability Thresholds

Risk Mitigation

Uncertainty in Transportation Risk Analysis - LNG by Rail

Example Transportation Cycle of LNG - ISOs



Defining a Train Accident Model

- Causing a loss of containment
- Route location
  - Grade crossing, tunnel, urban vs rural
- Rail activity
  - Main line, interchange, sidings, rail yards
- Rail speed
- Train configuration

Train Accident Model

Accident Model

Train Accident Rate × Derailment Probability × Release Size Probability = Scenario Frequency

Train Accident Rate – Sources of Uncertainty

Train Accident Rate × Derailment Probability × Release Size Probability = Scenario Frequency

	LNG Rail (avg/yr) (HAZMAT Pressure Cars)	LPG Rail (avg/year)
Annual Miles (CFS)	1,383,922,222	64,866,667
Annual Accidents (PHMSA)	765	39
Annual Frequency (/mile/yr)	5.5E-07	5.9E-07

Hart RJ and Morrison DR, "The hazard we know: Comparing transportation risk of LPG and LNG," in Spring National Meeting and 11th Global Congress on Process Safety, 2015.

Train and Road Accident Frequency Rates: Using Pressure Cars/Tankers as an Analog for DOT113/MC338

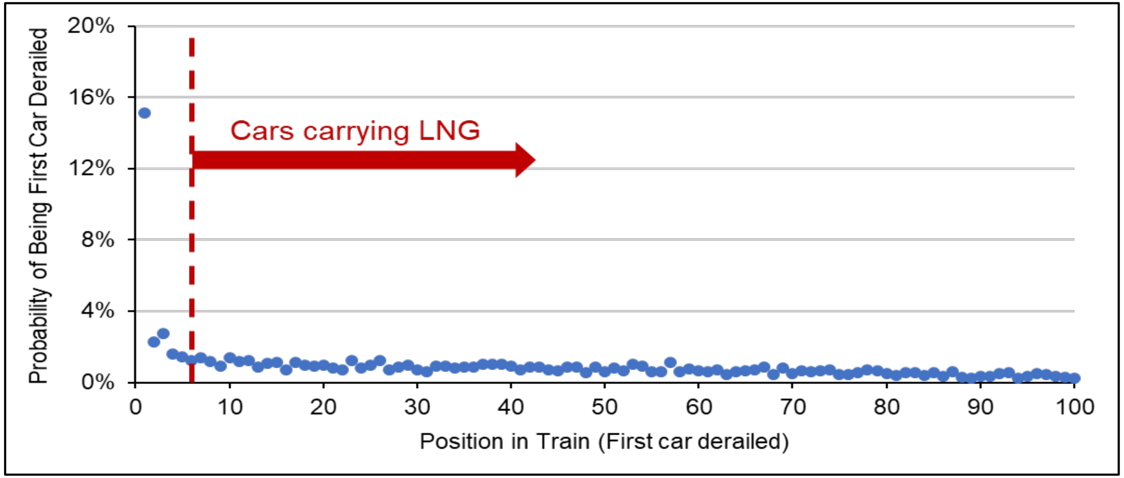
	LNG Rail (avg/yr) (HAZMAT Pressure Cars)	LPG Rail (avg/year)
Annual Miles (CFS)	1,383,922,222	64,866,667
Annual Accidents (PHMSA)	765	39
Annual Frequency (/mile/yr)	5.5E-07	5.9E-07

	LNG Road (avg/yr) (HAZMAT Pressure Tankers)	LPG Road (avg/yr)
Annual Miles (CFS)	10,357,300,000	293,300,000
Annual Accidents (PHMSA)	978	28
Annual Frequency (/mile/yr)	9.4E-08	9.4E-08

Hart RJ and Morrison DR, "The hazard we know: Comparing transportation risk of LPG and LNG," in Spring National Meeting and 11th Global Congress on Process Safety, 2015.

Derailment Probability – Sources of Uncertainty

Train Accident Rate × **Derailment Probability** × Release Size Probability = Scenario Frequency



Morrison DR, Hart RJ, Morris JM, Wikramanayake ED, Song S. "Minimizing Risk of Unit Trains of Hazmat," 17th Global Congress on Process Safety, Virtual Conference, April 18 - 22, 2021.

Release Size – Sources of Uncertainty

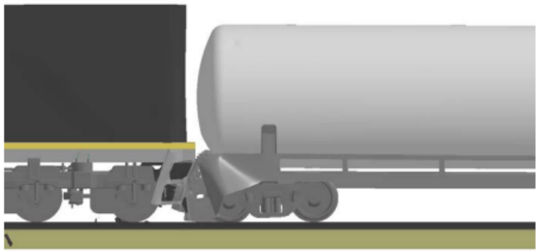
Train Accident Rate × Derailment Probability × **Release Size Probability** = Scenario Frequency

Crashworthiness and Puncture Protection Analyses of LNG Tenders

Final Report

Association of American Railroads

Applied Research Associates, Inc.



(b) Crash response at the leading locomotive interface

Figure 45. Analysis of the train crash scenario with the enhanced tender design (45 mph closing speed).

Figure 49. Tractor-trailer impact response on the tender.

Estimating Hole Size Probability

Train Accident Rate × Derailment Probability × **Release Size Probability** = Scenario Frequency

		LNG Releases (Pressurized Tank Cars)		Propane Releases	
Quantity Released	Release Type	Count	%	Count	%
No Release (=< 100)	no release	4946	95.9%	2293	94.5%
100 < x =< 1,000	0.5" hole	71	1.4%	32	1.3%
1,000 < x =< 30,000	2" hole	127	2.5%	84	3.5%
> 30,000	catastrophic	15	0.3%	17	0.7%

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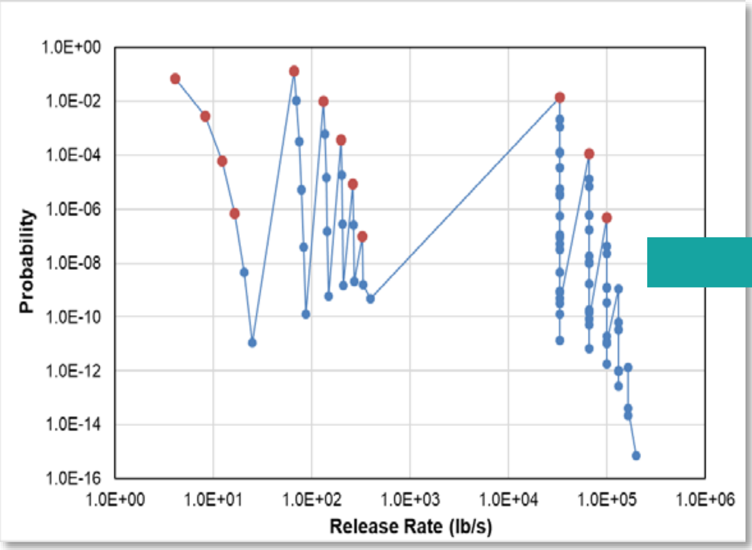
Accident Model

Train Accident Rate × Derailment Probability × Release Size Probability = Scenario Frequency

Probabilistic Scenario Frequency



Release rate (lb/s)	Release Frequency (/year)	Release rate (lb/s)	Release Frequency (/year)	Release rate (lb/s)	Release Frequency (/year)
6 T-75 ISOs		7 T-75 ISOs		8 T-75 ISOs	
0.00	4.46E-05	0.00	4.26E-05	0.00	4.06E-05
4.25	4.38E-06	4.28	4.91E-06	4.32	5.40E-06
65.5	8.50E-06	65.5	9.61E-06	65.5	1.06E-05
131	6.14E-07	131	8.33E-07	135	1.14E-06
197	2.37E-08	197	4.01E-08	264	2.30E-09
262	5.19E-10	263	1.18E-09	1 ISO	1.39E-06
1 ISO	1.05E-06	1 ISO	1.22E-06	2 ISOs	1.47E-08
2 ISOs	7.90E-09	2 ISOs	1.10E-08	3 ISOs	8.85E-11
3 ISOs	3.18E-11	3 ISOs	5.55E-11		
Release rate (lb/s)	Release Frequency (/year)	Release rate (lb/s)	Release Frequency (/year)	Release rate (lb/s)	Release Frequency (/year)
9 T-75 ISOs		10 T-75 ISOs		11 T-75 ISOs	
0.00	3.88E-05	0.00	3.70E-05	0.00	3.53E-05
4.35	5.84E-06	4.38	6.24E-06	4.42	6.60E-06
65.5	1.16E-05	65.5	1.25E-05	65.5	1.33E-05
135.1	1.43E-06	136	1.75E-06	131	1.92E-06
263.9	4.03E-09	264	6.55E-09	200	1.76E-07
1 ISO	1.56E-06	1 ISO	1.73E-06	329	4.01E-10
2 ISOs	1.88E-08	2 ISOs	2.34E-08	1 ISO	1.90E-06
3 ISOs	1.32E-10	3 ISOs	1.89E-10	2 ISOs	2.85E-08
				3 ISOs	2.59E-10

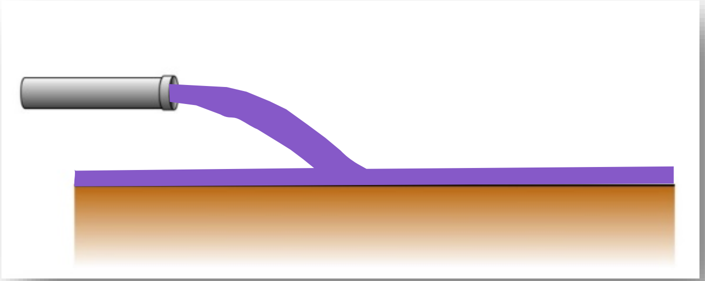
Morrison DR, Hart RJ, Morris JM, Wikramanayake ED, Song S. “Minimizing Risk of Unit Trains of Hazmat,” 17th Global Congress on Process Safety, Virtual Conference, April 18 - 22, 2021.

Release Analysis – Fluid Behavior

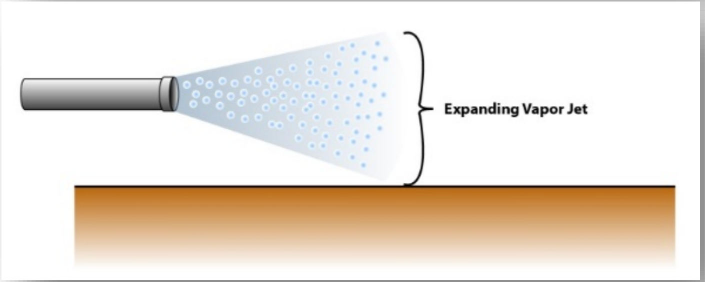
Release Dynamics

- Release Rates and Duration
- Liquid
  - Pooling
  - Flash fire/VCE from evaporation
- Gas
  - Flash fire to LFL
  - Explosion (VCE)
  - Jet Fire
- Liquid and Gas
  - All of the above

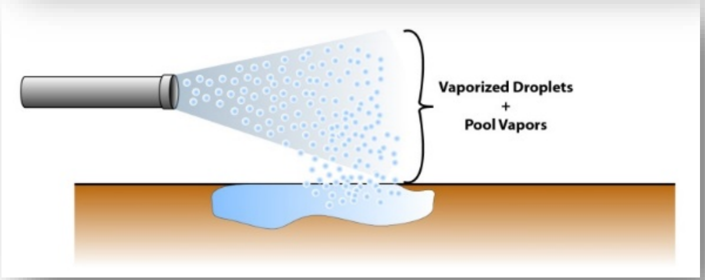
Liquid



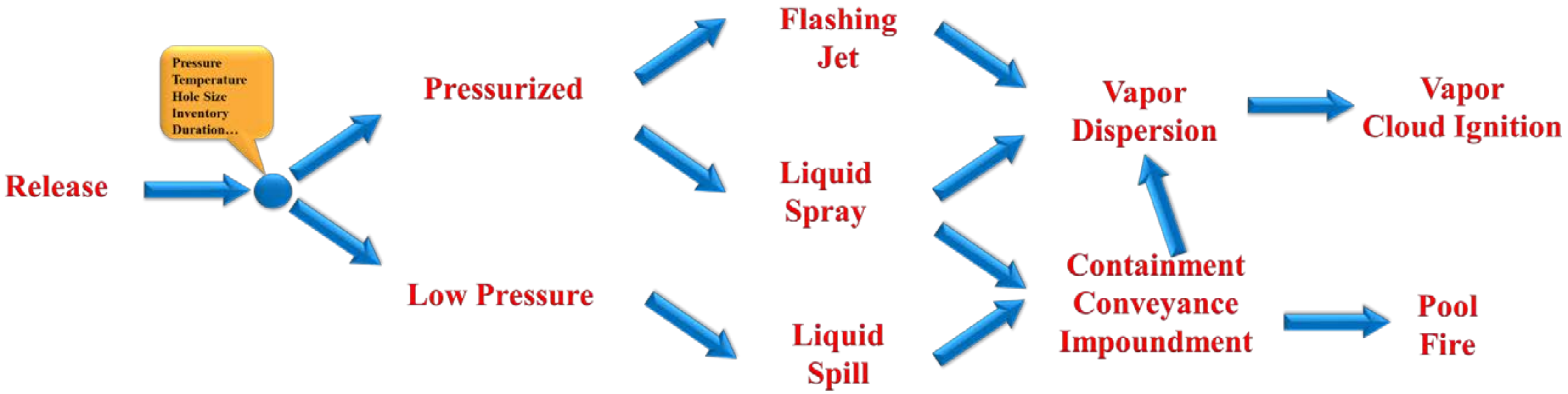
Gas



Liquid and Gas



Release Model



Release Conditions– Sources of Uncertainty

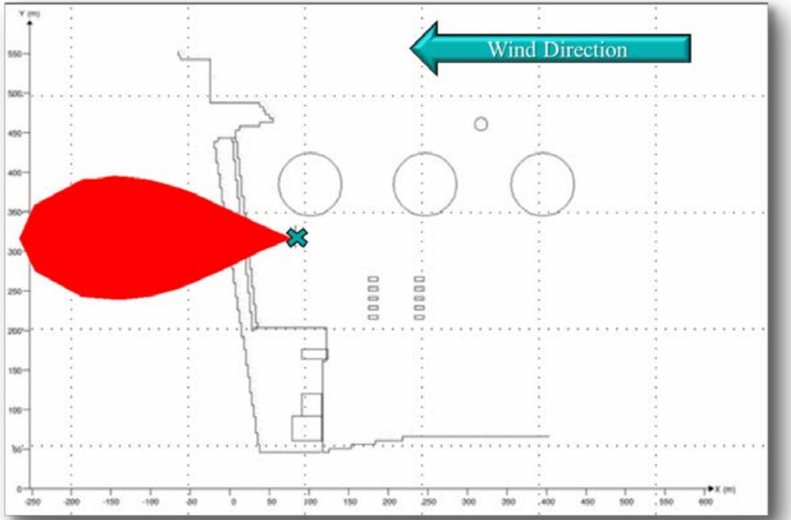
- Accidents: collision, fire, derailment, blockage, natural disaster, etc[1]
- Accident conditions are **not always at steady-state or equilibrium conditions**
- Accident conditions can have large effect on the release dynamics
  - **Pressure**
  - **Temperature**

Petroleum released from a tank derailment in Quebec resulting in 47 fatalities from the fires and explosions[2]

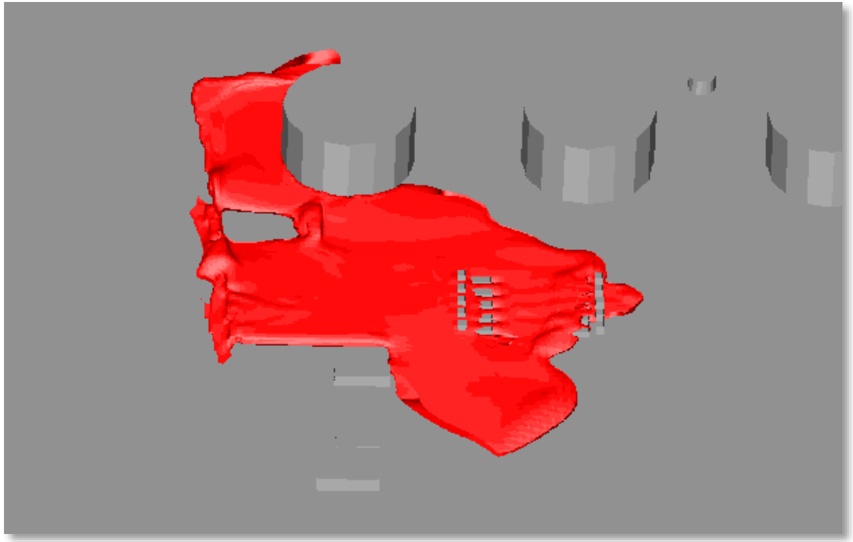
1 Pope M, Drewes J, May J. Generic hazard list for railway systems. In 7th World Congress on Railway Research, Montreal 2006.
2 Tadros WA. Chair, Transportation Safety Board of Canada, Lac-Mégantic, Quebec, Release of Railway Investigation Report R13D0054, August 19, 2014.

Modeling Tools/Complexity

Integral Models



CFD Models

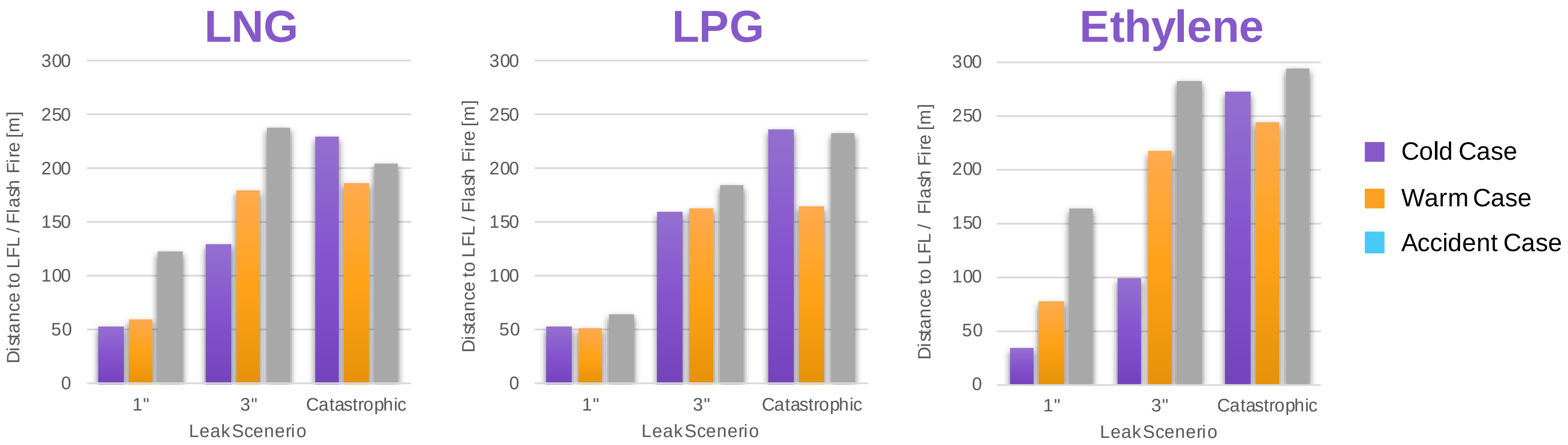


Study Release Conditions

- Three bounding release cases are investigated

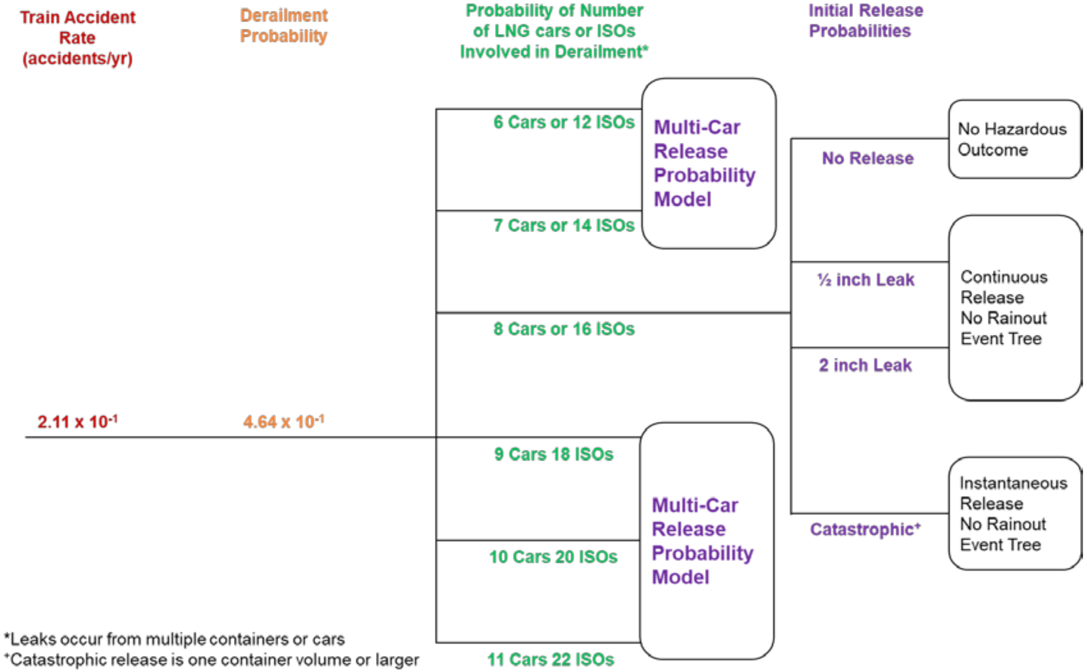
Case	Conditions
Cold	**Loading conditions** for the chemical at its normal boiling point and atmospheric pressure (LNG and ethylene) or slightly pressurized at room temperature (LPG).
Warm	**Transportation conditions** of increased temperature due to time in tank. Saturation temperature is observed at the pressure relief valve setpoint.
Accident	**Worst case scenario** where tank is compressed (likely to occur in an accident) recently after loading resulting in the pressure relief valve setpoint and normal boiling point

LFL / Flash Fires Hazard Distances



Morris JM, Morrison DR, and Hart RJ, "Sensitivity Analysis of Transport Conditions on Liquefied Gas Hazards," in 2019 Spring Meeting and15th Global Congress on Process Safety, AIChE, 2019.

Pulling the QRA Together



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Assessing the Risk Calculations

How do you measure risk?

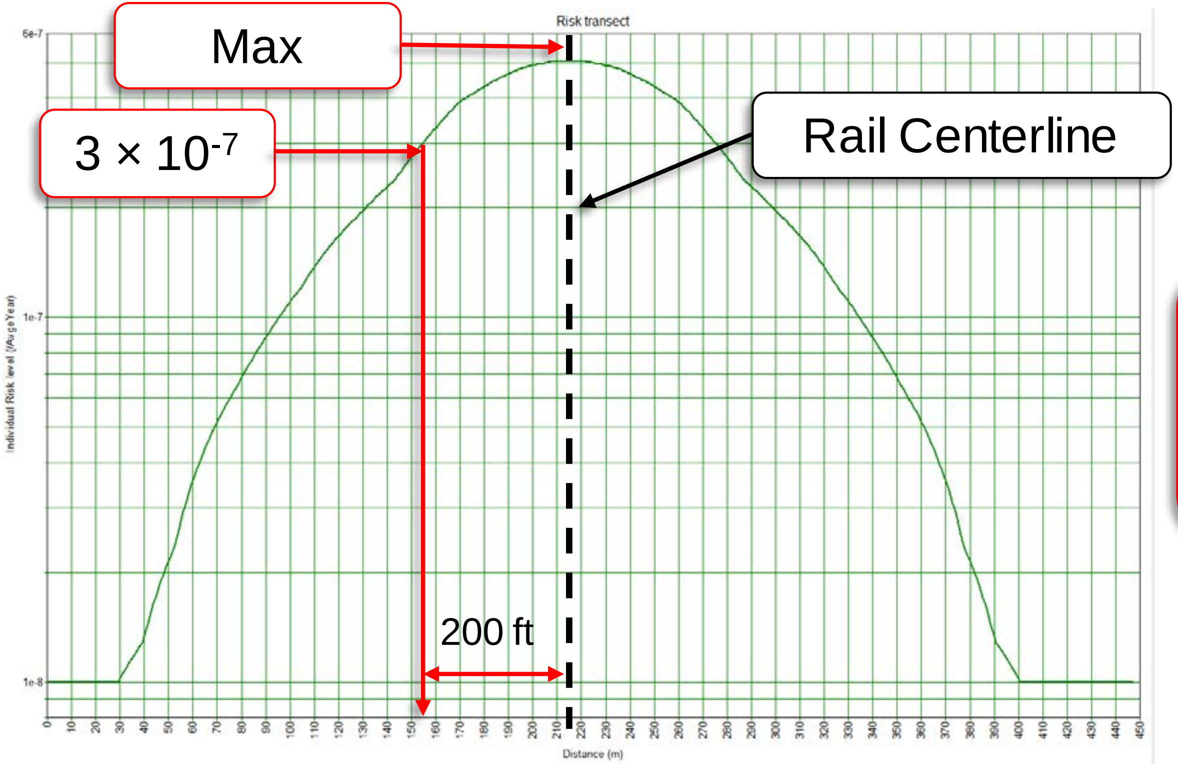
- What do calculations mean?
- These aren’t predictions
- Comparison to “acceptable” or “known” risks
- Comparison to regulatory thresholds, e.g., Netherlands
- Comparison to industry standards, e.g., NFPA 59A
- Identify opportunities for risk reduction

Individual Risk (IR) - Stationary LNG Plants

Criterion Annual Frequency (yr^{-1})	Permitted Developments
Zone 1 $IR > 10^{-5}$	All land uses under the control of the plant operator or subject to an approved legal agreement
Zone 2 $3 \times 10^{-7} \leq IR \leq 10^{-5}$	General public areas excluding sensitive establishments*
Zone 3 $IR < 3 \times 10^{-7}$	No restrictions
*Sensitive establishments are institutional facilities that might be difficult to evacuate. Examples include, but are not limited to, schools, daycare facilities, hospitals, nursing homes, jails, and prisons.	

NFPA 59A (2019)

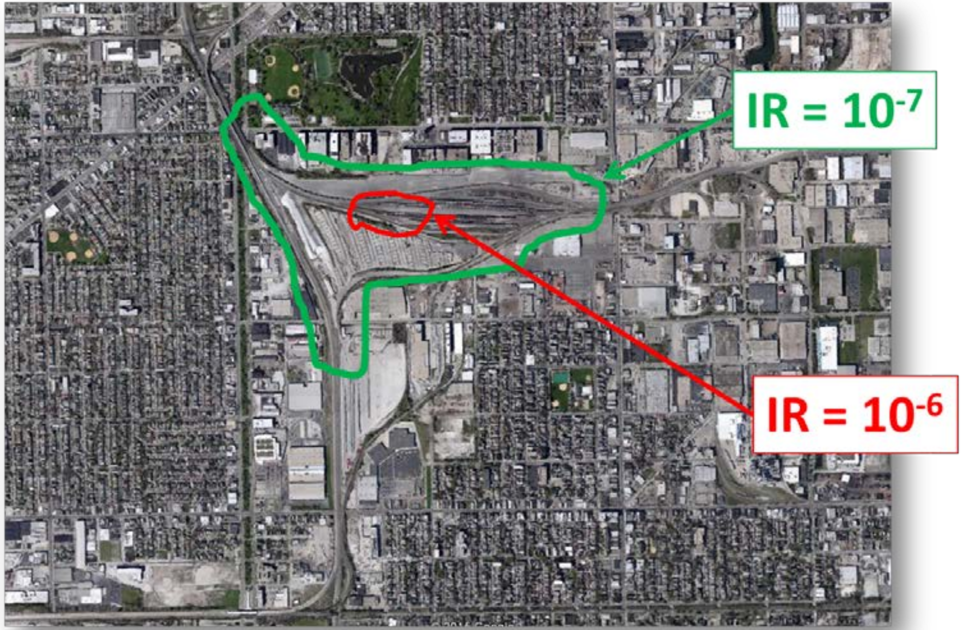
Example Mainline High Speed - IR Profile



Zone 3
Individual Risk
within 200 ft
of mainline

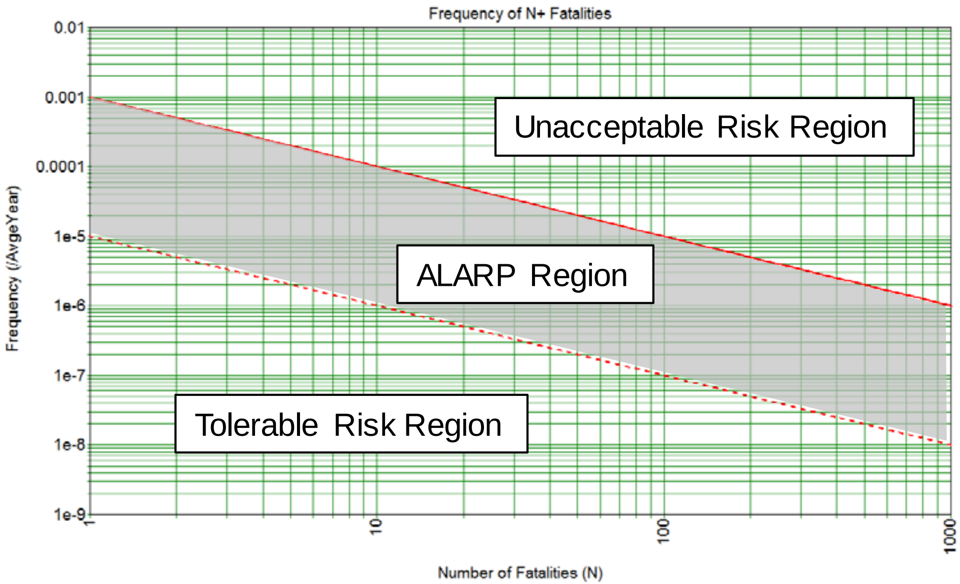
Using IR to Identify Sensitive Targets

- Can be used to focus efforts:
  - Hazard Communication
  - Community Engagement
  - Emergency Response



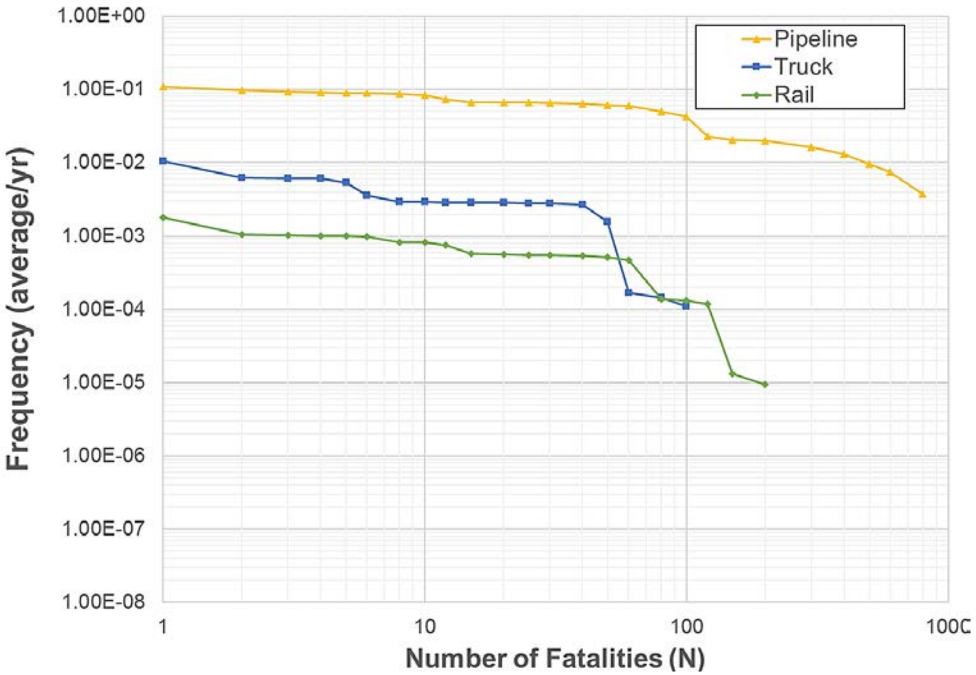
Measuring SR Outputs

- Comparative Analysis – lower risk lines or integral of FN curve
- Standard/Code Guidelines – e.g. NFPA 59A



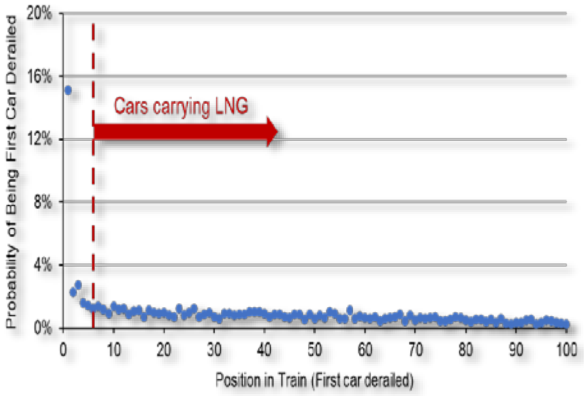
Using SR to Compare Transport Options

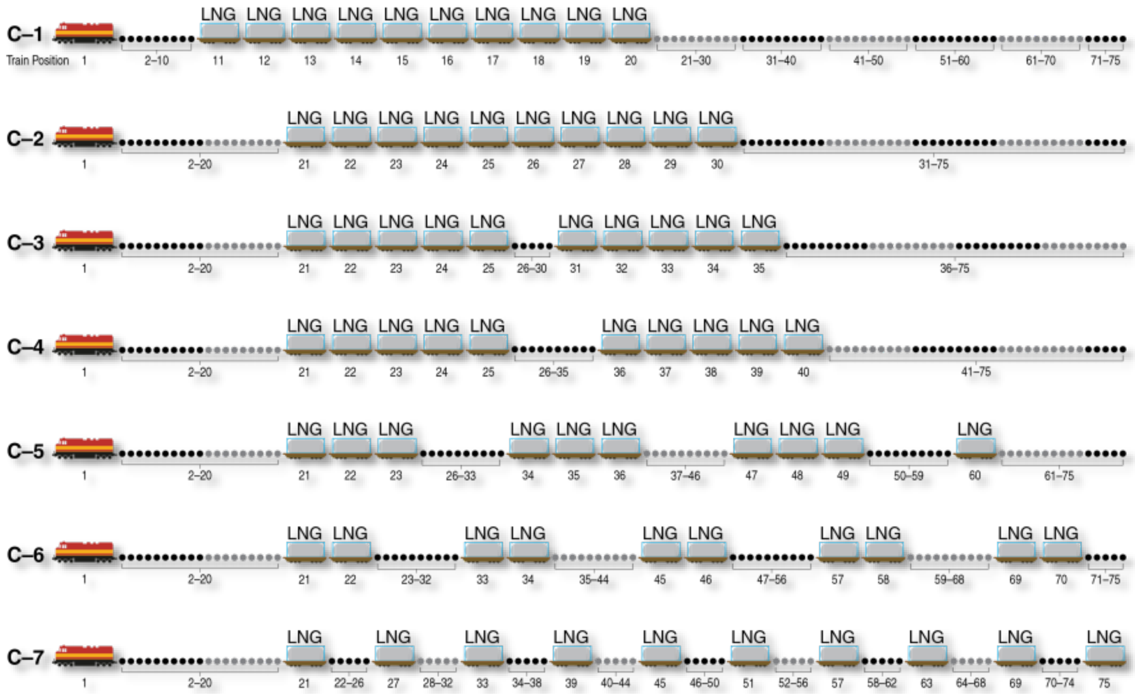
- Variables can be compared:
  - Transportation mode
  - Route
  - Operational Restrictions
    - Speed
    - Configuration



Hart RJ, Garcia ME, Morrison DR. What is the safest way to move LNG? 14th Global Congress on Process Safety, Orlando, Florida, April 22-25, 2018.

Example – Using Train Configuration to Mitigate Risk





Summary

Transportation Risk for LNG by Rail

- Different risk approaches for different applications
- Industry analogs provide reasonable comparisons or input approximations
- Opportunities exist to improve LNG risk model inputs/assumptions
- NFPA 59A criteria are complementary with international risk criteria
- TRA can be used to identify mitigation strategies or evaluate operational/logistics options

Example LNG in Rail Risk References

- Hart RJ, Garcia M, and Morrison DR, "What Is the Safest Way to Move LNG?," in AICHE Spring Meeting and 14th Global Congress on Process Safety, 2018.
- Hart RJ and Morrison DR, "The hazard we know: Comparing transportation risk of LPG and LNG," in Spring National Meeting and 11th Global Congress on Process Safety, 2015.
- Morris JM, Morrison DR, and Hart RJ, "Sensitivity Analysis of Transport Conditions on Liquefied Gas Hazards," in 2019 Spring Meeting and15th Global Congress on Process Safety, AIChE, 2019.
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- Hart RJ, Garcia ME, Morrison DR. What is the safest way to move LNG? 14th Global Congress on Process Safety, Orlando, Florida, April 22-25, 2018.
- Hart RJ, Morrison DR. Understanding Tolerable Risk Criteria - Considering the Growth of LNG Transportation. 13th Global Congress on Process Safety, San Antonio, Texas, March 26-29, 2017.
- Hart RJ, Morrison DR. The hazard we know: Comparing transportation risk of LPG and LNG. American Institute of Chemical Engineers, 2015 Spring National Meeting and 11th Global Congress on Process Safety, Austin, TX, April 26-30, 2015.
- Hart RJ, Morrison DR. Rail transportation risk assessment comparison: Ethanol versus LNG. 6th CCPS Latin American Conference on Process Safety, Buenos Aires, Argentina, September 15-17, 2014.