Crude-by-Rail Spill Risk Analysis For Proposed Shell Puget Sound Refinery Anacortes Rail Unloading Facility:

Rail Spill Probability and Volume Analysis

Draft Report

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Preface

Disclaimer

This document contains confidential information that is intended only for use by the client and is not for public circulation, publication, nor any third party use without the prior written notification to Environmental Research Consulting (ERC). While the opinions and interpretations presented are based on information from sources that ERC considers reliable, the accuracy and completeness of said information cannot be guaranteed. Therefore, ERC, its agents, assigns, affiliates, and employees accept no liability for the result of any action taken or not taken on the basis of the information given in this report, nor for any negligent misstatements, errors, and omissions. ERC shall not be liable or responsible for any loss, cost damages or expenses incurred or sustained by anyone resulting from an interpretation of this document. Except with permission from ERC, this report may only be used in accordance with the previously agreed terms. It must not be reproduced or redistributed, in whole or in part, to any other person than the addressees or published, in whole or in part, for any purpose without the express written consent of ERC. The reproduction or publication of any excerpts, other than in relation to the Admission Document, is not permitted without the express written permission of ERC.

Version Control

This is the 31 August 2016 revised version of the draft report, *Crude-by-Rail Spill Risk Analysis for Proposed Shell Puget Sound Refiner Anacortes Rail Unloading Facility: Rail Spill Probability and Volume Analysis*, prepared by Environmental Research Consulting.

Data Sources

Every attempt has been made in this study to present an objective, impartial, and unbiased analysis of the potential for crude-by-rail accidents and spills. Environmental Research Consulting has no vested interest in the outcomes of the analyses or their applications in the permitting and EIS processes for Shell Puget Sound Refinery or any other facility handling or proposing to handle crude-by-rail trains.

An exhaustive technical research literature search was conducted, including several hundred peer-reviewed papers, technical studies, industry studies, government studies and reviews, to provide the most up-to-date and scientifically-reliable information. Research studies that provided the most relevant and reliable data were selected to provide the inputs for modeling and the analysis of crude-by-rail accidents and spills.

The main source of the railroad accident data is the Federal Railroad Administration (FRA), an agency of the US Department of Transportation. The FRA's purpose is to promulgate and enforce rail safety regulations, administer railroad assistance programs, conduct research and development in support of improved railroad safety and national rail transportation policy, and consolidate government support of rail transportation activities. Other governmental sources of data include the Washington Department of Transportation and the Utilities and Transportation Commission.

Because crude-by-rail transport utilizing unit trains (trains of 100 to 120 tank cars that solely contain crude oil) is a relatively new phenomenon of the last decade, there are a limited number of studies specifically geared towards crude-by-rail accidents and spills. To the extent that specific reliable technical studies were available, they were utilized in the analysis.

Many of the studies employed in this analysis were conducted by researchers at the University of Illinois at Urbana-Champaign's RAILTEC Railroad Engineering Program. This institute has been among the leading academic institutions in rail transportation engineering and has been in operation for over 100 years. RAILTEC became the lead institution of the National University Rail Center affiliated with the US Department of Transportation. As such RAILTEC conducts many studies with and for the FRA and other government agencies.

As with many technical, engineering, and scientific studies that are used as the basis of decision-making, there are occasionally public concerns about biases that may be incorporated into the study design, "ulterior motives," or even misleading or false conclusions that may be presented as fact. True scientific studies are conducted under rigorous conditions that eliminate or significantly reduce any true or perceived biases. Scientific, technical, and engineering researchers are trained and expected to conduct studies in a manner that does not influence the outcome and should not be subject to outside influences. To the extent possible, the analyses in this report were conducted using studies that were carried out by academic or engineering researchers or government agencies that have no particular interest in the outcome.

In some cases, data or findings from research studies conducted by the railroad industry were included in the analysis, e.g., studies by the American Association of Railroads (AAR), because this was the best or only information available. Industry associations often have the most complete information on some issues and can provide practical information that may be relevant for consideration. When industry groups conduct studies that have outcomes that appear favorable to the industry represented, there are often questions about the validity of the conclusions, whether the study is actually biased or not. Industry studies are not necessarily biased or misleading. In some cases, the fact that a study is either conducted by or funded by industry researchers is solely because these groups have the funding and interest in conducting the studies.

In the last few months and years, particularly immediately after crude-by-rail accidents, there have been many media reports (newspapers, online blogs, television, radio) regarding crude-by-rail risks, safety and risk mitigation measures, and accident causes. Some of these media reports provide advocacy, opinions, unsubstantiated data, and anecdotal evidence about crude-by-rail issues. Issues that have caused concern to the general public and, at times, to government regulators, are addressed in this analysis to the extent that there are reliable data available. Sources of information, if not backed up by otherwise reliable technical data, are not included as inputs to the analysis, unless specifically indicated as such.

The sources of data and study conclusions are clearly indicated as citations (footnotes indicating the reference) or directly in the text. All reference citations are provided in the Reference section.

Purpose and Reliability of Higher vs. Lower Estimate of Spill Probabilities

Crude-by-rail transport is a relatively new practice in the US. Despite several high-profile crude-by-rail accidents in the US and Canada, which are discussed in this report, there are insufficient statistically-reliable data from which to make projections to future risks from this for Washington State due to the proposed Shell PSR traffic as well as that of other existing and proposed facilities.

At the request of Washington Department of Ecology and Skagit County, two estimates of spill probabilities were prepared for this analysis and are presented in this report to take into account uncertainties in developing meaningful projections of future spills related to crude-by-rail transport in Washington State for the Shell PSR, in particular, and the overall potential future crude-by-rail transport in Washington State with all current and proposed facilities fully operational as planned. The two estimates–Lower Estimate of Spills (LES) and Higher Estimate of Spills (HES)–reflect more "optimistic" and "conservative" estimates, respectively, based on various assumptions that are clearly outlined. Both the LES and HES are projections of future spill probabilities that are based on information and data that are available on past freight rail transport adjusted for the specific configurations and characteristics of crude-by-rail transport.

A conservative estimate is one in which one is cautious to avoid excess in approximating the quantity, degree, or worth of something. On the other hand, a liberal estimate would be one that is cautious to avoid underestimating the quantity in question. In this case, the conservatism in the HES comes into play with respect to the assumptions of safety enhancements and reduction of accident and spill rates with the improvements that have been made or are about to be made on rail lines and equipment. In effect, a conservative estimate of the accident and spill rate would assume that there are no benefits of safety improvements. This would result in a higher estimate of spill probability. The LES assumes that the safety enhancements and improvements will be as effective as predicted.

The LES and HES are only as "reliable" as the assumptions that are incorporated into their respective calculation processes. These assumptions are clearly defined and it is up to the reader to evaluate the legitimacy of the estimates. It is important to recognize that estimates of probabilities are not predictions of *exactly* how often accidents and spills will occur. If the crude-by-rail transport associated with Shell PSR is underway in the future there will be an increased risk of spills over the background of spills associated with other existing and proposed facilities in Washington State. The more crude-by-rail traffic, the more likely an accident and spill will occur. The greater the span of time over which crude-by-rail traffic transits Washington State rail tracks, the greater the likelihood that a spill will have occurred in that time frame. But, this neither guarantees that there *will* be a crude-by-rail spill incident, nor that any future spills will be limited to the number of spill incidents that are predicted in the modeling.

Terminology: "Accident" vs. "Incident"

The terms "accident" and "incident" are often confused and used interchangeably. There are, however, significant differences between the two terms when used in the context of railroad issues, as in this report. A railroad "incident" is an unplanned and undesired occurrence, action, or event associated with the operation of a railroad that requires some type of response but that ultimately has minor consequences. This could include such events as delays, switch operations problems, power outages, and similar occurrences that may cause inconveniences but generally result in no significant consequences of damage, injury, or fatality. In contrast, an "accident," in the context of this report, is an occurrence that results in property damage, railroad equipment damage, environmental impacts, injuries, or fatalities.

In common usage, there is often a connotation of a lack of culpability or inability of prevention in the term "accident," as in, "It was no one's fault. It couldn't be helped. It was merely an accident." The issue of culpability and prevention are not encompassed in the term "accident" as used in the current report and analyses. With regard to the level of damage, because the Federal Railroad Administration (FRA)

accident database is used, the damage threshold for defining an accident is a reportable event that results in a minimum of $10,500 in damages to track, equipment, or property, or that causes injuries or fatalities.

"Fire/Explosion" Rail Accidents

Among the different types of freight railroad accidents considered in the analysis of baseline accident rates, there is a category of "fire/explosion" accidents. These rail accidents are ones in which there is a fire and/or explosion that occurs on a train in transit for which the fire and/or explosion is the primary *cause* of the accident, not a *result* of the accident. In other words, the accident occurs because of a fire and/or explosion. This is distinct from an accident that may be caused by something else–e.g., a derailment–that then, because of damage to tank cars that occurs during the derailment results in a fire and/or explosion.

This would include accidents in which there is a fire or explosion on a locomotive, or perhaps a fire in a freight car, such as a fire in a car containing grain cargo, or even a tank car containing hazardous materials. This is not the same as the ignition of oil *after* the train derails and has released oil. These data do not in any way indicate the likelihood of a crude-by-rail spill with a fire and explosion, such as the accident that occurred at Lac-Mégantic, Quebec.

The likelihood that a crude-by-rail accident with spillage would result in a fire and/or explosion of any kind would depend on a large number of situation-specific factors, including the presence of an ignition source (e.g., an open flame or sparks) and its precise location with respect to the spilled oil and any flammable vapor clouds associated with it. Determinations of the probability of the presence of ignition sources or for the potential for there to be fires and explosions following crude-by-rail spills are outside the scope of the current report. A more detailed discussion of the potential for and effects of a fire, vapor cloud explosion, and/or boiling liquid expanding vapor explosion (BLEVE) are presented in another report.[1]

Likewise, in the analysis of the likelihood of hazardous material tank cars releasing material during an accident, the fire/explosion category does *not* in any way refer to fires and explosions that may occur after there is spillage of oil or other flammable materials. The data merely show that for accidents caused by fire and/or explosion, there may be a hazardous material tank car(s) involved and these may have a release of hazardous material.

Expected Frequency, Probability, and Return Periods

The objective of the analyses in this report is to calculate the expected annual frequency or probability that spill events of various sizes might occur with the crude-by-rail transport associated with the proposed Shell Puget Sound Refinery (PSR) in Anacortes. The results are represented in terms of expected *frequencies* and as *return periods*. (The return period is also sometimes called the "recurrence interval.") These terms express the same concepts in different ways. The expected frequency is an estimate of the likelihood or probability that an event (in this case, a spill of a certain volume from a crude-by-rail train) will occur in any given year.

[1] Risknology 2016 (Appendix I of the Draft EIS).

For example, say, hypothetically, that there is a 1% chance, or a one in 100 chance, that a large spill event will occur in one year. The “return period” for this event is 100 years. The return period is the inverse of the frequency.

$$Frequency(event) = \frac{number(events)}{year}$$

$$Return = \frac{1}{Frequency(event)} = \frac{years}{event}$$

$$Frequency(event) = \frac{0.01}{year}$$

$$Return(event) = \frac{1}{0.01} = 100$$

The return period (e.g., 100 years) is used in an attempt to simplify the definition of a specific statistically-determined chance of an event occurring in any one year (1%). It does not however mean that it will necessarily take 100 years before this event occurs or that it will only occur once in a 100-year time frame.

The probability of an incident occurring is a measure of the likelihood that an incident will happen in a given year. This is reported as either a frequency or a return period. The frequency is the anticipated number of times that incident will occur over a given period of time.

As an example, if an individual were to flip a coin once a minute hoping for a “heads”, the average frequency of a heads would be one in two throws or 50%. The average return period for a “heads” would be the inverse of one-half, or 2 throws. (If the throws occurred once every minute, the return period would be two minutes.) It is important to note that probabilities are estimates of likelihood and not a true prediction of an event occurring at a specific point in time. While there is a 50/50 chance that a heads will be thrown with each toss of the coin, it is impossible to predict if the next toss will be a heads. One would predict that every other throw would be a heads. However, it is quite possible to throw two, three, or even more tails in a row. The likelihood of throwing a heads on that fourth throw would still be 50%. Therefore, when speaking of the frequency or return period, the word “average” has been included as the statistic is a prediction of probability rather than a true certainty. To clarify, a return period of two years does not mean that an event will happen every two years like clockwork. The event could happen tomorrow, or it may happen in five years. However, on average and given a long enough period of time, the frequency of occurrence would average every two years.

When considering extremely low probability events, return periods help frame the likelihood of events with time. It is estimated that more than 100 lightning bolts strike the Earth every second. Even with so many lightning strikes, the odds of an individual person being struck by lightning in the US in any one year is roughly one in 700,000 years. However, we know that individual people do not live for 700,000 years and that some individuals are unfortunate enough to be struck by lightning. This statistic helps people understand that while an event could occur, it is not likely.

Another way of viewing the return period or return years is to turn this value into an expression of the "odds" of something happening. An event that has a 700,000-year return period is something that has a one in 700,000 chance of happening in any one year. An event that has a 70-year return period has a one in 70 chance of happening in any one year.

These odds or probabilities can also be viewed as something that might happen to an individual person. For example, a one in 8,938 chance they will die in a car accident in any one year (one in 606 in a lifetime), and a one in 767,303 chance that they will die in an airplane crash in any one year (one in 9,737 in a lifetime).[2]

Monte Carlo Analysis

A Monte Carlo analysis or simulation is one that produces distributions of possible outcomes based on variable inputs. It is named after the casino in Monte Carlo, because, figuratively speaking, there is a lot of virtual "dice-rolling" or "roulette" involved in its application, as there is, arguably, in crude-by-rail transport. While the vast majority of crude-by-rail trains arrive at their destinations as planned, there have been instances in which they have not. This is not unlike motor vehicle accidents. For every 100 million vehicle miles traveled, there were 1.08 motor vehicle accident fatalities in 2014.[3] Some factors increase the probability of an accident (alcohol consumption), others reduce it (increased driver age and experience).

A Monte Carlo analysis simulates the effects of a variety of different probabilities and uncertainties to provide predictions of outcomes. In the case of the current crude-by-rail accident and spill analysis, this approach is used to incorporate uncertainties and randomness in input values and probabilities that affect both accident and spill rates to derive predictions of outcomes.

In the current study, Monte Carlo simulations were conducted using computer models that randomly select values as stipulated in the inputs (the derivation of which are described in this report) for 100,000 simulations for the various factors that determine the probability that there will be a rail accident, the probability that that accident will result in a spill, and the number of tank cars (or locomotives) involved to determine the likelihood of spills of various sizes.

Rounding of Numbers and Significant Digits

Calculated data from modeling and various interim analyses are shown with as many as five digits after the decimal point. This is to allow for greater accuracy in adding and other mathematical processes and to avoid rounding errors that may be confusing to the reader.

In summary tables, however, such as those providing estimates of annual frequencies of specific volumes of spills and return years, the results have been rounded to two or three significant digits, as appropriate, starting with the first non-zero digit. This is a standard methodology applied in many analyses to avoid the implication that one could be so precise in determining the frequency of spill events in the future. For example, if the calculated spill frequency is 0.00128 per year, which would bring a return period of

[2] http://www.iii.org/fact-statistic/mortality-risk
[3] http://www-fars.nhtsa.dot.gov/Main/index.aspx

781.25 years, the spill frequency would be rounded to 0.0013 per year and the return period would be expressed as 780 years. Note that "significant digits" are also called "significant figures."

Rail Spill Risk Analysis for Shell Anacortes Rail Unloading Facility Draft Environmental Impact Statement: Rail Spill Probability and Volume Analysis

Executive Summary

With six crude-by-rail transports to and from the proposed rail unloading facility at the Shell Puget Sound Refinery (PSR) in Anacortes per week, there is a potential for spills or releases from both rail tank cars and locomotives. These six trains would represent 8.6 percent of the total potential future crude-by-rail traffic. Shell PSR-related crude-by-rail spills might occur within Washington State:

- Due to rail accidents during transits of loaded crude-by-rail trains from the Idaho border, along the Columbia River rail corridor up to the Shell PSR in Anacortes (Figure 1);
- Due to spill accidents during oil transfer operations or movements of crude-by-rail unit trains within the facility bounds of the Shell PSR; or
- Due to rail accidents during transits of empty trains on the return route to the mid-continent area.

Figure 1: BNSF Railway Main Line Rail Lines for Crude Oil Transport in Washington State

An analysis was conducted to determine the potential frequency of crude-by-rail spills and the potential volumes that may be involved. The analysis incorporated assumptions about the safety enhancements to crude-by-rail transport brought about by significant regulatory and industry changes that have occurred recently, are in process, or will be in place in the future.

The analyses in this report focused solely on quantifying to the extent possible:

- The probability of a spill associated with the transport of crude oil by rail to the Shell PSR;
- The probability of a spill from locomotives from crude-by-rail trains transiting to or leaving the Shell PSR;

- The probability of a crude-by-rail -related spill at the Shell PSR; and
- The potential distribution of volumes associated with a crude-by-rail -related spill, from more typical small spill events up to 90th percentile discharges (90PDs).

In order to provide a more conservative estimate of rail accident and spill probabilities in addition to an estimate that incorporates the safety enhancements and risk reduction measures that have been in place or are expected to soon be in place for freight rail traffic in general and crude-by-rail traffic in particular, two separate spill probability estimates were calculated:

- Lower Estimate of Spills (LES)
- Higher Estimate of Spills (HES)

The calculated Lower Estimate of Spills (LES) provides a more "optimistic" assessment of spills based on accident and tank car release rates by incorporating the following assumptions:

- The rail accident rate calculated from historical general freight accident data needs to be adjusted to take into account the changes in rail safety that have occurred over the last decade or more;
- There are particular aspects of crude-by-rail transport that need to be taken into account with regard to accident rates and spillage rates, such as speed restrictions, enhanced braking, positive train control, wayside detectors, thermal protection, and tank car design; and
- The greater train length of crude-by-rail unit trains will increase the likelihood of accidents relative to the more typical shorter freight trains.

Note that the LES incorporates two assumptions that may *increase* the likelihood of accidents over the "baseline" rate from historical rail accident data. Even with this adjustment, the overall estimate will be lower than that calculated with the HES assumptions described below. This is due to the fact that the safety enhancements would still tend to lead to a net decrease the accident and spill rates.

The reasoning behind assuming the two accident rate increase factors is that the purpose of the LES is to estimate an accident and spill rate that incorporates, to the extent possible and based on the available research data, the aspects of crude-by-rail transport that would affect the overall freight rail accident and spillage rates.

The calculated Higher Estimate of Spills (HES) provides a more "conservative" assessment of accident and spill rates by incorporating the following assumptions:

- The rail accident rate calculated from historical general freight accident data is appropriate for application to crude-by-rail traffic with no adjustments for safety measures;
- There are no particular aspects of crude-by-rail transport that would make the accident or tank car release rate different than for all freight traffic;
- There may be an increase in accident rates due to "sloshing" effects, as described in greater detail in Chapter 5; and
- The greater train length of crude-by-rail unit trains will increase the likelihood of accidents relative to the more typical shorter freight trains, as described in greater detail in Chapter 5.

The majority of the safety enhancements for freight rail (and crude-by-rail) transport have already been incorporated into the main line rail systems in Washington State. For example, the HES assumes that the track enhancements that were completed in Washington State in May 2016 should not be included in the adjustments to the estimation of accident probabilities, as these enhancements are privately initiated projects with no associated regulatory driver or public involvement. [This is discussed in greater detail in Chapters 5 and 7.]

The probability of crude oil spills or annual spill frequency *of any volume* from loaded crude-by-rail trains traveling to the Shell PSR was estimated to be 0.046 spills per year, based on the HES approach, and 0.0055 spills per year, based on the LES approach. This translates to one spill every 22 years as the HES, and one spill every 180 years as the LES. These estimates were based on analyses of historical freight train accidents, release rates from hazmat tank cars, and adjustments made to take into account safety enhancements for crude-by-rail transport, as described above. In addition to the crude spills, there are also projected to be 0.0038 diesel spills annually from locomotives carrying empty cars, based on HES, and 0.00098 diesel spills per year, based on LES. This is the equivalent of one spill every 264 years for the HES, and one spill every 1,000 years for the LES. These estimates are based on six crude-by-rail trains per week arriving at and departing from the Shell PSR.

These hypothetical spills would occur within the context of a larger set of crude-by-rail spills for current facilities and other potential future facilities. Currently, there are an estimated 21 weekly crude-by-rail trains arriving at two operating facilities. If all the facilities, including the Shell PSR were to be approved and become operational, the weekly trainloads would reach about 70. The Shell PSR would represent 8.6 percent of the total crude-by-rail traffic.

The higher estimates of spill probabilities by volume (HES) are shown in Table 1. The lower estimates (LES) are shown in Table 2. As with all spills, there is a much higher likelihood of smaller spills than larger ones.

Table 1: Projected Crude-by-Rail Spill Frequencies for the Shell PSR–Higher Estimate of Spills

Spill Source	Oil Type	Small Spills	Moderate Spills	Very Large Spills
Loaded Crude-by-Rail Train in Transit (Tank Cars)	**Crude**	**250 bbl**	**5,700 bbl**	**20,000 bbl**
		0.046/year	0.032/year	0.0069/year
		1 in 22 years	1 in 31 years	1 in 140 years
Loaded Crude-by-Rail Train in Transit (Locomotives)	**Diesel**	**5 bbl**	**100 bbl**	**250 bbl**
		0.0047/year	0.00047/year	0.00024/year
		1 in 210 years	1 in 21,00 years	1 in 4,200 years
Empty Crude-by-Rail Train in Transit (Locomotives)	**Diesel**	**5 bbl**	**100 bbl**	**250 bbl**
		0.0038/year	0.00038/year	0.00019/year
		1 in 260 years	1 in 26,00 years	1 in 5,300 years
Crude-by-Rail Trains at Facility Transfers (Tank Cars)	**Crude**	**1 bbl**	*Projections of larger spills for transfers and other activities at the facility were not possible due to the lack of historical accidents on large tank car transfer accidents of any kind.*	
		0.026/year		
		1 in 40 years		
Crude-by-Rail Trains at Facility Rail Accidents	**Diesel or**	**0.5 bbl–10 bbl**		
		0.000027/year		

Table 1: Projected Crude-by-Rail Spill Frequencies for the Shell PSR–Higher Estimate of Spills				
Spill Source	**Oil Type**	**Small Spills**	**Moderate Spills**	**Very Large Spills**
(Locomotives or Tank Cars)	**Crude**	1 in 37,556 years		

Table 2: Projected Crude-by-Rail Spill Frequencies for the Shell PSR–Lower Estimate of Spills				
Spill Source	**Oil Type**	**Small Spills**	**Moderate Spills**	**Very Large Spills**
Loaded Crude-by-Rail Train in Transit (Tank Cars)	**Crude**	**250 bbl**	**5,700 bbl**	**20,000 bbl**
		0.0055/year	0.0036/year	0.0055/year
		1 in 180 years	1 in 280 years	1 in 1,800 years
Loaded Crude-by-Rail Train in Transit (Locomotives)	**Diesel**	**5 bbl**	**100 bbl**	**250 bbl**
		0.0012/year	0.00012/year	0.00061/year
		1 in 820 years	1 in 8,200 years	1 in 16,000 years
Empty Crude-by-Rail Train in Transit (Locomotives)	**Diesel**	**5 bbl**	**100 bbl**	**250 bbl**
		0.00098/year	0.00098/year	0.000049/year
		1 in 1,000 years	1 in 10,000 years	1 in 20,000 years
Crude-by-Rail Trains at Facility Transfers (Tank Cars)	**Crude**	**1 bbl**	*Projections of larger spills for transfers and other activities at the facility were not possible due to the lack of historical accidents on large tank car transfer accidents of any kind.*	
		0.026/year		
		1 in 40 years		
Crude-by-Rail Trains at Facility Rail Accidents (Locomotives or Tank Cars)	**Diesel or Crude**	**0.5 bbl–10 bbl**		
		0.000027/year		
		1 in 38,000 years		

The spill events need to be considered not only in respect to their volumes but also with respect to their potential consequences to human health and safety, as well as impacts to important ecological, socioeconomic, and cultural resources. With crude-by-rail spills, there is the potential for human casualties (injuries and/or fatalities), particularly since the trains often transit through highly-populated areas. Even a relatively "small" spill may have significant impacts. The consequences or impacts of spills are discussed in greater detail in other reports.[4]

[4] Risknology 2016 and RPS ASA 2016 (Appendix H and I in the Draft EIS) .

Rail Spill Risk Analysis for Shell Puget Sound Refinery (PSR) Anacortes Rail Unloading Facility Draft Environmental Impact Statement:
Rail Spill Probabilities, Spill Volume, and Geographic Analysis

Chapter 1: Crude-by-Rail Spill Overview

Recent Crude-by-Rail Spill Accidents

A series of US and Canadian crude-by-rail accidents during 2013 through 2014 brought the issue of crude-by-rail risks to the general public, as well as to government regulators and emergency responders (Table 3). Several accidents then occurred in 2015 into 2016. There were also several incidents in which crude oil tank cars derailed without any spillage, including an incident in downtown Seattle in July 2014, which involved three derailed cars. Most recently, an accident occurred in Mosier, Oregon.

Table 3: Notable Crude-by-Rail US and Canadian Accidents with Spillage during 2013–2016[5]

Accident Location	Accident Date	Consequences of Accident			
		Tank Cars Derailed	Spilled Oil	Fire or Explosion	Other
Parkers Prairie, Minnesota	27 March 2013	14	714 bbl	No	Minimal damage due to frozen ground
Calgary, Alberta	3 April 2013	7	640 bbl	Yes	2 cars ruptured
Lac-Mégantic, Quebec	5 July 2013	63	37,719 bbl	Yes	47 fatalities; extensive damage to town; 2,000 people evacuated
Gainford, Alberta	19 October 2013	9 propane 4 crude	None	Yes (propane)	No crude burned; 3 propane cars burned; one home damaged
Aliceville, Alabama	7 November 2013	30	10,846 bbl	Yes	12 cars burned; wetland impact; no injuries
Casselton, North Dakota	30 December 2013	20	> 9,524 bbl	Yes	Collision; 1,400 residents evacuated; no injuries
Plaster Rock, New Brunswick	7 February 2014	5	3,000 bbl	Yes	45 homes evacuated; no injuries
Vandergrift, Pennsylvania	13 February 2014	19	108 bbl	No	4 cars spilled oil; no injuries
Lynchburg, Virginia	30 April 2014	15	1,190 bbl	Yes	3 cars burned; no injuries; some oil in river; immediate area evacuated
LaSalle, Colorado	9 May 2014	6	155 bbl	No	Spill contained in ditch; one tank car spilled oil
Mount Carbon, West Virginia	16 February 2015	27	9,800 bbl	Yes	14 cars burned; drinking water source for two counties affected; oil entered Kanawha River
Gogama, Ontario	14 February 2015	35	4,900 bbl	Yes	7 cars caught fire
Gogama, Ontario	7 March 2015	69	4,709 bbl	Yes	7 cars caught fire
Mosier, Oregon	3 June	11	1,000 bbl	Yes	Several cars burned; some oil

[5] Etkin et al. 2015b.

Table 3: Notable Crude-by-Rail US and Canadian Accidents with Spillage during 2013–2016[5]					
Accident Location	**Accident Date**	**Consequences of Accident**			
		Tank Cars Derailed	**Spilled Oil**	**Fire or Explosion**	**Other**
	2016				entered Columbia River

The occurrence of these accidents in apparent rapid succession when there had been no publicized oil rail accidents in previous years heightened concerns about continuously increasing risks of crude-by-rail accidents. Clearly, the July 2013 Lac-Mégantic accident in Quebec was of greatest concern given that there were 47 fatalities. But even incidents involving smaller volumes of spillage, especially those that involved fire, have created apprehension about crude-by-rail traffic through populated areas. The consequences of any crude-by-rail accident would be dependent on the volume spilled, whether ignition occurred, and the specific location involved, especially with regard to the proximity to populated areas.

History of US Oil Transport by Rail

The transport of oil by rail is not an entirely new practice. During the 1980s into the 2000s, railroads transported about 4.4 million bbl of oil annually by rail.[6] The majority of this oil was refined petroleum (e.g., diesel fuel) rather than crude oil. On average, annual oil rail transport involved about 15.4 million bbl-miles of crude oil and 360 million bbl-miles of refined products, for a total of 375.4 million bbl-miles.[7]

Significant Changes with Crude-by-Rail

In the last few years, there has been a significant increase in the transport of oil, particularly crude oil, by rail tank car. In fact, between 2005 and 2015, there was an 84-fold exponential increase in crude transport by rail (Figure 2). The significant change in oil transport by rail has been in the form of key trains or unit trains. Key trains contain at least 20 tank cars containing oil; unit trains exclusively carry oil tank cars in numbers ranging from 80 to as many as 100 to 120 cars. In 2005, there was about one 20-car key train operating in the US daily. By 2012, this had increased to there were seven unit trains of at least 100 cars on US rails. By 2014, this had increased to more than 14 unit trains per day throughout the US.

[6] Etkin et al. 2015a.
[7] A barrel-mile (bbl-mile) is a unit of measure that represents one bbl of oil transported one mile.

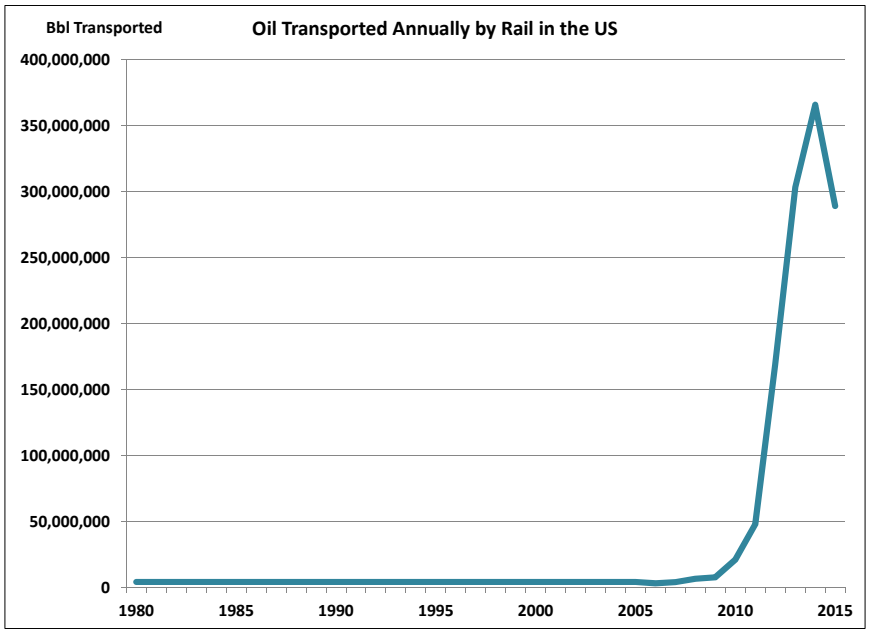


Figure 2: US Oil Transport by Rail 1980–2015[8]

The other significant change with the use of key and unit trains is the transport of crude oil. While in the past there were occasional transports of crude oil, the current key and unit trains exclusively contain crude oil. This crude oil comes from both the Bakken Formation in the Williston Basin (Figure 3) and the oil sands in Alberta, Canada (Figure 4) through new technologies for extracting shale oil.

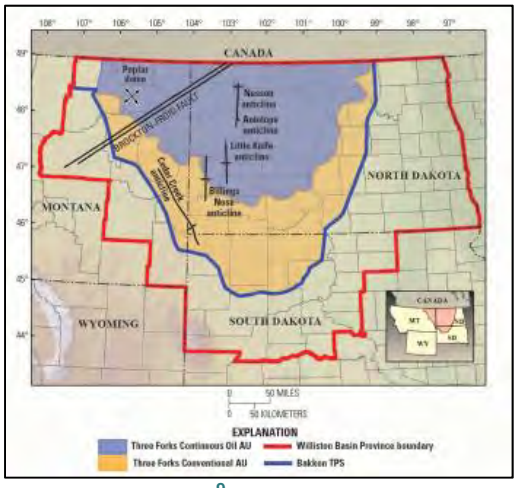


Figure 3: Bakken Formation in Williston Basin[9]

[8] Based on data from the Association of American Railroads 2013.
[9] US Geological Survey map.

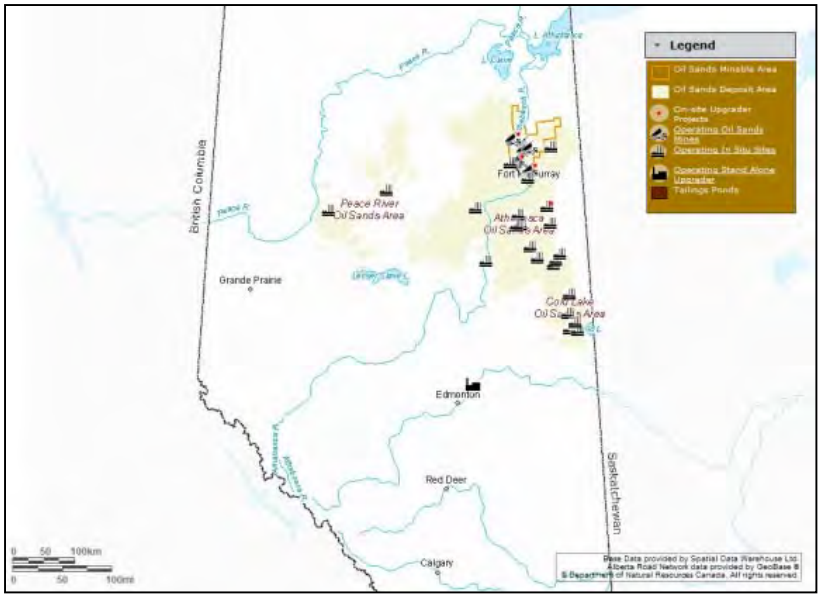


Figure 4: Oil Sands Mines in Alberta, Canada[10]

With the increase in oil transport by rail, there are more opportunities for spillage to occur. Oil spillage volumes are shown in Figure 5. While there have been peaks of spillage–notably the year 2013, comparing the pre-crude-by-rail time periods with the period of 2010 through 2015, the average annual oil spillage per amount of oil transported by rail has decreased by 93% since the 1990s and by 82% since the 2000s (Figure 6).

[10] Department of Natural Resources Canada.

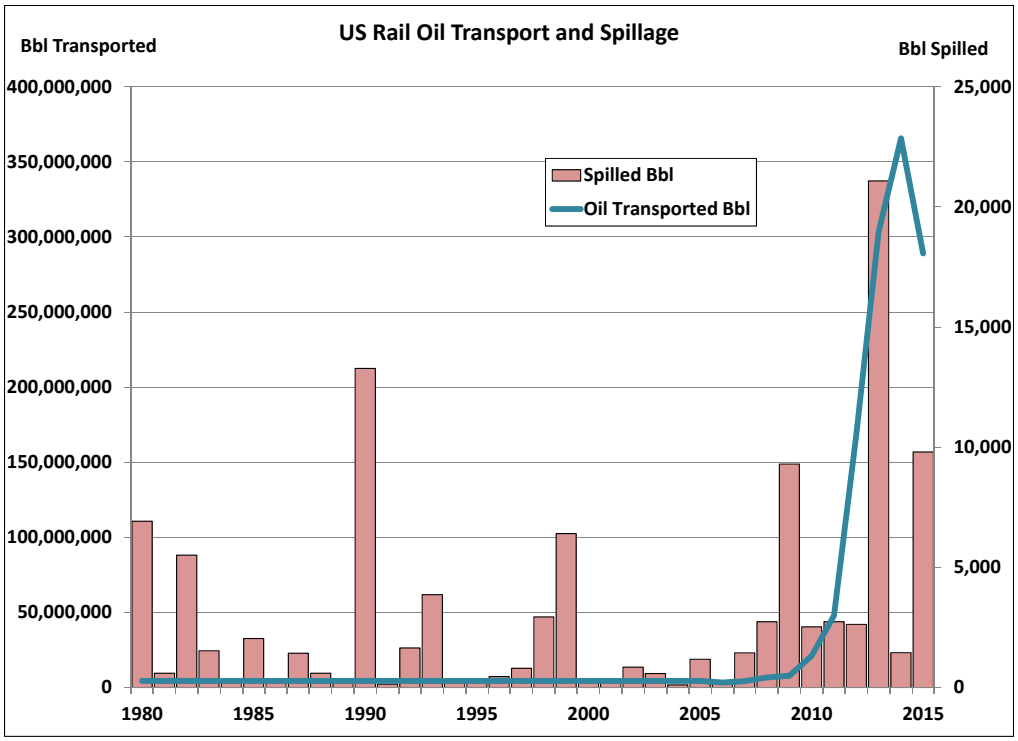


Figure 5: Average Annual Spillage per Oil Transported by Rail

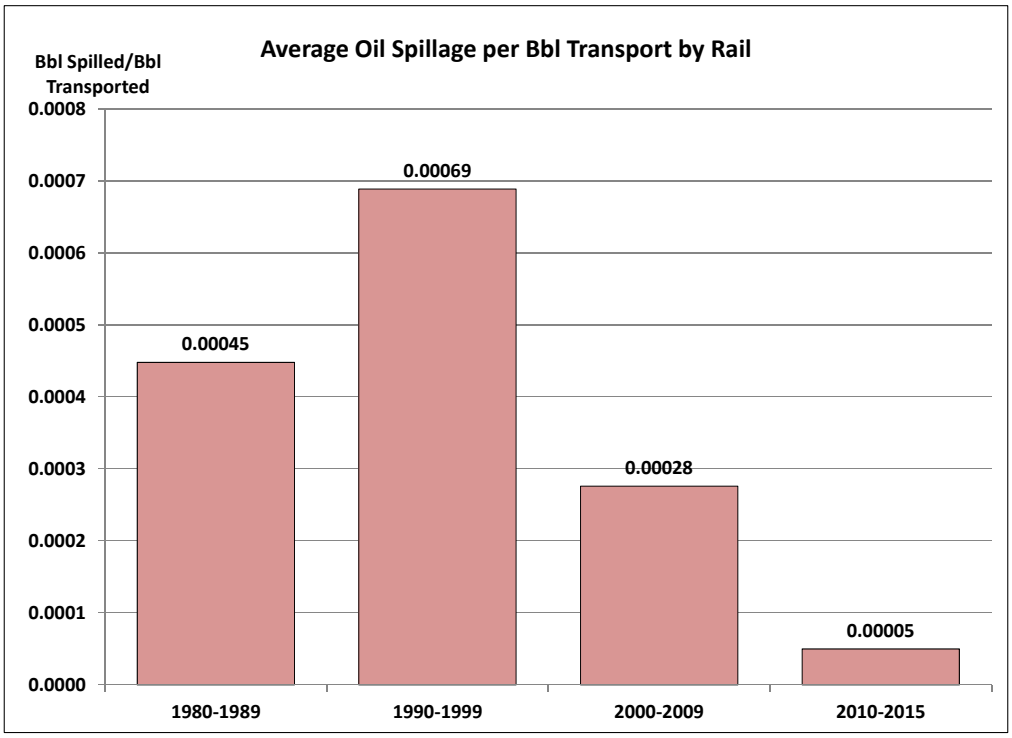


Figure 6: Annual Spillage per Oil Transported by Rail

Crude-by-Rail as Part of Total Freight Transport

The transport of crude oil (and refined petroleum products) makes up only a small portion of the total transport of freight in the US. Figure 7 shows total freight transport by rail over the last several years.

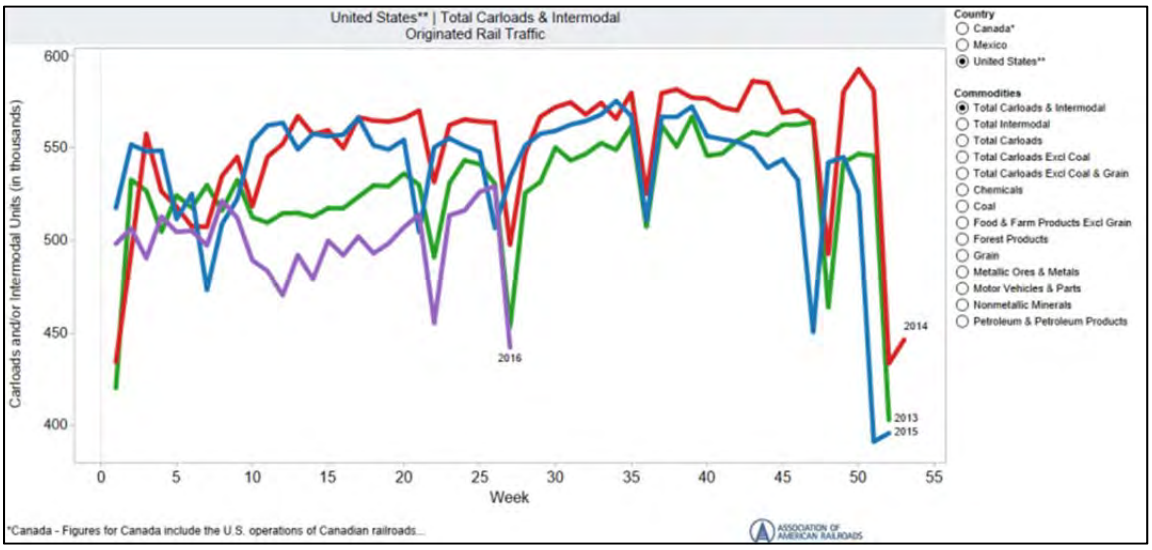


Figure 7: US Carloads and Intermodal Transport of Freight by Rail in the US (2014–present)[11]

Figure 8 shows the transport of petroleum (crude oil) and refined petroleum products by rail. The amount of petroleum transported by rail averages approximately three percent of the total freight carried by rail.

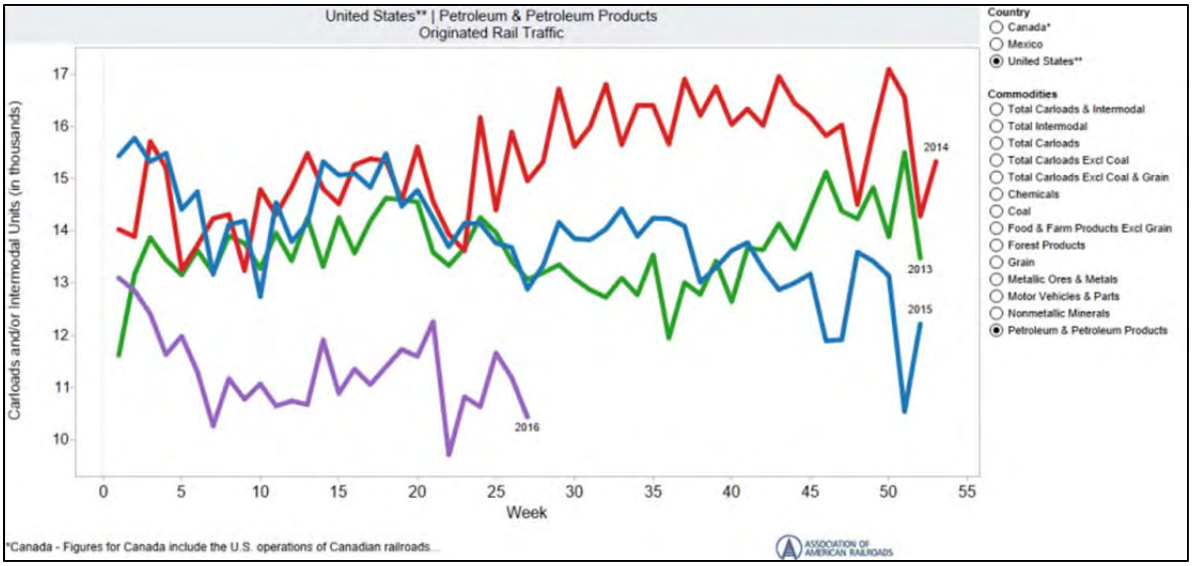


Figure 8: Petroleum and Petroleum Products Transport by Rail in the US (2014–present)[12]

[11] American Association of Railroads data. https://www.aar.org/pages/freight-rail-traffic-data.aspx
[12] American Association of Railroads data. https://www.aar.org/pages/freight-rail-traffic-data.aspx

Effect of Increased Crude-by-Rail Transport on Likelihood of Spill Accidents

With more oil being transported by rail and with the use of key trains and unit trains carrying as much as 84,000 bbl of oil at a time, there are more opportunities for spills to occur. While the spill rate per amount transported, as shown in Figure 6, has been reduced, there is still a greater opportunity for there to be a large-volume spillage in single accidents.

This risk presently exists in Washington State, as well as in other parts of the nation, including neighboring Oregon, with current crude-by-rail traffic. With the potential increase in crude-by-rail traffic in Washington State with proposed crude-by-rail facilities, including for Shell PSR, the risk will increase.

Another important point to consider is that the transport of Bakken crude oil, which is particularly volatile, has significantly increased the probability that a train oil spill will result in a fire and/or explosion. As can be seen by the accidents in Table 3, even a "relatively small" spill with respect to volume can be viewed as "significant" when there is a fire and/or explosion involved. In addition, the visual images of apparently mangled rail tank cars from a derailment accident may appear more "catastrophic" than a tanker spill even if it involves significantly more oil. The fact that crude-by-rail unit trains often pass through densely-populated areas increases public concern.

This report addresses the issue of the probability of spillage and the potential volumes of spillage from crude-by-rail traffic that would be associated with the proposed Shell PSR rail unloading facility, as well as other Washington State-specific crude-by-rail traffic. *This report includes probability analyses of spills, but not the probability of fire or explosion, nor potential impacts of a spill or fire/explosion event. The latter analyses are included in other reports.*

Chapter 2: Regulatory and Industry Requirements for Crude-by-Rail

In response to concerns about crude-by-rail accidents, as well as railroad accidents in general, the US federal government has taken various actions with the goal of preventing or mitigating accidents and spills. In addition, there have been numerous industry actions with the same purpose.

Note: The various safety enhancements are discussed in greater detail in Chapters 5 and 7.

US Federal Actions to Reduce Crude-by-Rail Accidents

The US Department of Transportation (USDOT) and the Pipeline and Hazardous Material Safety Administration (PHMSA) have taken a number of actions over the last few years to prevent crude-by-rail accidents, as summarized in Table 4.

Table 4: US Federal Action on Crude-by-Rail Accident Prevention Measures[13]

Date	Action
September 2012	PHMSA Administrator Quarterman visits North Dakota Bakken Region to observe operations at rail loading facilities and the application of USDOT regulations.
October 2012	PHMSA Bakken Field Working Group established to increase inspection focus on hazmat shipments by truck and rail from the Bakken region and increase awareness within the emergency response community.
December 2012	FRA begins Bakken Rail Accident Mitigation Project (RAMP).
July 29, 2013	In a letter to the American Petroleum Institute, FRA informed industry that it will use PHMSA's test sampling program to ensure that crude oil is being properly tested and classified.
August 2, 2013	FRA Safety Advisory 2013-06 "Preventing Unintended Movement of Freight Trains and Vehicles on Main lineTrack or Main line Siding Outside of a Yard or Terminal"
August 7, 2013	FRA Emergency Order 28, "Establishing Additional Requirements for Attendance and Securement of Certain Freight Trains and Vehicles on Main line Track or Main line Siding Outside of a Yard or Terminal"
August 27, 2013	FRA and PHMSA public meeting with industry stakeholders.
August 29, 2013	FRA convenes emergency session of Railroad Safety Advisory Committee (RSAC). RSAC established three working groups on new rulemaking: 1) hazardous materials by rail, 2) train crew size and 3) train securement procedures. Launch of Bakken Blitz.
September 6, 2013	PHMSA issues 78 FR 54849–ANPRM (2012-0082 HM-251), in response to railroad industry petitions and recommendations to improve the safety of railroad tank car transportation.
October 1, 2013	FRA Administrator Szabo sends a letter to railroad industry organization asking they detail actions they have taken in response to the Safety Advisory issued on August 2, 2013.
November 5, 2013	PHMSA extension of comment period of HM-251.
November 20, 2013	PHMSA and FRA issue Safety Advisory 2013-07 "Safety and Security Plans for Class 3 Hazardous Materials Transported by Rail".
December 11, 2013	FRA Safety Advisory, "Notice of safety advisory; Operational tests and inspections for compliance with maximum authorized train speeds and other speed restrictions".
January 2, 2014	PHMSA safety advisory issued stating that crude oil from the Bakken region may be more flammable than traditional crude.
January 16, 2014	Secretary Foxx meets with rail company CEOs and rail and energy association leadership as part of the USDOT's Call to Action to discuss how to maintain a safety record even as domestic crude oil production and movement has increased.

[13] Etkin *et al.* 2015a.

Table 4: US Federal Action on Crude-by-Rail Accident Prevention Measures[13]	
Date	**Action**
January 21, 2014	Secretary Foxx issues follow-up letter to Call to Action participants summarizing industry commitments.
February 4, 2014	PHMSA issues $93,000 in proposed civil penalties after investigation into the transportation of Bakken crude oil finds companies improperly classified shipments.
February 10, 2014	PHMSA meets with emergency response stakeholders and industry groups to discuss training and awareness related to the transport of Bakken crude. Follow-up meeting to be scheduled in late February 2014.
February 21, 2014	Secretary of Transportation sends letter to President/CEO of AAR to request members voluntarily: impose speed restrictions, braking signal propagation system, routing analysis, additional track and rail inspections, more frequent mechanical inspections, emergency response inventory, funding for emergency responder training, and more communication with communities.
February 25, 2014	USDOT Emergency Order requiring the testing and proper classification of oil being transported and does not allow crude oil to be transported at the lowest packing group.
March 6, 2014	To provide further clarity for shippers and to prevent attempts to circumvent the requirements in its recent Emergency Order concerning the safe transport of crude oil by rail, the USDOT issued an amended version that specifies which tests are required, while also prohibiting shippers from switching to an alternate classification that involves less stringent packaging.
April 9, 2014	FRA announced intention to issue proposed rule requiring two-person train crews on crude oil trains.
May 7, 2014	Joint safety advisory issued by FRA and PHMSA strongly urging those shipping Bakken crude oil to use tank car designs with the highest level of integrity. Also recommended avoiding use of older legacy DOT 111 or CTC 111 tank cars for shipment of Bakken crude.
May 7, 2014	DOT Emergency Order requiring reporting to State Emergency Response Committees (SERCs) of information on trains with more than one million gallons within 30 days of order.
July 23, 2014	USDOT releases regulations pertaining to the transportation of oil by rail and tank car standards.
September 10, 2014	FRA proposes amendments to the brake system safety standards for freight and other non-passenger trains and equipment to strengthen the requirements relating to the securement of unattended equipment. Specifically, FRA would codify many of the requirements already included in its Emergency Order 28, Establishing Additional Requirements for Attendance and Securement of Certain Freight Trains and Vehicles on Main line Track or Main line Siding Outside of a Yard or Terminal.
May 1, 2015[14]	USDOT (PHMSA and FRA) issues its Final Rule "Enhanced Tank Car Standards and Operational Controls for High-Hazard Flammable Trains."

USDOT Final Rule (May 1, 2015) Non-Tank Car-Related Standards[15]

In addition to provisions for tank car standards, this rulemaking also contains regulations regarding enhanced braking, operating speeds, classification of unrefined petroleum-based products, rail routing risk assessments, and rail routing information access:

- ***Enhanced Braking***
    - Requires high-hazard flammable trains (HHFTs) to have in place a functioning two-way end-of-train (EOT) device or a distributive power (DP) braking system;

[14] This is the most up-to-date list. That is the reason for May 1, 2015 being the last entry in this table.
[15] These are the standards that deal with safety issues other than the tank car specifications, i.e., standards that are mean to reduce the number of primary accidents but not specifically reducing the rate of spillage from the tank cars, which are discussed separately.

    - Requires any high-hazard flammable unit train (HHFUT) —a train comprised of 70 or more loaded tank cars containing Class 3 flammable liquids traveling at greater than 30 mph— transporting at least one packing group I flammable liquid be operated with an electronically controlled pneumatic (ECP) braking system by January 1, 2021; and
    - Requires all other HHFUTs be operated with an ECP braking system by May 1, 2023.
- ***Reduced Operating Speeds***
    - Restricts all HHFTs to 50-mph in all areas; and
    - Requires HHFTs that contain any tank cars not meeting the enhanced tank car standards required by this rule operate at a 40-mph speed restriction in high-threat urban areas defined by the Transportation Security Administration's regulations at 49 CFR § 1580.3.
- ***More Accurate Classification of Unrefined Petroleum-Based Products***
    - Requires documentation of sampling and testing program for all unrefined petroleum-based products, such as crude oil; and
    - Requires certification that programs are in place, documents the testing and sampling program outcomes, and makes information available to DOT personnel upon request.
- ***Rail Routing - Risk Assessment***
    - Requires railroads operating HHFTs to perform a routing analysis that considers, at a minimum, 27 safety and security factors, and to select a route based on its findings. These planning requirements are prescribed in 49 CFR § 172.820.
- ***Rail Routing–Information Access***
    - Ensures that railroads notify state and/or regional fusion centers, and that state, local and tribal officials who contact a railroad to discuss routing decisions are provided appropriate contact information for the railroad in order to request information related to the routing of hazardous materials through their jurisdictions.

Judicial and Administrative Challenges and November 2015 US DOT FAST Act

After the USDOT Final Rule was issued in May 2015, multiple judicial and administrative challenges were filed.[16] The judicial challenges were consolidated in the DC Circuit Court as American Petroleum Institute v. United States (DC Cir. No. 15-1131). The issues raised by the petitioners included the applicability of the rule's definition of HHFT, the timetable for phasing out DOT-111 cars and the retrofitting timetable (as shown in Table 5), the requirement for electronically-controlled pneumatic (ECP) brakes, and the lack of requirement for enhanced thermal protection.

In November 2015, PHMSA and FRA denied the administration petitions, after which the petitioners and government filed a joint motion proposing a briefing schedule and formats. While that motion was pending President Obama signed into law the Fixing America's Surface Transportation Act (FAST Act), which addressed some issues related to the transportation of flammable liquids by rail. The FAST Act requires additional study in connection with ECP braking. By 4 December 2017, the Secretary of Transportation is required to make a determination, based on the results of study and testing, about

[16] USDOT 2016.

whether the ECP braking requirement is justified. This remains the only issue that the petitioners intend to pursue.[17]

Key Route/HHFT Route AAR Requirements

The American Association of Railroads (AAR) defines a "key route" (or HHFT) route[18] as "Any track with a combination of 10,000 car loads or intermodal portable tank loads of hazardous material, or a combination of 4,000 car loadings of PIH or TIH (Hazard zone A, B, C, or D), anhydrous ammonia, flammable gas, Class 1.1 or 1.2 explosives, environmentally sensitive chemicals, Spent Nuclear Fuel (SNF),[19] and High Level Radioactive Waste (HLRW)[20] over a period of one year."[21] AAR's wayside detector requirements specifically for key routes are:

- Wayside defective bearing detectors shall be placed at a maximum of 40 miles apart, or equivalent level of protection may be installed based on improved technology;
- Main track should be inspected by rail defect detection and track geometry inspection cars or any equivalent level of inspection no less than two times each year;.
- Sidings should be similarly inspected no less than one time each year;
- Main tracks and sidings should have periodic track inspections that will identify cracks or breaks in joint bars;
- Any track used for meeting and passing "key trains" must be classified as FRA Class 2[22] or higher; and
- If a meet or pass must occur on less than FRA Class 2 track, due to an emergency, one of the trains must be stopped before the other train passes.

For HHFT/key trains, AAR provides the following restrictions:

- Unless siding or auxiliary track meets FRA Class 2 standards, a key train will hold main track at meeting or passing points, when practicable;
- Only cars equipped with roller bearings will be allowed in a key train;
- If a defect in a key train bearing is reported by a wayside detector, but a visual inspection fails to confirm evidence of a defect, the train will not exceed 30 mph until it has passed over the next wayside detector or has been delivered to a terminal for a mechanical inspection; and
- If the same car again sets off the next detector or is found defective, it must be removed.

[17] USDOT 2016.
[18] AAR 2013 (*Circular OT-55-N).*
[19] Irradiated fuel or targets containing uranium, plutonium, or thorium that is permanently withdrawn from a nuclear reactor or other neutron irradiation facility following irradiation, the constituent elements of which have not been separated by reprocessing.
[20] Waste generated in core fuel of a nuclear reactor, found at nuclear reactors or by nuclear fuel reprocessing.
[21] *AAR Circular OT-55-N*, Effective August 5, 2013, II. *Designation of "Key Routes"*, para. A.
[22] Track classified by FRA with respect to maximum speed for track condition as 25 mph for freight, 30 mph for passenger. Branch lines, secondary main lines, many regional railroads, and some tourist operations frequently fall into this class.

Trackside Warning Devices (TWD) inspect passing trains for defects or monitor for unusual trackside conditions that could adversely affect the safe and efficient movements of trains. Examples of such devices in operation in Washington include the following:

- Overheated journal bearings (HBD);
- Hot wheels;
- Dragging equipment detector (DED);[23]
- High/wide/shifted load (SLD);
- High water detector; and
- Earth/rock slide fence.

Safer Tank Car Designs

One of the standards that is being addressed in the rulemaking process, and clearly the one that has captured public attention, is the tank car standard. Because tank car designs are intended to reduce the probability of spillage in the event of an accident, and not the precipitating accident *per se*, this issue is addressed in the analysis related to *spillage* probability, not rail *accident* probability.

There are four basic components of a rail tank car that may release material during an accident–the tank head, the tank shell, the top fittings, and the bottom fittings (Figure 9). All tank car safety improvements focus on these components.

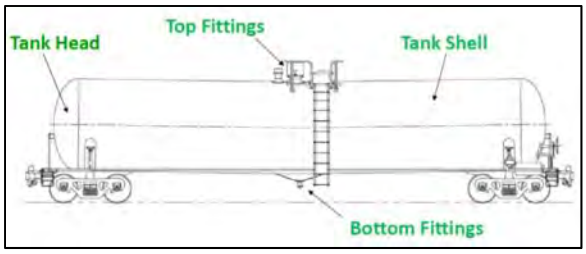


Figure 9: Key Components of Tank Car that May Release Material during Accidents[24]

A "safer" tank car design (CPC-1232) is analogous to a double-hulled tanker with similar reductions in spillage probability from older "DOT-111" tank cars (Figure 10). A 1991 National Transportation Safety Board study[25] found that the DOT-111 tank car is significantly more likely to release its product, suffer a failure, or experience a head or shell puncture than other tank car models (DOT-105, DOT-112, and DOT-114 pressurized tank cars), which have a tank shell thickness of 14.3 millimeters (mm) and thermal protection.

[23] A device that detects dragging equipment on a railroad, which can damage the track and grade crossings.
[24] Treichel 2014.
[25] NTSB 1991.

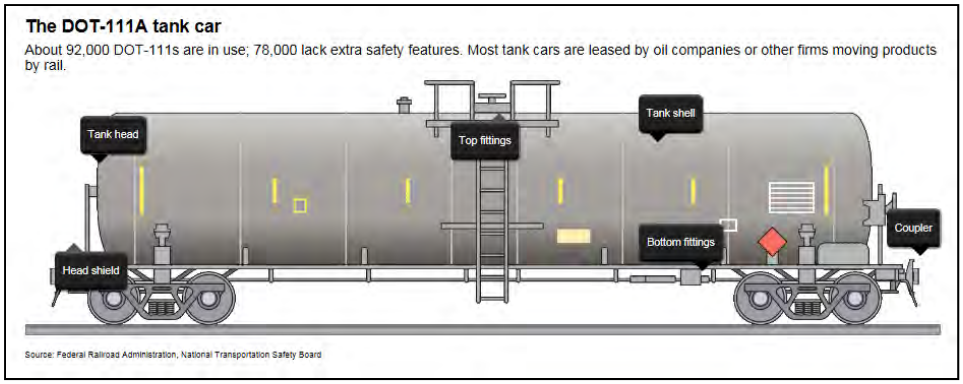


Figure 10: DOT-111 Tank Car Design (Federal Railroad Administration)

The CPC-1232 (Figure 11) standard originated with Transport Canada in October 2011. Anecdotal evidence from recent crude-by-rail accidents indicates that the newer tank car standards (CPC-1232) do not necessarily prevent spillage, however. Notably, in the Lynchburg, Virginia, accident,[26] the only tank cars that spilled oil were of the newer CPC-1232 design built after 2011. In addition, two recent derailments in Canada and in Galena, Illinois, involved CPC-1232 cars that spilled oil and burned.

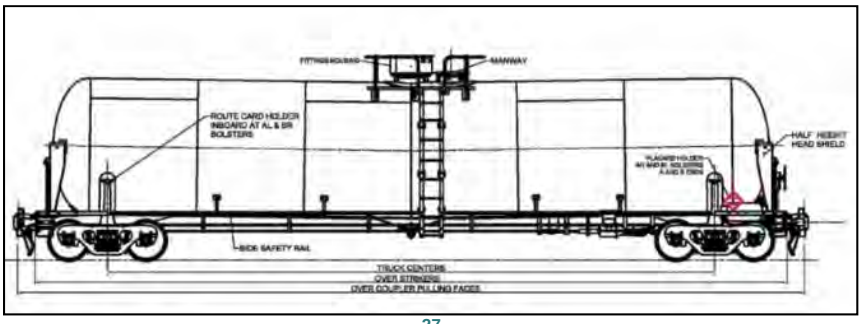


Figure 11: CPC-1232 Compliant Tank Car Design[27]

On May 1, 2015, the US Department of Transportation (PHMSA and FRA) issued a final rulemaking, "Enhanced Tank Car Standards and Operational Controls for High-Hazard Flammable Trains," [28] that included a number of provisions aimed at reducing risk from "high-hazard flammable trains" (HHFTs).[29] This rulemaking is directly relevant to crude-by-rail transport for the proposed Shell PSR project. The rule contained a new standard for tank cars–the DOT-117 specification (Figure 12).

[26] The 30 April 2014 Lynchburg, Virginia, accident involved 15 derailed cars; three cars spilling oil and burned.
[27] Barkan *et al.* 2013.
[28] 49 CFR Parts 171, 172, 173, 174, and 179: DOT Pipeline and Hazardous Materials Safety Administration Docket No. PHMSA-2012-0082 (HM-251) ROM 2137-AE91
[29] HHFTs are trains that have a continuous block of 20 or more tank cars loaded with a flammable liquid or 35 or more cares loaded with a flammable dispersed through a train (i.e., with other cargo-type cars interspersed)

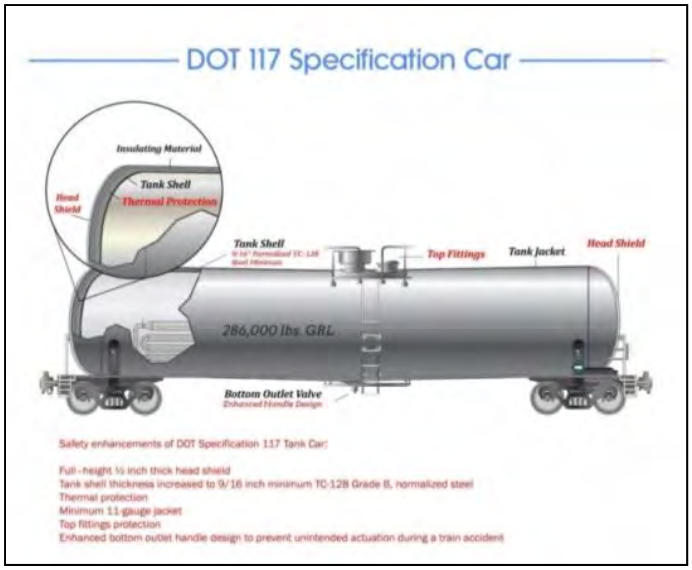


Figure 12: DOT-117 Specification Car[30]

The timeline for retrofitting of affected tank cars for use in North America for HHFTs, including crude-by-rail trains, is summarized in Table 5.

Table 5: Timeline for Retrofit of Affected Tank Cars for Use in US HHFTs[31]

Tank Car Type/Service	US Retrofit Deadline
Non Jacketed DOT-111 tank cars in PG I service[32]	January 1, 2018
Jacketed DOT-111 tank cars in PG I	March 1, 2018
Non Jacketed CPC-1232 tank cars in PG I service	April 1, 2020
Non Jacketed DOT-111 tank cars in PG II service	May 1, 2023
Jacketed DOT-111 tank cars in PG II service	May 1, 2023
Non Jacketed CPC-1232 tank cars in PG II service	July 1, 2023
Jacketed CPC-1232 tank cars in PG I and PG II service and all remaining tank cars carrying PG III materials in an HHFT (pressure relief valve and valve handles).	May 1, 2025

According to the rule, new tank cars constructed after October 1, 2015 are required to meet enhanced DOT Specification 117 design or performance criteria for use in an HHFT. Existing tank cars must be retrofitted in accordance with the DOT-prescribed retrofit design or performance standard for use in an HHFT. Retrofits must be completed based on a prescriptive retrofit schedule. The retrofit timeline focuses on two risk factors, the packing group and differing types of DOT-111 and CPC-1232 tank car. A retrofit reporting requirement is triggered if consignees owning or leasing tank cars covered under this rulemaking do not meet the initial retrofit milestone.

[30] http://www.dot.gov/mission/safety/rail-rule-summary
[31] http://www.dot.gov/mission/safety/rail-rule-summary
[32] January 1, 2017 triggers a reporting requirement, and shippers would have to report to DOT the number of tank cars that they own or lease that have been retrofitted, and the number that have not yet been retrofitted.

DOT/PHMSA Notice of Proposed Rulemaking on HHFT Spill Response Plans

On 13 July 2016, PHMSA released an advanced copy of a Notice of Proposed Rulemaking (NPRM) to be published in the *Federal Register*.[33] The rulemaking involves contingency planning for crude-by-rail spills. In this, PHMSA defines the "worst-case discharge" (WCD) as:

> *"The largest foreseeable discharge in adverse weather conditions," as defined at 33 U.S.C. 1321(a)(24). The largest foreseeable discharge includes discharges resulting from fire or explosion. The worst-case discharge from a train consist is the greater of: (1) 300,000 gallons of liquid petroleum oil; or (2) 15% of the total lading of liquid petroleum oil transported within the largest train consist reasonably expected to transport liquid petroleum oil in a given response zone."*

Chapter 3: Analytical Approach and Assumptions

Rail Spill Probability Analysis Scope

The overall approach to assessing rail spill risk associated with the proposed Shell PSR rail unloading facility involved determining the probability of a spill occurring as well as the potential impacts of a spill. This report focuses solely on the following:

- The probability of a crude oil spill associated with the rail transport of crude oil to the Shell PSR;
- The probability of a diesel spill from locomotives transiting to or leaving the Shell PSR;
- The probability of a crude-by-rail spill at the Shell PSR; and
- The potential distribution of volumes associated with a crude-by-rail spillage, including more typical small spill events[34] up to a 90th percentile discharge (90PD).

Geographic Coverage of Analysis

The geographic area covered in the rail spill accident probability analyses included all main line railways that would carry crude oil through Washington State. The crude-by-rail unit trains would enter the state at the Idaho border near Spokane, and travel southwest and then west through the Columbia River Valley to the Vancouver area. Then, turning north, the trains would run generally parallel to the Interstate-5 corridor toward Burlington. The crude-by-rail unit trains would then exit the Bellingham Subdivision onto the Anacortes Subdivision rail line and head north and west toward the Shell PSR facility. Trains on the return trip to the mid-continent area would take a different route by moving south along the Interstate-5 corridor, turning southeast near Auburn, traveling through Stamped Pass, and the Yakima Valley. An

[33] DOT/PHMSA 49 CFR Parts 130, 171,173, and 174 [Docket No. PHMSA-2014-0105 (HM-251-B)] RIN 2137-AF08, Hazardous Materials: Oil Spill Response Plans and Information Sharing for High-Hazard Flammable Trains. Notice of Proposed Rulemaking. (http://www.phmsa.dot.gov/hazmat/phmsa-proposes-new-safety-oil-spill-response-plans-and-information-sharing-for-high-hazard-flammable-trains)

[34] There is no regulatory definition for average most-probable discharges (AMPDs) for rail spills. Small spill volumes were evaluated based on historical data.

alternate route for the return trip would be through Stevens Pass. Trains would join up with the original route in Pasco and then travel north back through Spokane, as shown in Figure 1.[35]

The analysis of spillage within the Shell PSR facility boundaries was specifically limited to spills from crude-by-rail trains and not from any other refinery- or oil storage-related operations at the facility. Within any facility, the train, *i.e.*, the locomotive(s) and the tank cars, are covered under the US Environmental Protection Agency (EPA) Spill Prevention, Control, and Countermeasures (SPCC) regulations (40 CFR 112). Technically, a rail tank car at a facility is considered a temporary storage tank. According to current Washington State regulation RCW 90.56, a facility includes cargo trains within facility boundaries. This would include trains during cargo offloading or loading operations.

Rail Traffic Assumptions

There have been significant changes to the transport of crude oil to Washington State refineries in the last decade (Figure 13). In 2003, 91 percent of oil was imported by tank vessel and the rest by pipeline. By 2013, 8.4 percent was being brought in by rail, 24.2 percent by pipeline, and only 67.4 percent by tank vessel.[36] Note that the overall volume has not changed because there is a limited combined capacity of the refineries in the state.

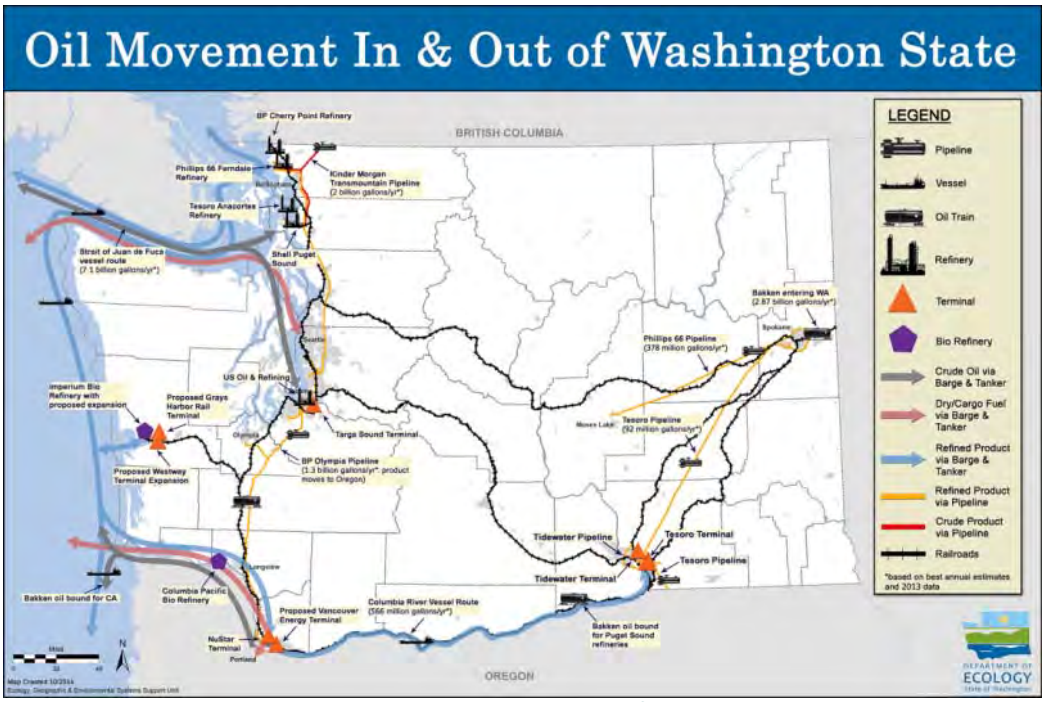


Figure 13: Oil Movement into and Out of Washington State[37]

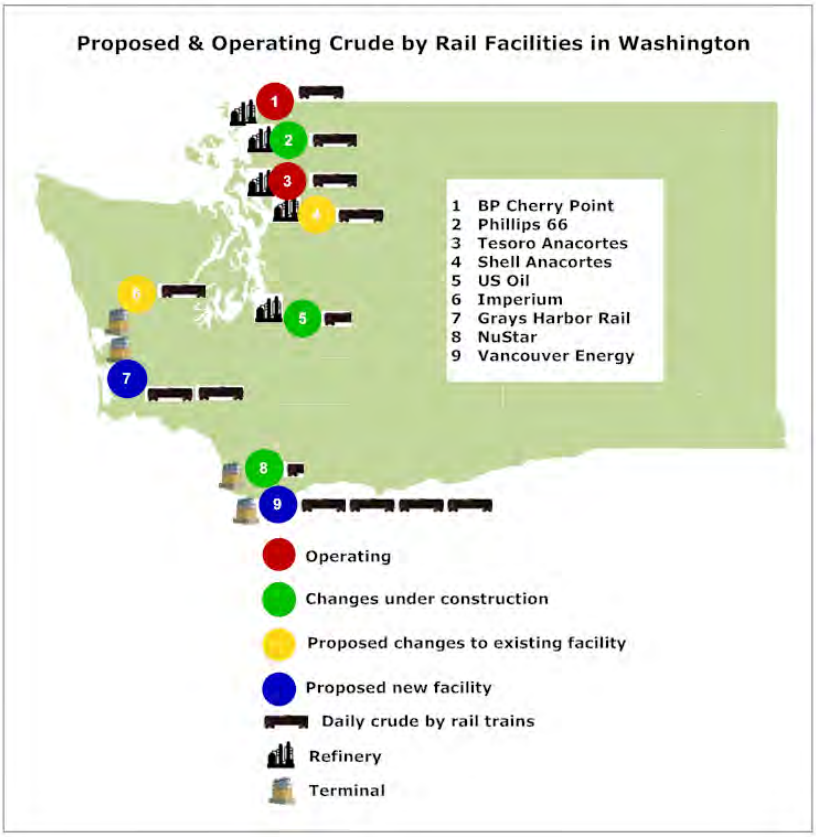
With the advent of crude-by-rail transport, there are several new proposed facilities to handle rail-transported Bakken crude originating in the mid-content area and other crude oil (mainly tar sands oil

[35] For the analysis of rail spill accident rates based on all Washington main line traffic, the additional routes shown in green and yellow were included.
[36] This is described in greater detail in Etkin *et al.* 2015b.
[37] Etkin *et al.* 2015b.

from Alberta, Canada, as well as changes to existing refining facilities to receive and refine rail-transported oil (Figure 14 and Table 6).

Table 6: Crude-by-Rail Facilities and Proposals (Status as of July 2016)[38]

Owner or Proponent/ Location	Throughput (bbl/day)	Status	Daily Trains Offloading
BP Refinery/ Cherry Point	146,000	Operating	1
Tesoro Refinery/Anacortes	75,000	Operating	2
Phillips66 Refinery/Ferndale	75,000	Changes under construction	0.5
U.S. Oil Refinery/Tacoma	48,000	Changes under construction	0.5
NuStar Terminal/ Vancouver	41,000	Changes under construction	0.29
Imperium Terminal/Grays Harbor	82,192	Proposed changes to existing facility	0.29
Shell PSR/Anacortes	75,000	Proposed changes to existing facility	0.86
Grays Harbor Rail Terminal	45,000	Proposed new facility	0.5
Vancouver Energy/Vancouver	292,000	Proposed new facility	4
TOTAL[39] Daily			**9.94**
TOTAL Weekly			**69.58**
TOTAL Annually			**3,628.1**



[38] Revised and updated from Etkin *et al.* 2015b. Not all facilities are exclusively receiving or expected to exclusively receive Bakken crude; other oil types, such as diluted bitumen derived from Canadian tar sands, may be transported.
[39] Assuming all facilities are operational.

Figure 14: Proposed and Operating Crude-by-Rail Facilities in Washington[40]

This includes the proposed Shell PSR project. The assumed level of crude-by-rail traffic to and from Shell ARUF is one unit train per day, each with approximately four locomotives and 102 oil tank cars, with a maximum of six unit trains[41] per week.[42]

The probability analysis determined the *net change* in probability with the addition of the Shell PSR rail unloading facility compared with an assumed baseline of all other facilities being approved and operational. It is possible that one or more of the proposed facilities may not be approved, which would change the baseline level of crude-by-rail traffic (Table 6). The analysis did not take into account the recent repeal of the crude oil export ban, which may cause considerable increases in the number of crude-by-rail unit trains transiting Washington State if there is a significant increase in the price of crude oil.

Washington State Train-Mile Assumptions

Accident and spill rates were determined on a per train-mile[43] basis. Train-mile data are readily available nationally and for specific railroads through the Federal Railroad Administration (FRA), but not for specific states. The Washington Department of Transportation (WSDOT) and the Utilities and Transportation Commission (UTC) were unable to provide specific train-mile data because they track mostly intra-state activity and not interstate traffic. A generalized estimate of "more than 10 million annual train miles" had previously been provided in the 2015 *Marine and Rail Oil Transportation Study*.[44]

A method of deriving Washington train-mile data from publicly-available information was employed by combining the data in Figure 15, which provided information for the year 2010 for average daily trains in different subdivisions, and data on subdivision length.[45]

Table 7: Track Mileage of Washington Rail Subdivisions with Daily Freight Train Numbers 2010

Map #	Subdivision/Region Name	End Points	Track Miles[46]	Daily Freight Trains[47]	Annual Train-Miles
A	**Kootenai-Spokane**	Sand Point, ID, to Spokane	68.5	52	1,300,130
B	**Lakeside**	Spokane to Pasco (BNSF)	146.4	30	1,603,080
C	**Spokane-Hinkle**	Spokane to Pasco (UP)	155	11	622,325
D	**Kettle Falls**	Spokane to Kettle Falls	80	1	29,200
E	**Fallbridge**	Pasco to Vancouver	219.8	26	2,085,902
F	**Vancouver-Seattle**	Vancouver to Seattle	136.2	31	1,541,103
G	**Seattle Scenic**	Seattle to Everett	32.2	28	329,084

[40] Etkin *et al.* 2015b.
[41] A unit train is a train containing only one type of freight/cargo, in this case crude oil.
[42] http://www.skagitcounty.net/Departments/PlanningAndPermit/shellpermit.htm; also in Etkin *et al.* 2015b.
[43] Unit of measure the combines the tonnage of cargo or freight and the distance traveled; a single ton-mile is a ton of cargo being transported one mile.
[44] Etkin *et al.* 2015a.
[45] Etkin *et al.* 2015a, and derived from map in Figure 15
[46] Based on information in Etkin *et al.* 2015b (except for Anacortes Subdivision).
[47] Derived from data in Figure 15.

Table 7: Track Mileage of Washington Rail Subdivisions with Daily Freight Train Numbers 2010					
Map #	**Subdivision/Region Name**	**End Points**	**Track Miles[46]**	**Daily Freight Trains[47]**	**Annual Train-Miles**
H	**Stampede**	Auburn to Ellensburg	102.6	6	224,694
I	**Yakima Valley**	Ellensburg to Pasco	125.1	6	273,969
J	**Bellingham (I)**	Everett to Mt. Vernon	34.1	19	236,484
K	**Bellingham (II)**	Mt. Vernon to Vancouver, BC	85.2	13	404,274
L	**Sumas**	Mt. Vernon to Sumas	70	1	25,550
M	**Anacortes**	Mt. Vernon to Anacortes	20	2	14,600
N	**Olympic Peninsula (I)**	Centralia to Elma	19	4	27,740
O	**Olympic Peninsula (II)**	Elma to Aberdeen	32	2	23,360
P	**Olympic Peninsula (III)**	Elma to Bremerton	59	2	43,070
Q	**Stevens Pass (Scenic)**	Everett to Wenatchee	134.5	14	687,295
R	**Stevens Pass (Columbia)**	Wenatchee to Spokane	125.1	13	593,600
Total			**1,644.7**	**261**	**10,065,459**

The train-mile estimate of 10,065,459, as shown in Table 7, corresponds with the "more than 10 million" applied in the 2015 *Marine and Rail Oil Transportation Study*.

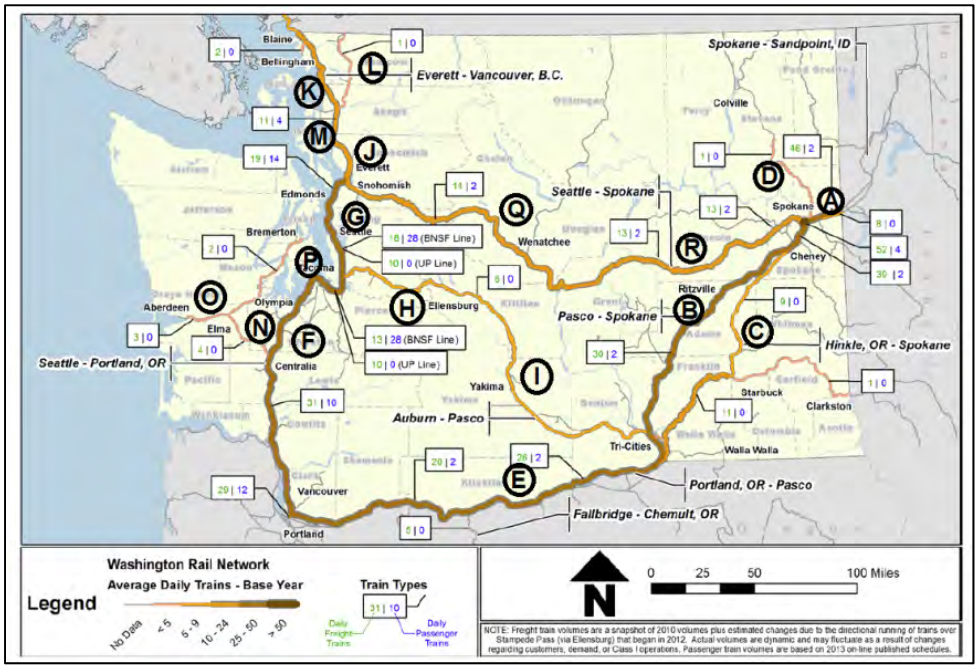


Figure 15: Average Known and Estimated Daily Train Volumes in Washington 2010[48]

[48] Cambridge Systematics, Inc. 2013a. (WSDOT study).

Washington Crude-by-Rail Train-Mile Assumptions

The train-miles for the current and projected future crude-by-rail transits listed in Table 6 were calculated as in Table 8. The estimated route of each train and the number of transits based on the facility were determined using the map in Figure 15 and the mileage in Table 7. The various train-mile estimates were required for the analysis to estimate spill rates for current crude-by-rail traffic, as well as for future traffic assuming that all planned and proposed facilities would be in operation, with and without the Shell PSR.

Table 8: Estimated Crude-by-Rail Train-Miles by Crude-by-Rail Facility

Facility	Daily Trains	Mileage to Facility (Loaded)	Return Mileage (Empty)	Annual Train Miles Loaded	Annual Train Miles Empty
BP Refinery/ Cherry Point	1	722.4	447.4	263,676	163,301
Tesoro Refinery/Anacortes	2	657.2	528.9	479,756	386,097
Phillips66 Refinery/Ferndale	0.5	722.4	447.4	131,838	81,651
U.S. Oil Refinery/Tacoma	0.5	570.9	452.6	104,189	82,600
NuStar Terminal/ Vancouver	0.29	434.7	578.8	46,013	61,266
Imperium Terminal/Grays Harbor	0.29	621.9	533.6	65,828	56,482
Shell PSR/Anacortes	0.86	657.2	528.9	206,295	166,022
Grays Harbor Rail Terminal	0.5	621.9	533.6	113,497	97,382
Vancouver Energy/Vancouver	4	434.7	578.8	634,662	845,048
Total Current	**2**	**1,379.6**	**976.3**	**743,432**	**549,398**
Total with all Facilities	**9.94**	**5,443.3**	**4,630.0**	**2,045,754**	**1,939,847**
Total with all Facilities Except Shell	**9.08**	**4,786.1**	**4,101.1**	**1,839,459**	**1,773,825**

Description of CBR Spill Probability Analysis Approach

For determining probabilities of crude-by-rail spills, a series of probabilities are at stake, as summarized in Figure 16. There is a probability of a accident (primarily a derailment, but also including collisions and other types of rail accidents), the probability that the accident involves freight (tank) cars rather than just locomotives, the probability distribution of tank cars involved in the accident, the probability that there is release from the tank cars, and the resulting probability distribution of spill volumes.

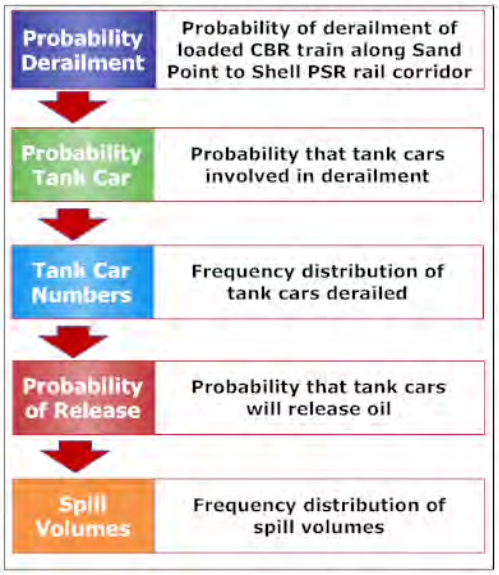


Figure 16: Steps in Determining Probabilities for Crude-by-Rail Spills[49]

This approach was selected for determining crude-by-rail spill probabilities and spill volumes because there is a lack of anecdotal data on these types of accidents given that crude-by-rail transport has only been in existence since about midway through 2011. Therefore, freight trains were used as a proxy for crude-by-rail unit trains. The basic approach of analyzing accidents and probabilities of cargo release has been applied in several other studies, including the risk analyses conducted at the University of Illinois at Urbana-Champaign Rail Transportation and Engineering Center (Rail TEC), which used the approach shown in Figure 17.[50]

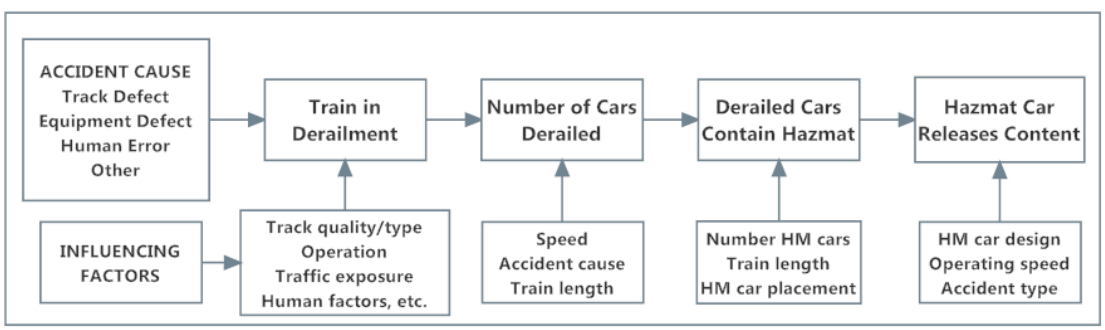


Figure 17: Rail Hazardous Material Spill Risk Analysis Approach of Rail TEC[51]

Forty-five years of freight train accident data (from the FRA) were used to determine the frequency of rail accidents, numbers of cars derailed per accident, and the probability of spillage from tank cars as a result of an accident. The data were used to determine national statistics, as well as statistics specific to Washington State. The probabilities of accidents per unit train mile were determined based on the FRA data to determine the frequencies of derailments along the corridor segments shown in Figure 1.

[49] Based on: Etkin *et al.* 2015b.
[50] Etkin *et al.* 2015a, 2015b; Saat *et al.* 2014; Saat and Barkan 2006.
[51] Etkin *et al.* 2015a, 2015b; Saat *et al.* 2014; Saat and Barkan 2006.

Both loaded and unloaded crude-by-rail unit trains may have spills. For a loaded train, there may be spillage of cargo oil (*i.e.*, Bakken crude oil for the Shell PSR crude-by-rail trains) and/or diesel fuel from the locomotives. For an unloaded train, the content of cargo is negligible (*i.e.*, only trace amounts that cling to the insides of the tank car), therefore, the only significant concern is over spillage of diesel fuel (Figure 18).

Five basic types of accidents were included in the analyses–derailments, collisions, fire-explosion events, highway-rail accidents, and miscellaneous events.[52]

This report includes analyses of rail "accidents" in keeping with industry terminology. This term is used by the Federal Railroad Administration (FRA) in describing train accidents or occurrences that result in a minimum of $10,500 in damages and/or personal injury. Minor "incidents" below this damage threshold are not included in the analysis. Accidents analyzed include derailments, collisions, highway-rail crossing accidents, and other events that resulted in damages to trains, rails, systems, or personnel. In this vain, the term "accident" is used to denote an event that is unplanned, but results in consequences of concern. Applying the term "accident" to a rail event does not imply that the event was unavoidable or could not have been prevented in some manner. The accident could be caused by human error, faulty equipment, and other factors.

The probability analyses were conducted as Monte Carlo-based fault-tree analyses to incorporate uncertainties and probability distributions within each category. While US national data were used to determine baseline probabilities, additional analyses were conducted on Washington State data to determine whether significant differences existed. Different time frames were evaluated. In the final probability analysis, factors that could affect accident and spillage probability (such as the use of safer tank cars and implementation of various regulations) were considered.

The overall probabilistic approach takes into account that no two accidents are identical, and also accounts for randomness and uncertainty in the factors that contribute to the probability of a crude-by-rail spill.[53]

[52] Four collision types combined: broken train (moving train breaks into parts and impact occurs between parts, or portion of broken train collides with another consist); raking (between parts or consist on adjacent track, or with structure, *e.g.*, bridge; "side-swiping collision"); rear-end; and side. Fire/explosion accidents include fires, violent ruptures, or detonations occurring as primary cause; does not include accidents in which spills ignite or explode secondarily. Highway rail crossing accidents involve other vehicles impacting trains at crossings. Miscellaneous includes obstruction accidents that occurs when trains hits object on train right-of-way, various other kinds of impacts, and other accidents that cannot be captured under the other categories.
[53] Jeong 2009.

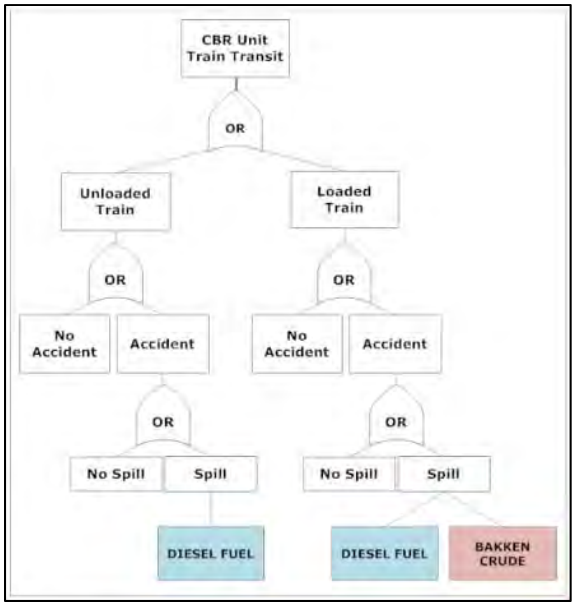


Figure 18: Basic Event Tree for Crude-by-Rail Spill Probability

Basic Fault Tree Analysis Methodology

The probability of a failure event is typically dependent on a constant failure rate, λ, and the exposure time, *t*, as in Equation 1and Equation 2:

Equation 1

$$P = 1 - \exp(-\lambda t)$$

Equation 2

$$P \approx \lambda t, \lambda t < 0.1$$

The probabilities can be calculated as the event rate of the scenario on an annual basis. This can then be calculated as the probability of the scenario occurring over the course of a longer period of time, such as over the course of 20 to 30 years, as in Equation 3.

The event rates can also be expressed in "return years" (*RY*), which is the amount of time (in years) that it would generally take for the event to occur once, as in Equation 4.

Equation 3

$$P(event)_t = \frac{N_{event}}{t}$$

Equation 4

$$RY = \frac{1}{N_{event}}, t = 1 year$$

The series of event probabilities is analyzed by means of a "fault tree," which is based on Boolean logic, *i.e.*, a statement (*e.g.*, "There was an oil spill," or "A derailment occurred.") is either true or false, except that there are also probabilities associated with the "true" and "false" determinations.

The fault tree combines a series of lower-level failure events to determine the likelihood of a "system failure." With the transport of oil by rail, the system functions properly when there is no spillage. That is, there are no errors or other precipitating events that could lead to an accident or spill to occur. If one of the components of the system "fails," there is the possibility of oil spillage.

In a simple fault tree, there are events that have probabilities of occurrence (Figure 19).

The probabilities of a series of events occurring are characterized by "gates" that represent whether two or more events are all required for the failure to occur ("and" gate), or if the events independently can cause the failure to occur ("or" gate). The probability that both events occur is the product of the probabilities of the two events, as in Equation 5.

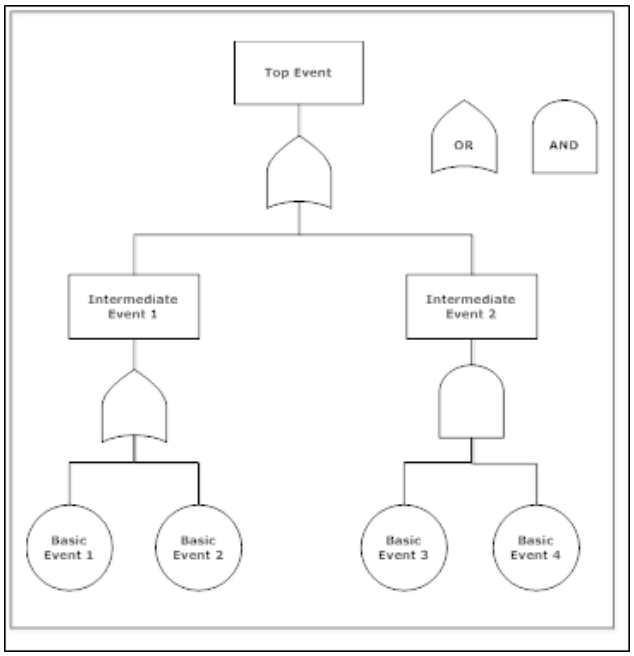


Figure 19: Basic Fault Tree Design

Equation 5

$$P(AandB) = P(A \cap B) = P(A) \cdot P(\mathrm{B})$$

The probability that two independent events occur to cause a failure ("or" gate) is represented by Equation 6 and Equation 7:

Equation 6

$$P(AorB) = P(A \cup B) = P(A) + P(B) - P(A \cap B)$$

Equation 7

$$P(AorB) = P(A) + P(B), \mathrm{P}(\mathrm{A} \cap \mathrm{B}) \approx 0$$

The probabilities of the output event of the OR- and AND-gates are calculated according to Equation 8 and Equation 9, where P_i is the probability of the input events (i) to the gates.

Equation 8

$$P_{occurrenceOR} = 1 - \prod_i (1 - P_i)$$

Equation 9

$$P_{occurrenceAND} = \prod_i P_i$$

Monte Carlo Simulation Methodology

Given that there is some uncertainty and variability in the probabilities that are incorporated into the fault tree analysis, an additional step of Bayesian statistical approach must be added. Bayesian statistical methodologies take into account the variability and distributions of inputs as opposed to point values for probabilities. A Monte Carlo simulation[54] can be used to incorporate variable inputs into a basic fault tree analysis, as in Figure 20.

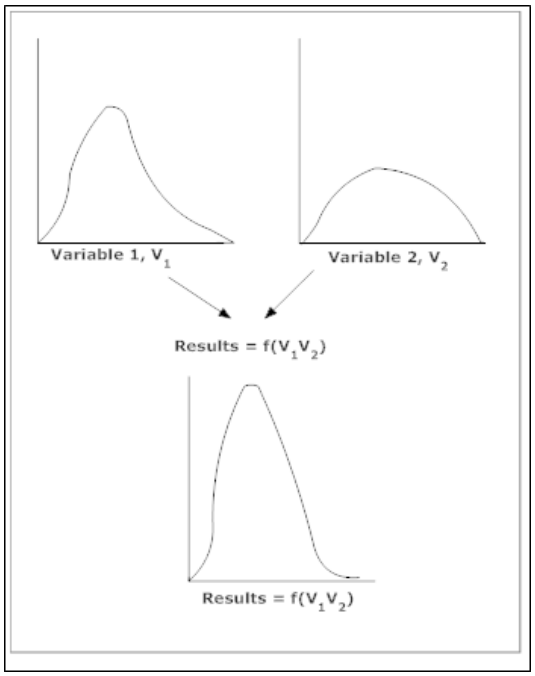


Figure 20: Monte Carlo Simulation Basis[55]

In this study, the Monte Carlo simulation was applied using Decisioneering Oracle Crystal Ball® software. This allowed for incorporation of variable probabilities for each of the series of events to determine the overall probability of each of the spillage scenarios.

[54] Monte Carlo simulation is a problem solving technique used to approximate the probability of certain outcomes by running multiple trial runs, called simulations, using random variables.
[55] Uncertainties of input variables are included in the result, which is a function of v1 and v2.

Approach to the Determination of Volumes for Spill Effects Modeling

Spill volumes were based on the number of tank cars that actually release oil in cargo spill events, and the volume of diesel fuel for spills from locomotives. The distributions of numbers of tank cars involved per accident were based on historical data, as were the probabilities of spillage from tank cars and locomotives.

These data were used to determine the expected probability distributions of spill volumes, including a determination of the reasonableness of the spill volumes applied in the spill and fire/explosion effects modeling scenarios.[56]

The spill volumes for those scenarios were selected prior to the modeling of spill probabilities and volumes, as described in this report. The volumes selected in cooperation with the co-lead agencies for the Shell PSR EIS were roughly based on a previous analysis.[57] That study involved only derailment accident data and an application of release rates from historical data with no adjustments for crude-by-rail-specific research as contained in this report. The agreed-upon volumes were based on the assumption of complete release from about eight or nine tank cars for a spill of 5,700 bbl, a volume that might approximate a "maximum most-probable discharge" or moderate-sized spill, and about 28 to 30 cars for the a very-large spill of 20,000 bbl, or an "effective" worst-case discharge (WCD).

Currently, there are no federal or state[58] definitions of a WCD, or average most-probable or maximum most-probable spill volumes, from trains that are analogous to those designated for vessels, pipelines, and facilities. As such, one might consider there to be two different definitions of WCD that may be applied in risk analyses for crude-by-rail transport:

- ***Theoretical* WCD:** This is the volume based on a single historical derailment event (of a non-crude-by-rail freight train) in which all of the freight cars derailed, but did not all release their contents. While this particular historical event did not result in the spillage from all the freight cars, the volume of the "theoretical WCD" is based on the hypothetical assumption that the train had been a unit train transporting crude oil and all of the contents of the tank cars spilled all of their contents. With a train length of 102 tank cars carrying about 650 bbl of oil each, as proposed for the Shell PSR, this would mean a spill of 66,300 bbl. For crude-by-rail trains with 120 cars, as proposed for some of the state's facilities, the spill volume could theoretically be 78,000 bbl. These magnitudes of spill scenarios are extremely unlikely based on the very low probability of all the cars derailing and the very low probability that all the cars would release oil.
- ***Effective* WCD:** This is the volume that is the most credible, or realistic, very large spill volume with respect to the likelihood of the largest number of tank cars involved in a derailment and the likelihood of the tank cars releasing all of their contents.

[56] Risknology 2016; RPS ASA 2016.
[57] Etkin et al. 2015b.
[58] As of 20 April 2016, the Washington Department of Ecology is proposing that the entire cargo load of a train be considered a WCD as Chapter 173-185 WAC (Washington Administrative Code). This proposed definition of WCD is currently out for public comment. (http://www.ecy.wa.gov/programs/spills/rules/1513docs.html)

Incorporation of CBR Train Risk Mitigation and Safety Measures

The historical data that were used to establish baseline probabilities for rail accidents involve equipment and practices that do not necessarily include the most up-to-date regulatory changes and safety measures that may reduce the incidence of accidents to mitigate risk. Risk mitigation measures that may affect the likelihood of future crude-by-rail unit train spills include:

- Speed restrictions;
- Enhanced braking;
- Positive train control;
- Wayside detectors;
- Thermal protection; and
- Tank car design.

The first four measures reduce the likelihood of accidents. The last two measures, tank car design and thermal protection, reduce the probability of spillage due to breaches and thermal damage in the event of an accident. To the extent possible, the potential reductions in accident and spill risk were evaluated for future Shell PSR crude-by-rail traffic.

Another risk mitigation measure that has been implemented is the pre-conditioning of Bakken crude oil to reduce volatility. This measure does not reduce the likelihood of spillage, but does reduce the probability of fires and explosions in the event of spills. Bakken crude oil pre-conditioning is considered in the separate fire and explosion analyses.

Application of Two Spill Probability Estimate Approaches

In order to provide a more conservative estimate[59] of rail accident and spill probabilities in addition to an estimate that incorporates the safety enhancements and risk reduction measures that have been in place or is expected to soon be in place for freight rail traffic in general and crude-by-rail traffic in particular, two separate spill probability estimates were calculated:

- Lower Estimate of Spills (LES)
- Higher Estimate of Spills (HES)

The calculated Lower Estimate of Spills (LES) provides a more "optimistic" assessment of spills based on accident and tank car release rates by incorporating the following assumptions:

- The rail accident rate calculated from historical general freight accident data needs to be adjusted to take into account the changes in rail safety that have occurred over the last decade or more;

[59] A conservative estimate is one that is cautious to avoid excess in approximating the quantity, degree, or worth of something. On the other hand a liberal estimate would be one that is cautious to avoid underestimating the quantity in question. In this case, the conservatism comes into play with respect to the assumptions of safety enhancements and reduction of accident and spill rates with the improvements that have been made or are about to be made on rail lines and equipment. In effect, a conservative estimate of the accident and spill rate would assume that there are no benefits of safety improvements. This would result in a higher estimate of spill probability.

- There are particular aspects of crude-by-rail transport that need to be taken into account with regard to accident rates and spillage rates, such as speed restrictions, enhanced braking, positive train control, wayside detectors, thermal protection, and tank car design; and
- The greater train length of crude-by-rail unit trains will increase the likelihood of accidents relative to the more typical shorter freight trains, as described in greater detail in Chapter 5.

Note that the LES incorporates two assumptions that may *increase* the likelihood of accidents over the "baseline" rate from historical rail accident data, which did not include the longer trains typical of crude-by-rail transport. Even with this adjustment, the overall estimate will be lower than that calculated with the HES assumptions described below. This is due to the fact that the safety enhancements would still tend to lead to a net decrease the accident and spill rates. [This is described in greater detail in Chapter 5.]

The reasoning behind assuming the two accident rate increase factors is that the purpose of the LES is to estimate an accident and spill rate that incorporates, to the extent possible and based on the available research data, the aspects of crude-by-rail transport that would affect the overall freight rail accident and spillage rates.

The calculated Higher Estimate of Spills (HES) provides a more "conservative" assessment of accident and spill rates by incorporating the following assumptions:

- The rail accident rate calculated from historical general freight accident data is appropriate for application to crude-by-rail traffic with no adjustments for safety measures;
- There are no particular aspects of crude-by-rail transport that would make the accident or tank car release rate different than for all freight traffic;
- There may be an increase in accident rates due to "sloshing" effects; and
- The greater train length of crude-by-rail unit trains will increase the likelihood of accidents relative to the more typical shorter freight trains, as described in greater detail in Chapter 5.

The majority of the safety enhancements for freight rail (and crude-by-rail) transport have already been incorporated into the main line rail systems in Washington State. However, to remain conservative, the HES assumes that the track enhancements that were already completed in Washington State in May 2016 would not be included in the estimation of accident probabilities. [This is discussed in greater detail in Chapters 5 and 7.]

Chapter 4: Analysis to Determine Baseline Accident Probabilities

The first step in the spill probability analysis was to determine the likelihood of a rail accident that may potentially lead to a spill, either in transit or at the Shell PSR rail unloading facility. Because of the lack of data specifically on crude-by-rail accidents, a larger data set was used to determine "baseline" accident probabilities that could then be adjusted to project for future potential CBR accidents, and ultimately, CBR spills. Data on freight rail accidents were thus used as proxies for CBR accidents.

Use of Federal Railroad Administration Accident Data

FRA rail accident data provide information on individual accidents, including train identification and characteristics, location, cause, and outcome with respect to car damage, spillage, and casualties. FRA data only include train accidents involving one or more railroads that have sustained combined track, equipment, and/or structures damage in excess of the reporting threshold. This threshold, which is adjusted annually, was $10,500 in 2014. This means that minor incidents below this damage threshold are not recorded. However, accidents that could lead to spillage would generally involve damages of at least the reporting threshold because significant car damage is necessary for there to be a release from tank cars. FRA states:

> *The computed accident damage only includes the loss and/or repair of cars and locomotives, repair of signal systems and other structures, and repair of roadbed and track. Not included in this calculation are the costs associated with clean-up, hazmat clean-up (support from fire department and other groups), loss of lading, societal damage (e.g., closing a business area during clean-up), loss of life or injury, loss of use of main line track, and loss of use of equipment/locomotives.*[60]

For the analysis in this report, the data set of 1975 through 2015 of 96,527 accidents from freight rail traffic was analyzed. Passenger train accidents were eliminated from the data set, because of significant differences in mode of operation, regulations, and track usage. The original set of accidents was broken down into the following categories based on type of track:

- Main Line:[61] 59,379 accidents
- Facility/Industry:[62] 4,772 accidents
- Siding:[63] 5,070 accidents
- Yard:[64] 25,916 accidents
- Unclassified: 1,390 accidents

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[60] http://safetydata.fra.dot.gov/OfficeofSafety/Documents/Railroad%20Safety%20Data%20Frequently%20Asked%20Questions.pdf?V=9

[61] Main line track means a track of a principal line of a railroad, including extensions through yards, upon which trains are operated by timetable or train order or both, or the use of which is governed by block signals or by centralized traffic control (23CFR §646 Subpart B).

[62] Tracks within industrial facilities other than rail yards.

[63] Low-speed track section distinct from a running line or through route such as a main line or branch line or spur.

[64] Rail yard, railway yard, or railroad yard is the US term for a complex series of tracks for storing, sorting, or loading/unloading, railcars and/or locomotives. Rail yards have many tracks in parallel for keeping rolling stock stored off the main line, so that they do not obstruct the flow of traffic. Rail cars are moved around by specially designed yard switchers, a type of locomotive.

For the purposes of analyzing the probability of accidents that could lead to spillage and present risks along the rail corridors to/from the Shell PSR, only main line-related accidents were included. For analyzing the probability of accidents related to the Shell PSR unloading operations, facility/industry-related accidents were analyzed, as these would be most analogous to activities at the facility.

Among the different types of freight railroad accidents considered in the analysis of baseline accident rates, there is a category of "fire/explosion" accidents. These rail accidents are ones in which there is a fire and/or explosion that occurs on a train in transit for which the fire and/or explosion is the primary cause of the accident. This would include accidents in which there is a fire or explosion on a locomotive, or perhaps a fire in a freight car, such as a fire in a car containing grain cargo, or even a tank car containing hazardous materials. This is not the same as the ignition of oil *after* the train derails and has released oil. These data do not in any way indicate the likelihood of a crude-by-rail spill with a fire and explosion, such as the accident that occurred at Lac-Mégantic, Quebec.

Main Line Rail Accident Probabilities: National

The breakdown of main line accidents by time period is shown in Table 9. Overall, nearly 79 percent of accidents were derailments. Derailments have decreased significantly over the last 40 years (Figure 21), as well as in the last decade. Other accident numbers have also decreased. However, there has been an increase in primary-cause fire/explosion accidents in the last decade. These findings correspond with other studies, including one that showed that the rate of freight train derailments in the US decreased significantly from 2000 to 2012 by a rate of 5.8 percent per year.[65]

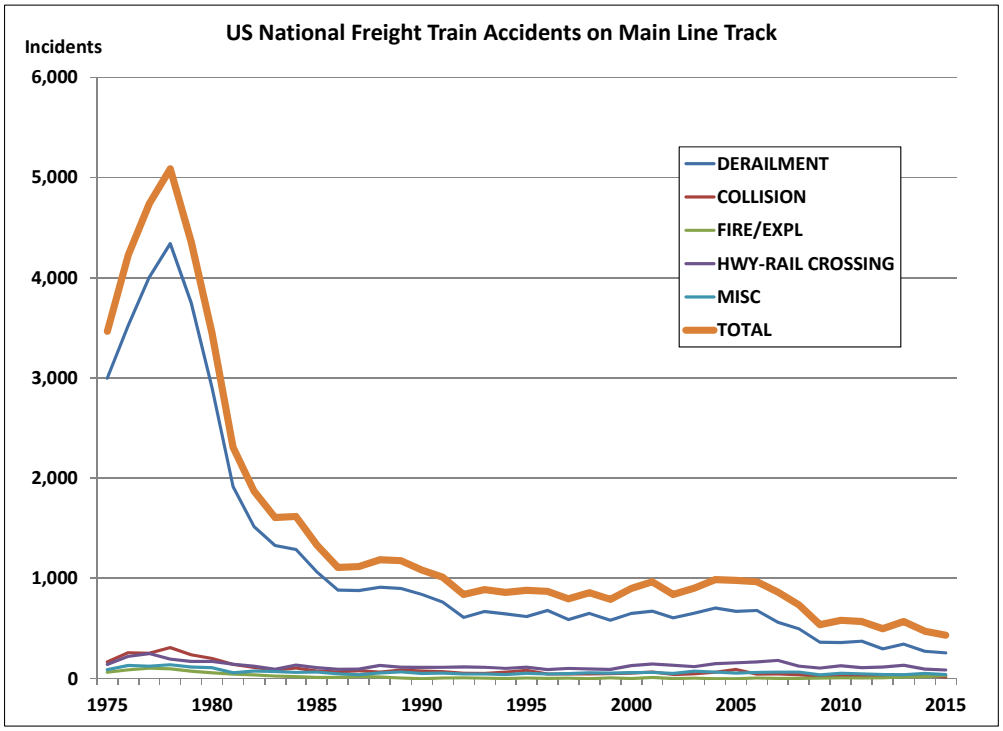


Figure 21: US National Main Line Freight Accidents 1975–2015

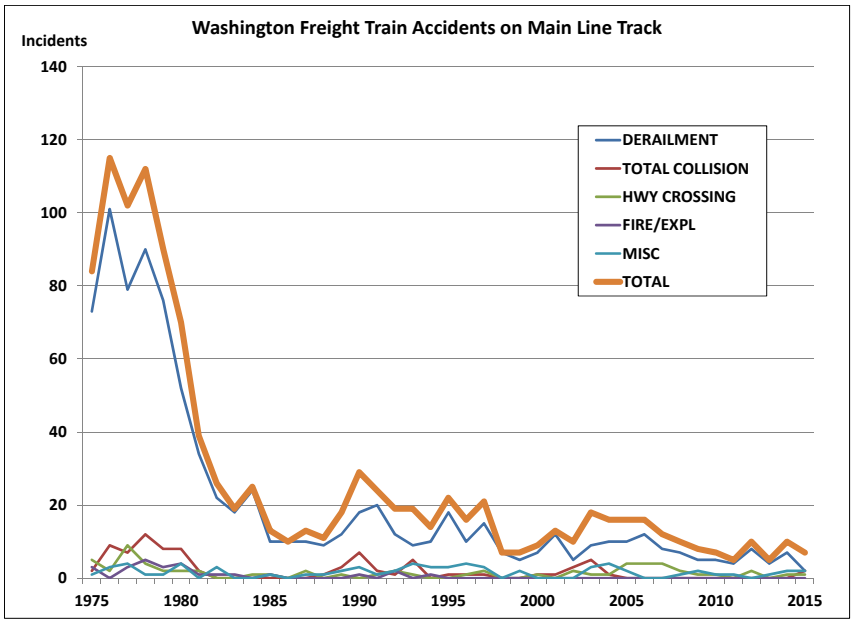
[65] Liu 2015.

Table 9: US National Freight Train Main Line Accidents by Time Period and Type[66]					
Accident Type	**Average Annual Accidents During Specific Time Periods**				
	1975–1984	**1985–1994**	**1995–2004**	**2005–2015[67]**	**1975–2015**
Derailment	2,756	818	642	430	**1,145**
Collision	188	70	56	38	**87**
Fire/Explosion	63	10	5	11	**22**
Highway-Rail Crossing	167	112	119	130	**132**
Miscellaneous	99	53	59	52	**65**
Total	**3,273**	**1,062**	**880**	**661**	**1,451**

Main Line Rail Accident Probabilities: Washington

The same analyses were conducted for Washington State accidents alone. Again, derailments make up the majority (84 percent) of accidents, and these rates have decreased, as shown in Table 10 and Figure 22.

Table 10: Washington Freight Train Main Line Accidents by Time Period and Type					
Accident Type	**Average Annual Accidents During Specific Time Periods**				
	1975–1984	**1985–1994**	**1995–2004**	**2005–2015[68]**	**1975–2015**
Derailment	57	12	10	7	**21**
Collision	5	2	1	0	**2**
Fire/Explosion	3	1	1	2	**2**
Highway-Rail Crossing	2	1	0	0	**1**
Miscellaneous	2	2	2	1	**2**
Total	**68**	**17**	**14**	**10**	**27**



[66] Based on Federal Railroad Administration data.
[67] Data are current through 30 November 2015. 2015 data are pro-rated to 11 months.
[68] Data are current through 30 November 2015. 2015 data are pro-rated to 11 months.

Figure 22: Washington Main Line Freight Accidents 1975–2015

Analysis of Causes for Freight Rail Accidents

The various types of accidents can be attributed to five basic primary causes:[69]

- Track conditions;
- Mechanical/electrical failures or malfunctions;
- Human error;
- Signal failures or malfunctions; and
- Miscellaneous/other.

The national accident data were parsed by accident type and cause, as shown in Table 11 and Table 12. The same analyses were conducted for Washington only (Table 13 and Table 14).

Table 11: Freight Rail Accident Causes on Main Lines (1975–2015)

Accident Type	Accident Number by Primary Cause Category					
	Track	Mech/Elect	Human	Signal	Misc.	Total
Derailment	21,203	14,517	5,704	74	5,356	**46,854**
Collision	96	376	2,540	14	533	**3,559**
Fire/Explosion	6	674	9	0	217	**906**
Highway-Rail Crossing	2	4	8	1	5,368	**5,383**
Miscellaneous	80	687	869	9	1,031	**2,676**
Total	**21,387**	**16,258**	**9,130**	**98**	**12,505**	**59,378**

Table 12: Percent Freight Rail Accident Causes on Main Lines (1975–2015)

Accident Type	Percent by Primary Cause Category					
	Track	Mech/Elect	Human	Signal	Misc.	Total
Derailment	45.25%	30.98%	12.17%	0.16%	11.43%	**100%**
Collision	2.70%	10.56%	71.37%	0.39%	14.98%	**100%**
Fire/Explosion	0.66%	74.39%	0.99%	0.00%	23.95%	**100%**
Highway-Rail Crossing	0.04%	0.07%	0.15%	0.02%	99.72%	**100%**
Miscellaneous	2.99%	25.67%	32.47%	0.34%	38.53%	**100%**
Total	**36.02%**	**27.38%**	**15.38%**	**0.17%**	**21.06%**	**100%**

Table 13: Freight Rail Accident Causes on Washington Main Lines (1975–2015)

Accident Type	Accident Number by Primary Cause Category					
	Track	Mech/Elect	Human	Signal	Misc.	Total
Derailment	308	302	123	0	126	**859**
Collision	0	8	58	0	17	**83**
Fire/Explosion	0	22	1	0	66	**89**
Highway-Rail Crossing	0	0	0	0	0	**0**

[69] A spill may be attributable to a derailment, *e.g.*, but the derailment may be caused by human error or track issues.

Miscellaneous	2	10	26	1	27	**66**
Total	**310**	**342**	**208**	**1**	**236**	**1,097**

Table 14: Percent Freight Rail Accident Causes on Washington Main Lines (1975–2015)

Accident Type	Percent by Primary Cause Category					
	Track	Mech/Elect	Human	Signal	Misc.	Total
Derailment	35.86%	35.16%	14.32%	0.00%	14.67%	**100%**
Collision	0.00%	9.64%	69.88%	0.00%	20.48%	**100%**
Fire/Explosion	0.00%	24.72%	1.12%	0.00%	74.16%	**100%**
Highway-Rail Crossing	0.00%	0.00%	0.00%	0.00%	0.00%	**-**
Miscellaneous	3.03%	15.15%	39.39%	1.52%	40.91%	**100%**
Total	**28.26%**	**31.18%**	**18.96%**	**0.09%**	**21.51%**	**100%**

Review of Other Studies on Rail Accidents

A 2012 study[70] examined train derailments in particular with respect to their route causes. The researchers concluded that the single most common cause of derailments was broken rails, and that track conditions were the primary cause of 41 percent of derailments. Track-related accidents also resulted in the highest average number of derailed cars per accident.

The study also examined the effect of rail speed at the time of derailment. The researchers found that regardless of speed, broken rails or welds were the most frequent cause of derailments. At speeds below 10 mph, certain track-related and human factor-related accidents occurred more frequently. At derailment speeds greater than 25 mph, human factor accidents (*e.g.*, improper train handling, braking operations, and improper use of switches) were almost completely absent. Equipment causes (*e.g.*, bearing failure, broken wheel, and axle and journal defects) were common factors. The results of this study are summarized in Table 15.

Table 15: Derailment Causes on Class I Main Lines 2001–2010[71]

Cause Category	Cause	%	Average Cars Derailed
Track	**Broken tracks or welds**	15.3%	12.8
	Track geometry (excluding wide gauge)	7.3%	6.5
	Wide gauge	3.9%	10.2
	Buckled track	3.4%	12.7
	Turnout defects (switches)	2.7%	5.1
	Miscellaneous track and structure defects	1.8%	8.6
	Joint bar defects	1.5%	15.8
	Roadbed defects	1.5%	9.9
	Other rail and joint defects	1.3%	20.2
	Rail defects at the bolted joint	1.1%	20.2
	Non-traffic, weather causes	1.0%	7.7
	Turnout defects: frogs	0.3%	8.8

[70] Liu *et al.* 2012 based on 2001 to 2010 FRA accident data.
[71] Based on Liu *et al.* 2012.

Table 15: Derailment Causes on Class I Main Lines 2001–2010[71]			
Cause Category	**Cause**	**%**	**Average Cars Derailed**
	Total	**41.1%**	**Weighted Average: 11.02**
Mechanical/ Electrical	**Bearing failure (car)**	5.9%	6.8
	Broken wheels (car)	5.2%	6.4
	Other wheel defects (car)	3.3%	8
	Coupler defects (car)	3.1%	5.8
	Other wheel defects (car)	3.0%	5.2
	Sidebearing, suspension defects (car)	2.9%	6.5
	Centerplate of carbody defects (car)	2.3%	5.2
	Stiff truck	1.3%	6.6
	All other car defects	1.1%	5.3
	Locomotive trucks, bearings, wheels	1.1%	3.5
	Track–train interaction (hunting) (car)	0.9%	10.5
	Other brake defect (car)	0.9%	5.1
	Truck structure defects (car)	0.8%	7.6
	Brake rigging defect (car)	0.6%	5.5
	Air hose defect (car)	0.4%	7.8
	All other locomotive defects	0.3%	11.9
	UDE (car or locomotive)	0.2%	10.8
	Locomotive electrical and fires	0.2%	2.8
	TOFC–COFC defects	0.1%	1
	Handbrake defects (car)	0.0%	2
	Total	**33.6%**	**Weighted Average: 6.41**
Human Error	**Train handling (excluding brakes)**	4.6%	7.7
	Use of switches	2.4%	3.9
	Brake operation (main line)	2.2%	9.3
	Train speed	1.4%	6.6
	Miscellaneous human factors	1.0%	8.6
	Handbrake operations	0.9%	4.3
	Switching rules	0.7%	6.6
	Mainline rules	0.3%	5.1
	Employee physical condition	0.1%	13.7
	Brake operations (other)	0.1%	11.8
	Failure to obey or display signals	0.1%	5.8
	Radio communications error	0.1%	4.3
	Total	**13.9%**	**Weighted Average: 6.95**
Miscellaneous	**Obstructions**	3.5%	11.9
	Track–train interaction	3.4%	7.4
	Lading problems	3.1%	5.9
	Other miscellaneous	1.2%	7.8
	Total	**11.2%**	**Weighted Average: 8.4**
Signal	**Signal failures**	**0.4%**	**7.1**

Table 15: Derailment Causes on Class I Main Lines 2001–2010[71]			
Cause Category	**Cause**	**%**	**Average Cars Derailed**
	Total	**0.4%**	**Weighted Average: 7.1**
		Weighted Average	**8.6 cars**

Accident Rates per Train-Mile

Accident rates were re-calculated on a per-train-mile[72] basis for the various data (Table 16 and Figure 23).

Table 16: Freight Train Main Line Accident Rate per Train Mile by Period and Type						
Accident Type	**Jurisdiction**	**Average Accidents per Million Train Miles[73]**				
		1975–1984	**1985–1994**	**1995–2004**	**2005–2015**	**1975–2015**
Derailment	**National**	5.2701	1.6323	1.0318	0.6475	**2.1089**
	Washington	5.6530	1.1922	0.9736	0.6503	**2.0817**
Collision	**National**	0.3609	0.1387	0.0900	0.0575	**0.1592**
	Washington	0.4769	0.1887	0.1391	0.0181	**0.2011**
Fire/Explosion	**National**	0.1193	0.0198	0.0081	0.0171	**0.0405**
	Washington	0.2086	0.0497	0.0000	0.0000	**0.0630**
Highway-Rail Crossing	**National**	0.3226	0.2211	0.1895	0.1968	**0.2316**
	Washington	0.2682	0.0795	0.0795	0.1806	**0.1527**
Miscellaneous	**National**	0.1913	0.1052	0.0939	0.0799	**0.1167**
	Washington	0.1689	0.1788	0.1888	0.1084	**0.1599**
Total	**National**	**6.2642**	**2.1170**	**1.4134**	**0.9988**	**2.6569**
	Washington	**6.7757**	**1.6889**	**1.3809**	**0.9574**	**2.6585**

[72] A train-mile is a single train traveling one mile.
[73] National train mile data from FRA; Washington train mile data from Etkin *et al.* 2015a.

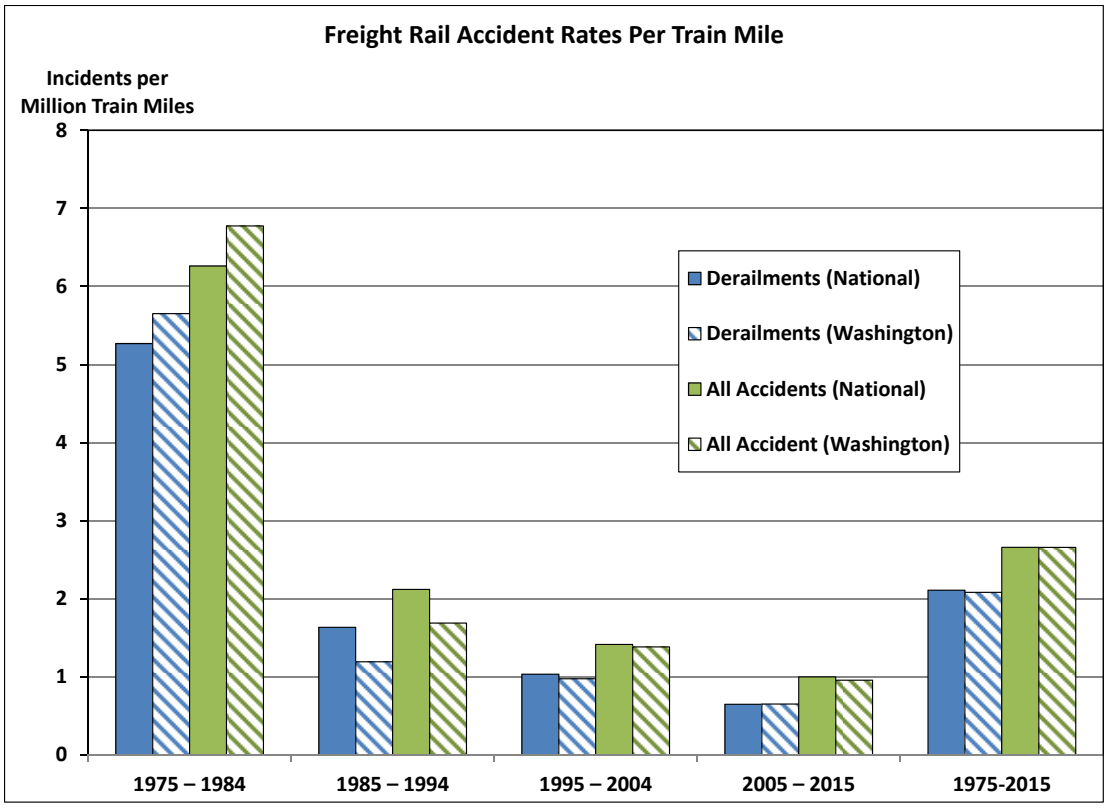


Figure 23: Freight Rail Accident Rates per Train Mile on Main Lines (National and Washington)

Limited Data on Crude-by-Rail Accident Rates

Data on accidents specifically involving crude-by-rail "unit" trains or "key" trains[74] are not readily available from FRA. Trains are not specifically categorized as "unit trains" or identified with respect to their cargo, including crude oil. The FRA data do, however, include information about the numbers of "hazmat" cars (*i.e.*, cars carrying hazardous materials as cargo) on board each train involved in an accident, as well as the total number of freight cars. Based on this information, a selection of accident data that met the following criteria was developed to provide the best possible representation of crude-by-rail unit trains:

- Occurrence between 2008 and 2015 (dates during which crude-by-rail transport occurred)[75];
- Rail carriers including: BNSF, Union Pacific (UP), Norfolk Southern (NS), CSX, Genesee & Wyoming (GSWY), and Montreal, Maine & Atlantic (MMA);[76]
- At least 30 percent of tank cars on train identified as hazmat cars; and
- At least 20 total hazmat cars on the train.

[74] Trains with blocks of at least 20 hazmat tank cars.

[75] While crude-by-rail had not started in Washington State until later in 2010, there were some crude-by-rail key trains that were in transit during 2008-2009. The point here was to identify any train that might possibly have been a crude-by-rail train. In 2005-2008, there was about one key train (with about 20 cars) on the rails in the US each day (4.4 million bbl per year). By 2008, there was 6.7 million bbl being moved by rail per year. By 2010, it was up to 21.2 million bbl being moved nationally. (See Figure 2).

[76] Carriers reported by FRA to have had crude-by-rail accidents and/or to have been carrying crude oil.

Based on this data subset, estimated annual accident numbers were calculated (Figure 24 and Table 17). The crude-by-rail accident causes are analyzed in Table 18 and Table 19.

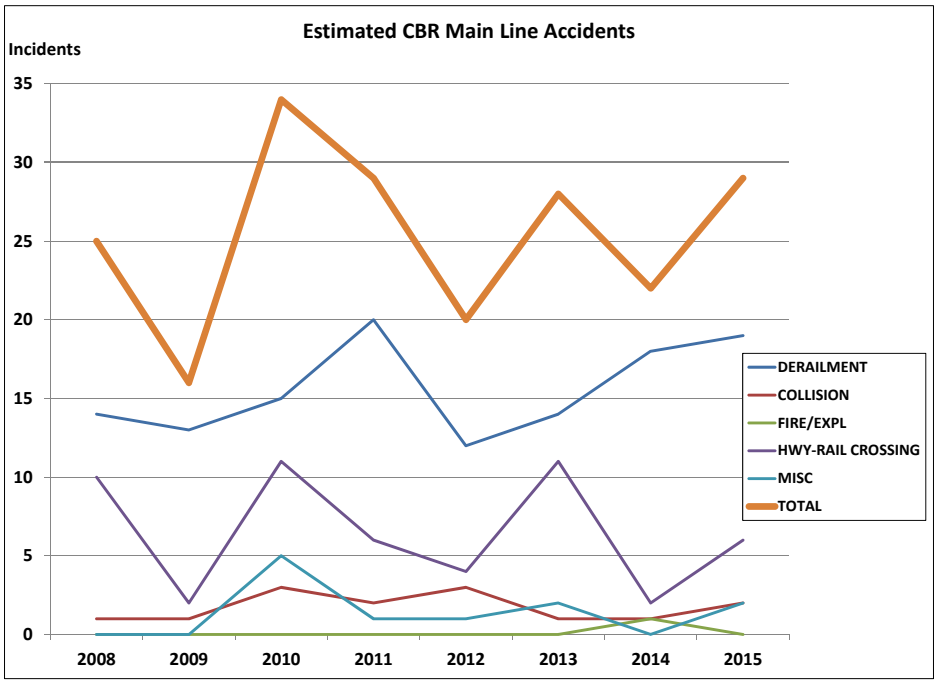


Figure 24: Estimated National Crude-by-Rail Accidents (2008–2015)

Table 17: US Crude-by-Rail Unit/Key Train Main Line Accidents by Type (2008–2015)										
Accident Type	**Estimated Annual Accidents**									
	2008	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**Total**	**Avg**
Derailment	14	13	15	20	12	14	18	19	125	**14.0**
Collision	1	1	3	2	3	1	1	2	14	**1.6**
Fire/Explosion	0	0	0	0	0	0	1	0	1	**0.1**
Highway-Rail	10	2	11	6	4	11	2	6	52	**5.8**
Miscellaneous	0	0	5	1	1	2	0	2	11	**1.2**
Total	**25**	**16**	**34**	**29**	**20**	**28**	**22**	**29**	**203**	**22.8**

Table 18: US Crude-by-Rail Unit/Key Train Accident Causes on Main Line Track (2008–2015)						
Accident Type	**Accident Number by Primary Cause Category**					
	Track	**Mech/Elect**	**Human**	**Signal**	**Misc.**	**Total**
Derailment	54	38	20	0	13	**125**
Collision	0	3	11	0	0	**14**
Fire/Explosion	0	1	0	0	0	**1**
Highway-Rail Crossing	0	0	0	0	52	**52**
Miscellaneous	0	7	3	0	1	**11**
Total	**54**	**49**	**34**	**0**	**66**	**203**

Table 19: Percent US Crude-by-Rail Unit/Key Train Accident Causes (2008–2015)						
Accident Type	**Percent by Primary Cause Category**					
	Track	**Mech/Elect**	**Human**	**Signal**	**Misc.**	**Total**
Derailment	43.2%	30.4%	16.0%	0.0%	10.4%	**100%**
Collision	0.0%	21.4%	78.6%	0.0%	0.0%	**100%**
Fire/Explosion	0.0%	100.0%	0.0%	0.0%	0.0%	**100%**
Highway-Rail Crossing	0.0%	0.0%	0.0%	0.0%	100.0%	**100%**
Miscellaneous	0.0%	63.6%	27.3%	0.0%	9.1%	**100%**
Total	**26.6%**	**24.1%**	**16.7%**	**0.0%**	**32.5%**	**100%**

There were seven crude-by-rail accidents in Washington based on the assumptions above (summarized in Table 20). Prior to 2012, the accidents most likely involved key trains rather than unit trains, as there are no records of significant amounts of oil being transported by rail in Washington.

Table 20: Washington Crude-by-Rail Unit/Key Train Main Line Accidents by Type (2008–2015)										
Accident Type	**Annual Accidents**									
	2008	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**Total**	**Avg**
Derailment	0	0	1	0	0	0	1	0	**2**	**0.25**
Collision	0	0	0	0	0	0	0	1	**1**	**0.13**
Fire/Explosion	0	0	0	0	0	0	0	0	**0**	**0.00**
Highway-Rail	1	0	1	0	0	0	0	1	**3**	**0.38**
Miscellaneous	0	0	0	0	0	0	0	1	**1**	**0.13**
Total	**1**	**0**	**2**	**0**	**0**	**0**	**1**	**3**	**7**	**0.88**

The estimation of crude-by-rail accident rates is more difficult than for other freight traffic due to the lack of availability on specific data on national crude-by-rail track mileage. An alternate approach employed was to determine the accident rate per crude-by-rail train, which does not take into account the varying distances that the trains travel. Annual estimates of numbers of crude-by-rail unit trains, nationally and in Washington State, are shown in Table 21.

Based on the estimates of unit train numbers, accident rates per crude-by-rail train were calculated, with the results shown in Table 22. Note that the accidents that occurred prior to 2012 in Washington were not included because there are no data on crude oil transport for this time period. Accident rates per crude-by-rail train-mile were estimated for Washington State traffic, as shown in Table 23.

Table 21: Annual Numbers of Crude-by-Rail Unit Train Transits (US and Washington)

Year	National			Washington[77]	
	Bbl/day[78]	Loaded Unit Train Transits/Day	Loaded Unit Train Transits/Year[79]	Loaded Unit Train Transits/Day	Loaded Unit Train Transits/Year
2008	18,000	0.3	117	0	0
2009	21,000	0.4	137	0	0
2010	58,000	1.0	371	0	0
2011	131,000	2.3	839	0	0
2012	463,000	8.1	2,957	0.5	183
2013	831,000	14.6	5,313	0.7	256
2014	1,002,000	17.5	6,403	2.7	986
2015	792,000	13.8	5,046	2.7	986

Table 22: Estimated Crude-by-Rail Accident per Unit or Key Train Transit

Year	National			Washington		
	Train Transits[80]	Derailments Per Transit	Total Accidents Per Transit	Train Transits	Derailments Per Transit	Total Accidents Per Transit
2008	234	0.0598	0.1068	0	-	-
2009	274	0.0474	0.0584	0	-	-
2010	742	0.0202	0.0458	0	-	-
2011	1,678	0.0119	0.0173	0	-	-
2012	5,914	0.0020	0.0034	366	0.0000	0.0546
2013	10,626	0.0013	0.0026	512	0.0000	0.0547
2014	12,806	0.0014	0.0017	1,972	0.0005	0.0005
2015	10,092	0.0019	0.0029	1,972	0.0000	0.0015
Average	**-**	**0.0183**	**0.0299**	**-**	**0.0001**	**0.0278**

[77] Based on Etkin 2015a.
[78] Energy Information Administration data (https://www.eia.gov/petroleum/transportation/ accessed September 2014 through January 2016).
[79] Assuming at least 80 cars with about 700 barrels of oil each.
[80] Train numbers doubled as each train would transit one-way loaded and make return trip unloaded.

Table 23: Accident Rates per Crude-by-Rail Train-Mile in Washington State (2012–2015)						
Year	CBR[81] Transits	Total Train-Miles (Loaded + Empty)	CBR Derailments	All CBR Accidents	CBR Accidents per Train-Mile	
					Derailments	All Accidents
2012	366	432,246	0	0	0.0000000	0.0000000
2013	512	604,672	0	0	0.0000000	0.0000000
2014	1,972	2,328,932	1	1	0.0000004	0.0000004
2015	1,972	2,328,932	0	3	0.0000000	0.0000013
Average	-	-	**0.25**	**1.00**	**0.0000001**	**0.0000004**

Loaded versus Unloaded Train Accident Rates

A brief analysis of accident rates from loaded and unloaded freight trains was conducted to determine if there was a significant difference. The results are shown in Table 24. Assuming that there are roughly an equal number of loaded and empty trains, the probability of an accident is about twice as likely with a loaded train versus an unloaded train. There is a higher probability of an accident with a loaded train for all accident types except for highway-rail crossing accidents. The probabilities of accidents for each of the individual accident types are used in apportioning the probabilities of accidents with loaded and empty trains.

Table 24: US National Accident Rates with Loaded and Empty Trains (1975–2015)[82]						
Accident Type	**Loaded #**	**Loaded %**	**Empty #**	**Empty %**	**Total #**	**Total %**
Collision	281	57.8%	205	42.2%	**486**	**100.0%**
Derailment	5,858	70.4%	2,462	29.6%	**8,320**	**100.0%**
Fire/Explosion	41	71.9%	16	28.1%	**57**	**100.0%**
Hwy-Rail	194	38.5%	310	61.5%	**504**	**100.0%**
Miscellaneous	218	64.1%	122	35.9%	**340**	**100.0%**
Total	**6,592**	**67.9%**	**3,115**	**32.1%**	**9,707**	**100.0%**

Washington Crude-by-Rail Accident Rates

The overall probability data for accidents by jurisdiction and accident type are shown in Table 25.

Table 25: National Accident Rates Applied in Crude-by-Rail Probability Analysis: All Freight						
Accident Primary Cause	Accident Rates on Main Lines Per Million Train Miles[83]					
	All Freight			Washington State Freight		
	High	Low	Average	High	Low	Average
Collision	0.3609	0.0575	0.1592	0.4769	0.0181	0.2011
Derailment	5.2701	0.6475	2.1089	5.6530	0.6503	2.0817
Fire/Explosion	0.1193	0.0081	0.0405	0.2086	0.0000	0.0630
Hwy-Rail Crossing	0.3226	0.1895	0.2316	0.2682	0.0795	0.1527
Miscellaneous	0.1913	0.0799	0.1167	0.1888	0.1084	0.1599

[81] CBR stands for "crude-by-rail"
[82] Includes only FRA data that includes information about whether train was loaded/empty at the time of accident.
[83] High value based on highest time period; low value based on lowest time period; average based on average in all years (as in Table 16).

These probabilities were then apportioned by loaded and empty trains according to the data in Table 24, with the results shown in Table 26, Figure 25, and Figure 26.

Table 26: Accident Probabilities for Crude-by-Rail Probability Analysis: Loaded/Empty Trains

Source	Accident Primary Cause	Accident Rates on Main Lines Per Million Train Miles					
		All Freight			Washington State Freight		
		High	Low	Avg	High	Low	Avg
Loaded Train	Collision	0.2086	0.0332	0.0920	0.2756	0.0105	0.1162
	Derailment	3.7102	0.4558	1.4847	3.9797	0.4578	1.4655
	Fire/Explosion	0.0858	0.0058	0.0291	0.1500	0.0000	0.0453
	Hwy-Rail Crossing	0.1242	0.0730	0.0892	0.1033	0.0306	0.0588
	Miscellaneous	0.1226	0.0512	0.0748	0.1210	0.0695	0.1025
Empty Train	Collision	0.1523	0.0243	0.0672	0.2013	0.0076	0.0849
	Derailment	1.5599	0.1917	0.6242	1.6733	0.1925	0.6162
	Fire/Explosion	0.0335	0.0023	0.0114	0.0586	0.0000	0.0177
	Hwy-Rail Crossing	0.1984	0.1165	0.1424	0.1649	0.0489	0.0939
	Miscellaneous	0.0687	0.0287	0.0419	0.0678	0.0389	0.0574

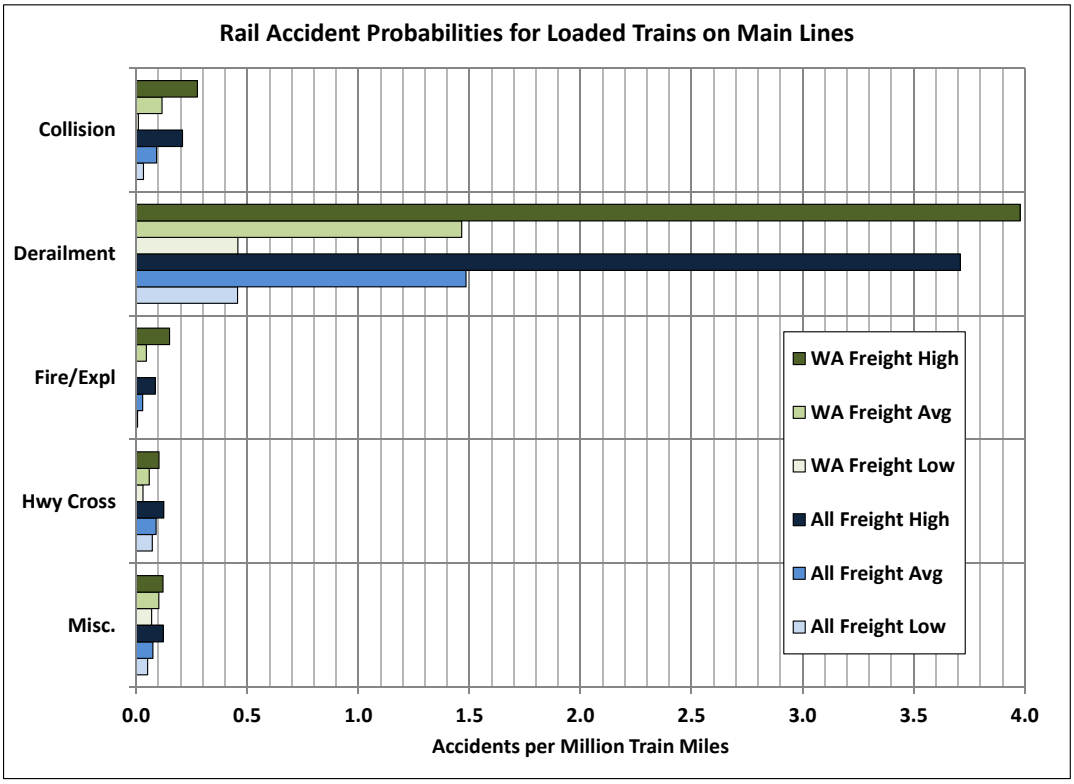


Figure 25: Calculated Rail Accident Probabilities for Loaded Freight Trains

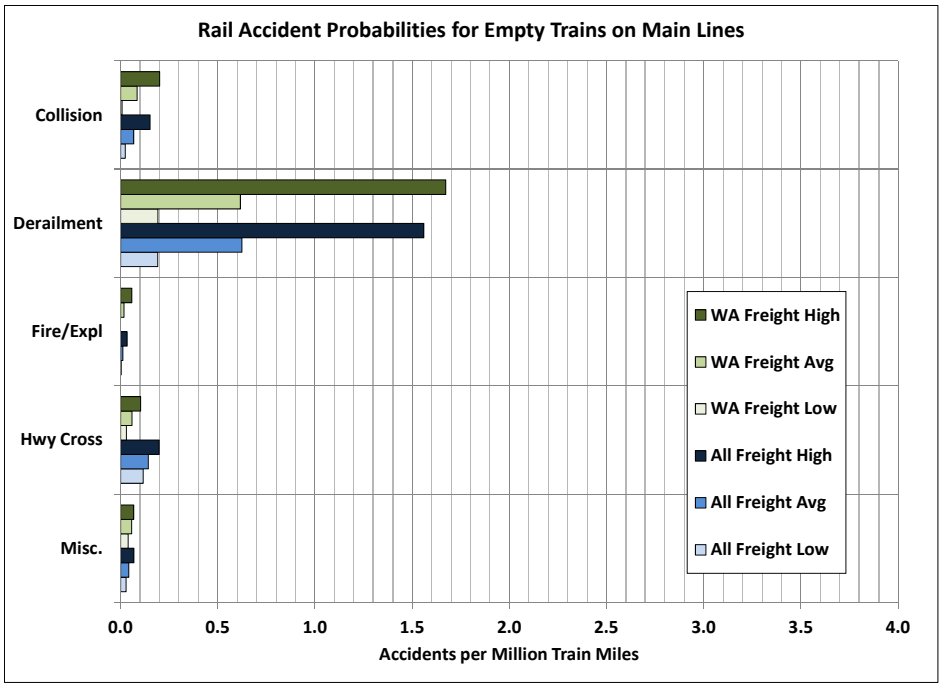


Figure 26: Calculated Rail Accident Probabilities for Empty Freight Trains

Within Facility Rail Accidents

National FRA data for rail accidents within facilities (*i.e.*, during loading/unloading, moving along rails within facility grounds) were analyzed for number of accidents by cause, as in Figure 27 and Table 27. About 83 percent of rail accidents within a facility were derailments.

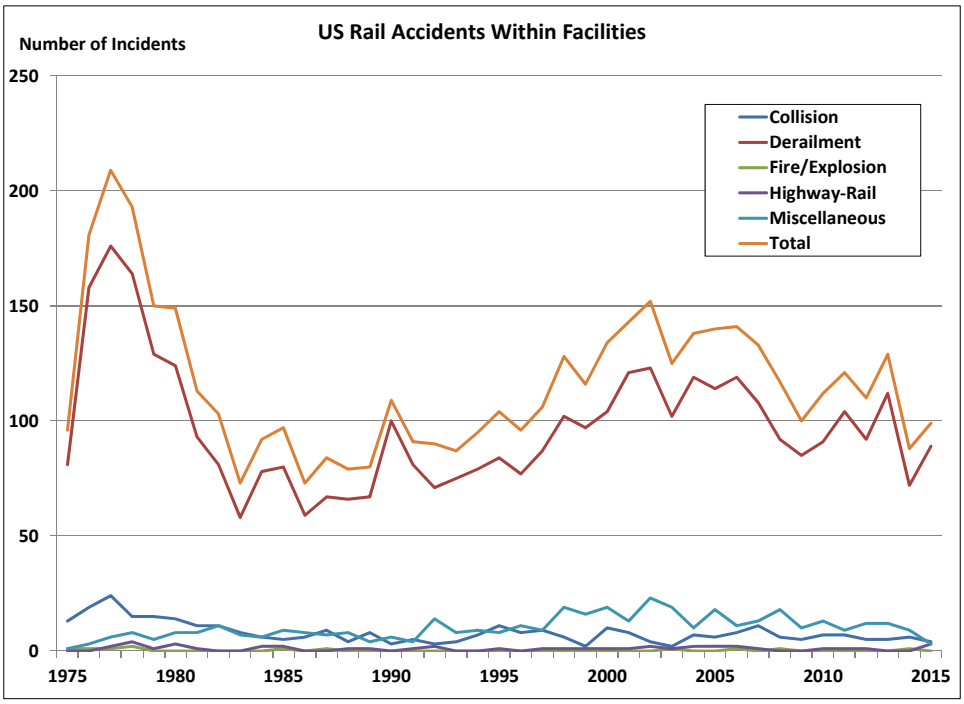


Figure 27: US Rail Accidents within Facilities (1975–2015)

Table 27: US National Rail Accident Rates within Facilities (1975–2015)						
Year	**Accident Number**					
	Collision	**Derailment**	**Fire/Explosion**	**Highway-Rail**	**Miscellaneous**	**Total**
1975	13	81	1	0	1	**96**
1976	19	158	1	0	3	**181**
1977	24	176	1	2	6	**209**
1978	15	164	2	4	8	**193**
1979	15	129	0	1	5	**150**
1980	14	124	0	3	8	**149**
1981	11	93	0	1	8	**113**
1982	11	81	0	0	11	**103**
1983	8	58	0	0	7	**73**
1984	6	78	0	2	6	**92**
1985	5	80	1	2	9	**97**
1986	6	59	0	0	8	**73**
1987	9	67	1	0	7	**84**
1988	4	66	0	1	8	**79**
1989	8	67	0	1	4	**80**
1990	3	100	0	0	6	**109**
1991	5	81	0	1	4	**91**
1992	3	71	0	2	14	**90**
1993	4	75	0	0	8	**87**
1994	7	79	0	0	9	**95**
1995	11	84	0	1	8	**104**
1996	8	77	0	0	11	**96**
1997	9	87	0	1	9	**106**
1998	6	102	0	1	19	**128**
1999	2	97	0	1	16	**116**
2000	10	104	0	1	19	**134**
2001	8	121	0	1	13	**143**
2002	4	123	0	2	23	**152**
2003	2	102	1	1	19	**125**
2004	7	119	0	2	10	**138**
2005	6	114	0	2	18	**140**
2006	8	119	1	2	11	**141**
2007	11	108	0	1	13	**133**
2008	6	92	1	0	18	**117**
2009	5	85	0	0	10	**100**
2010	7	91	0	1	13	**112**
2011	7	104	0	1	9	**121**
2012	5	92	0	1	12	**110**
2013	5	112	0	0	12	**129**
2014	6	72	1	0	9	**88**

Table 27: US National Rail Accident Rates within Facilities (1975–2015)						
Year	**Accident Number**					
	Collision	**Derailment**	**Fire/Explosion**	**Highway-Rail**	**Miscellaneous**	**Total**
2015	4	89	0	3	3	**99**
Total	**327**	**3,981**	**11**	**42**	**415**	**4,776**

During the time period 1975–2015, there were 70 within-facility accidents in Washington State reported to FRA, as summarized in Table 28 and Figure 28. In the last 20 years, there have been, on average, 1.45 facility-related rail accidents per year. (Note that these accidents are ones that would cause at least $10,500 worth of damage to rail equipment or infrastructure.) None of these accidents involved the release of hazardous materials. Just over 81 percent were derailments, similar to the national data.

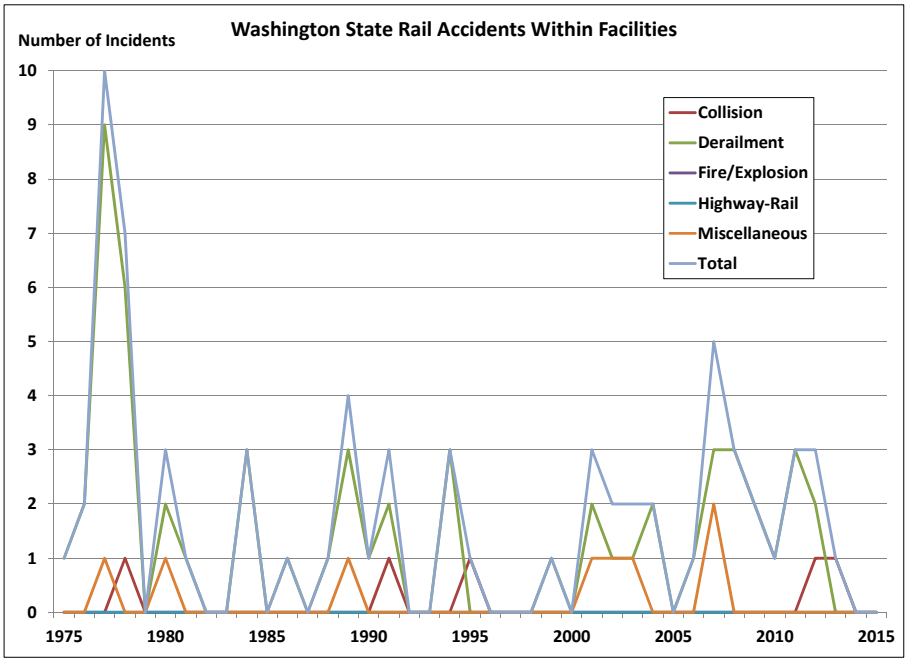


Figure 28: Washington State Rail Accidents within Facilities (1975–2015)

Table 28: Washington State Rail Accident Rates within Facilities (1975–2015)						
Year	**Accident Number**					
	Collision	**Derailment**	**Fire/Explosion**	**Highway-Rail**	**Miscellaneous**	**Total**
1975	0	1	0	0	0	**1**
1976	0	2	0	0	0	**2**
1977	0	9	0	0	1	**10**
1978	1	6	0	0	0	**7**
1979	0	0	0	0	0	**0**
1980	0	2	0	0	1	**3**
1981	0	1	0	0	0	**1**
1982	0	0	0	0	0	**0**
1983	0	0	0	0	0	**0**
1984	0	3	0	0	0	**3**

Table 28: Washington State Rail Accident Rates within Facilities (1975–2015)						
Year	**Accident Number**					
	Collision	**Derailment**	**Fire/Explosion**	**Highway-Rail**	**Miscellaneous**	**Total**
1985	0	0	0	0	0	**0**
1986	0	1	0	0	0	**1**
1987	0	0	0	0	0	**0**
1988	0	1	0	0	0	**1**
1989	0	3	0	0	1	**4**
1990	0	1	0	0	0	**1**
1991	1	2	0	0	0	**3**
1992	0	0	0	0	0	**0**
1993	0	0	0	0	0	**0**
1994	0	3	0	0	0	**3**
1995	1	0	0	0	0	**1**
1996	0	0	0	0	0	**0**
1997	0	0	0	0	0	**0**
1998	0	0	0	0	0	**0**
1999	0	1	0	0	0	**1**
2000	0	0	0	0	0	**0**
2001	0	2	0	0	1	**3**
2002	0	1	0	0	1	**2**
2003	0	1	0	0	1	**2**
2004	0	2	0	0	0	**2**
2005	0	0	0	0	0	**0**
2006	0	1	0	0	0	**1**
2007	0	3	0	0	2	**5**
2008	0	3	0	0	0	**3**
2009	0	2	0	0	0	**2**
2010	0	1	0	0	0	**1**
2011	0	3	0	0	0	**3**
2012	1	2	0	0	0	**3**
2013	1	0	0	0	0	**1**
2014	0	0	0	0	0	**0**
2015	0	0	0	0	0	**0**
Total 1975-2015	**5**	**57**	**0**	**0**	**8**	**70**

Note that there were no fire/explosion or highway-rail accidents within facilities in Washington State during the time period 1975–2015.

Chapter 5: Crude-by-Rail Accident Probability Adjustments

The calculated probabilities of rail accidents were based on historical data that may not be completely relevant for *future* crude-by-rail operations for a number of reasons:

- Crude-by rail unit trains are operated differently from other freight trains with respect to maximum speed and other factors;
- Crude-by rail unit trains act differently from other freight trains with respect to lateral stability;
- Operators (such as BNSF Railway) plan to make capital improvements on rail lines; and
- A number of safety improvements have been, or will be, in place due to federal and state regulations.

Adjustments that would tend to *increase* the rate of accidents for crude-by-rail unit trains were incorporated in both the HES and LES modeling processes. Adjustments that would tend to *decrease* the rate of accidents for crude-by-rail unit trains were only incorporated in the LES modeling process.

Electronically-Controlled Pneumatic (ECP) Brakes

With conventional brakes on trains, the brake signal reaches the end of a long train after several minutes, which causes significant push and pull forces on the train. Front cars on the train are braked first, while cars at the end continue to run free – i.e., there is sequential braking. The end cars push against the braking front cars, extending the braking distance. During braking, brake couplers experience tremendous force, which shortens the useful lifespan of the couplers. Cargo may be damaged by the extreme forces caused by sequential braking. In long heavy freight trains braking sequential braking may cause train cars to buckle and derail.[84]

Electronically-controlled pneumatic (ECP) brakes differ from conventional brakes in that they transmit the brake signal at the speed of light rather than the speed of air. ECP brakes require locomotives and cars to be equipped with special hardware. The major differences between the two braking systems are shown in Table 29.

Table 29: Differences between ECP Brakes and Conventional Brakes[85]

Conventional Brakes	Electronically-Controlled Pneumatic (ECP) Brakes
• Brake signal transmitted by air pressure in brake pipe • Brakes applied in sequential order from front to back with in-train forces • Reservoirs cannot be charged while brakes applied; engineers must calculate remaining brake power to avoid runaway trains • Cars not wired, requiring hand inspections to detect problems	• Brake signals transmitted electronically • Brakes applied simultaneously eliminating in-train forces • Reservoirs continuously charged eliminating danger of losing braking power • Cars wired allowing communication back to locomotive from potential multitude of car sensors

[84] Booz Allen Hamilton 2006. See also: http://www.transportation.northwestern.edu/docs/2007/2007.11.08.Murphy.Presentation.pdf

[85] Booz Allen Hamilton 2006.

ECP Brake Studies

A 2006 study conducted for the Federal Railroad Administration (FRA)[86] on the effectiveness of ECP brakes was conducted before crude-by-rail transport was in operation in the US. Its conclusions are based on the potential effectiveness for all types of freight trains. The findings with regard to the safety benefits and effectiveness of ECP brake technology were:

- **Brake Signal Transmission Rate:** Brake signal transmission rate is increased with ECP brakes. With conventional brakes and air signal transmits brake communications at approximately two-thirds the speed of sound. With ECP brakes, the signal is transmitted electronically (i.e., instantaneously) so that all the cars brake together rather than in a slower sequence. This significantly reduces in-train forces (i.e., the push and pull of cars against each other that damages both rail equipment and cargo).
- **Brake Application Rate:** With ECP brakes, the brakes in each car receive approximately the same cylinder pressure, which also reduces in-train forces caused by transient differences in cylinder pressure with conventional brakes.
- **Graduate Brake Release:** The ability of ECP brakes to lower braking level after making a brake application enables the adjustment of braking level to more closely follow safe speed limits.
- **Constant Charging Reservoirs:** With ECP brakes the brake pipe acts as a reservoir supply pipe so that it continuously supplies reservoirs. Whether the brake application is released gradually or by a sudden total release, the reservoirs are always recharged so that there is no risk of having no brake pressure.
- **Longer Trains:** ECP brakes make it possible to safely operate longer trains. The use of electrical signals instead of air pressure allows the brake pipe to be maintained at full pressure at all times. Uniform braking and constant pressure reduces end-of-train pressure problems and in-train forces that otherwise restrict train lengths.[87]
- **Elimination of Power Braking:** ECP brakes eliminate the need for braking well ahead of a reduced-speed area, such as a curve or switch, this reduces unnecessary wear on the brakes and reduces wheel damage.
- **Shorter Stopping Distances:** ECP brakes can reduce stopping distances by 40 to 60 percent compared with conventional brake stop distances. Shorter stopping distances help to reduce collisions and grade-crossing accidents in which the engineer is able to see the threat on the tracks but would not otherwise be able to stop the train in time to avoid an accident.
- **Improved Train Handling:** Since ECP brakes allow all cars to stop simultaneously, in-train forces are lessened, which reduce the likelihood of derailments. Improved train handling afforded by ECP brakes also reduces the chance of operating error. Operating a train with conventional brake technology is an extremely complex task, requiring extensive knowledge of the rail line over which the train is running, and constant pre-planning of train speed and braking options several miles ahead. For example, on grades, the operator is constantly watching gauges,

[86] Booz Allen Hamilton 2006.

[87] Note that this study was conducted prior to the introduction of 100–120 car unit trains for crude-by-rail operations.

monitoring speed, air pressure, and dynamic brake effort, and must be prepared to make a decision instantly if something is wrong.

- **Train Monitoring:** ECP technology provides the engineer with immediate information on brake failures. Conventional braking systems only provide this information during 1,000-mile physical inspections.
- **Continuous Brake Pipe Pressure:** The continuous brake pipe pressure of ECP brakes provides the ability to stop the train at all times, which removes the threat of premature air reservoir depletion and possible runaway trains.[88]
- **Real-Time Train Status Reporting:** The ECP brake system's wire-based communications platform transmits information about each car back to the locomotive. These communications include information about bearing conditions and wheel problems.
- **Reduced Train Crew Fatigue:** Since ECP brake systems do not require operators to be constantly focused on pressure levels in the brakes, the crew can better focus on the current train operating environment rather than prepare for likely brake level pressures miles ahead.

In 2015, in the aftermath of a collision between a grain trains and a crude-by-rail unit train in Casselton, North Dakota,[89] the National Transportation Safety Board (NTSB) conducted a train braking simulation study.[90] The purpose of the study was to estimate the reduction in stopping distance with ECP brakes compared with conventional brakes and distributed power pneumatic (DP) brakes. NTSB concluded that ECP brakes outperform other systems, including distributed power systems, which in turn outperform conventional brakes.[91] The results are summarized in Table 30 through Table 32.

Table 30: Stopping Distance Reduction Due to Brake Signal Propagation Rate at 10% NBR[92]

Braking Configuration	Speed (mph)	Stopping Distance Reduction	
		Distributed Power (DP) Brakes	Electronically-Controlled Pneumatic (ECP) Brakes
Emergency	20	4–17%	5–26%
	30	4–11%	5–19%
	40	3–9%	4–15%
	50	3–8%	4–13%
Full Service	20	7–46%	37–75%
	30	11–39%	37–68%
	40	10–39%	30–64 %

[88] A runaway train due to brake problems was a precipitating cause of the Lac-Mégantic accident (see Chapter 9.)
[89] See Table 2.
[90] Renze 2015.
[91] http://www.ntsb.gov/news/press-releases/Pages/PR_20150723c.aspx
[92] NBR = net braking ratio, defined as the ratio of braking force against a car's wheels to the car's weight. An increase in the NBR for any brake system substantially improves the stopping performance (Renze 2015). According to AAR *Manual of Standards and Recommended Practices, Section E-11, Electronically-Controlled Brake Systems, Appendix A*, NBR is defined as "the sum of the actual normal (perpendicular) brake shoe forces on all of the wheels on a car divided by the actual weight of the car on the rail; the term is used specifically in tread braking applications. In this standard, NBR refers to the loaded net brake ratio resulting from a full-service (100%) brake application from a 90-psi brake pipe pressure."

	50	9–37%	25–60%

Table 31: Stopping Distance Reduction Due to Increased NBR Level Grade[93]

Braking Configuration	Speed	Stopping Distance Reduction					
		12.8% NBR			14% NBR		
		Conventional	DP	ECP	Conventional	DP	ECP
Emergency	20	12%	14%	15%	16%	18%	19%
	40	15%	17%	17%	20%	22%	23%
	60	17%	18%	19%	22%	24%	24%
Full Service	20	8%	8%	16%	11%	11%	21%
	40	10%	11%	18%	13%	15%	24%
	60	11%	13%	19%	15%	18%	25%

Table 32: Stopping Distance Reduction for ECP Brake Signal Propagation Rate and NBR[94]

Braking Configuration	Speed	Stopping Distance Reduction (Relative to Conventional Brakes at 10% NBR)		
		ECP 10% NBR	ECP 12.8% NBR	ECP 14% NBR
Emergency	20	5–26%	13–39%	16–43%
	30	5–19%	16–33%	21–38%
	40	4–15%	17–31%	22–36%
	50	4–13%	19–30%	24–36%
Full Service	20	37–75%	42–80%	45–82%
	30	37–68%	45–74%	48–76%
	40	30–64%	41–71%	44–73%
	50	25–60%	40–68%	44–71%

The overall conclusions of the NTSB study are:

- The benefits from the use of advanced braking systems, such as ECP, comes from three sources:
  - Reduced stopping distances (fewer cars in a potential pileup);
  - Reduced vehicle kinetic energy (less energy available to puncture cars in a pileup); and
  - Lower and more uniform in-train coupler forces (more compatible car-to-car interaction);
- For emergency braking, the ECP brake system provides "somewhat better" stopping performance than the DP configuration; and
- The results on overall reductions in stopping distance with ECP (shown in Table 32) indicate that ECP brakes exhibit reduced stopping distances that vary by speed, NBR, and by braking configuration (emergency vs. full service):
  - At slower speeds, the stopping distance reduction is somewhat greater than for higher speeds;
  - Full service braking stopping distance reductions are greater than for emergency braking; and

[93] Relative to conventional 10% NBR, distributed power 10% NBR, and ECP 10% NRB baseline (Renze 2015).
[94] Relative to conventional 10% NBR baseline (Renze 2015)

- Stopping distances reductions are greatest for the highest NBRs.

A study commissioned by the industry group AAR[95] used the same simulation tool as that conducted by the NTSB.[96] The results of the AAR study are shown in Table 33. This study evaluated the reduction in energy dissipation and the degree to which that would affect a reduction in the numbers of derailed cars.

Table 33: Average Percent Reduction in Energy Dissipated Derailment and Number Derailed Cars

Performance of ECP System Compared to:	Average % Reduction in Energy Dissipated in Derailment	Average Reduction in Number of Cars Reaching Point of Derailment
Conventional Brakes (Head-End)	13.3%	1.6
Conventional Break with End-of-Train Device	11.6%	1.3
Rear-End Distributed Power Pneumatic Brakes	12.8%	1.5
Mid-Train Distributed Power Pneumatic Brakes	10.5%	1.2
Distributed Power Pneumatic Brakes at 2/3	10.8%	1.2

While better braking ability with ECP brakes clearly would be expected to reduce crude-by-rail accidents, as well as reduce the likelihood of damage to tank cars, it is difficult to assess a specific accident reduction rate for ECP brakes. The testing data for reduced stopping distance vary considerably, depending on various parameters, from 4 percent to 82 percent.

In addition, the effectiveness and benefits of ECP brakes have been hotly contested by industry, particularly by AAR.[97] AAR maintains that ECP brakes will not result in fewer accidents and will not provide significant safety benefits. AAR states that less than one percent of all train accidents are related to failures in brake equipment,[98] and that there have not been any brake-related accidents involving a crude or ethanol train.[99]

In addition, AAR states that ECP brakes are "costly and have issues with reliability that could erode network efficiency." According to AAR, the FRA estimated the cost of ECP brakes (system-wide) at $1.7 billion with a negative cost/benefit ratio of almost 9 to 1.[100] ECP technology has been in limited use in rail service for 15 years, and, according to AAR, "has yet to meet reliability standards for service and are more than three times more likely to incur a mechanical delay."

These objections and concerns are the basis of the judicial challenges encompassed by the American Petroleum Institute v. United States (DC Cir. No. 15-1131) filing described previously.

[95] Brousseau 2014.
[96] Renze 2015.
[97] AAR 2014.
[98] This contrasts with the data in Table 15 that indicate that 4.5% of accidents over the 2001-2010 decade to be attributable to brake failures (Liu *et al.* 2012). The time period considered in AAR's analysis could explain the discrepancy. AAR considered accidents that occurred on main *and* siding track through 2014.
[99] AAR may not be considering the brake issues involved in the Lac-Mégantic accident (see Chapter 9 for a more complete analysis of that accident.)
[100] AAR 2014.

ECP Brake Assumptions for HES and LES

There are three important factors to consider in applying the potential reduction in accident rates to this current analysis:

- The probability that ECP brakes will or will not eventually be required on crude-by-rail unit trains;
- The actual effectiveness of ECP brakes in reducing stopping distances and accidents; and
- The percentage of accidents that can properly be attributed to brake problems, or the percentage of accidents that may have been prevented with more effective braking systems.

For the purposes of this analysis, different assumptions were made for the Lower Estimate Spills (LES) and Higher Estimate of Spills (HES):

- For the HES, it was conservatively assumed that there is no benefit to ECP brakes because they will either not be part of the future regulations for crude-by-rail trains or, if they are, they are no better than conventional braking systems; and
- For the LES, it was assumed that the ECP brakes will eventually be part of the future regulations and that the effectiveness for reducing accidents associated with braking problems would result in a reduction of 4 percent to 82 percent for the 4.5 percent of accidents that are attributed to braking problems.[101] In other words, overall, a 0.007 percent to a 3.7 percent reduction in accidents.

Positive Train Control (PTC) Studies

Another aspect of regulatory action is positive train control (PTC), an advanced automatic train protection system that enforces movement authorities, speed restrictions[102] (signal and civil), and protection of roadway workers. The US federal government had originally mandated PTC for all railroads by the end of 2015, but in October 2015, the statutory deadline was extended to 2018. There are also provisions for case-by-case extensions possible up to the end of 2020 to allow time for railroads to adequately test their systems.[103] This extension was based on the findings of an August 2015 report from FRA on delays in the implementation of PTC.[104]

PTC is defined in federal law as: "a system designed to prevent train-to-train collisions, over-speed derailments, incursions into established work zone limits, and the movement of a train through a switch left open in the wrong position."[105]

PTC incorporates technologies that are designed to automatically stop a train before certain accidents caused by human error occur. PTC is designed to prevent:

- Train-to-train collisions;

[101] Based on Liu *et al.* 2012, as summarized in Table 15.
[102] Kawprasert and Barkan 2010.
[103] AAR 2015c.
[104] FRA 2015.
[105] 49 CFR §236.

- Derailments caused by excessive speed;
- Unauthorized incursions by trains onto sections of track where maintenance activities are taking place; and
- The movement of a train through a track switch left in the wrong position.

There are no specific technical requirements and federal law allows railroads to adopt PTC systems suited to their needs.[106] All PTC systems include the use of radio communications to provide in-cab signals to the train engineer and the ability for a dispatcher to stop the train in an emergency.[107]

There are divergent views on the capacity impact that PTC will make. As a result of a catastrophic accident in Southern California involving a commuter train and a Union Pacific freight train, any line segment that handles passenger operations is required to install PTC. PTC is designed to remotely monitor train movements and cause a train to be stopped if it appears to be dangerously close to overtaking or colliding with another train. There have been projections that PTC will allow trains, in conjunction with existing signal systems, to be able to operate at faster speeds at closer distances apart than existing signal systems alone will allow. The industry group AAR avers that it is possible that PTC may make existing rail operations *less* efficient, especially if put into place without adequate testing. [108]

The concept of PTC is not new to US railroad systems, nor specific to crude-by-rail. In fact, earlier versions of PTC were considered and sometimes implemented as far back as the 1920s. Its current form began to take shape in the 1990s, especially with the formation of the Railroad Safety Advisory Committee (RSAC) to the FRA. [109]

The actual effectiveness of PTC in reducing accidents is difficult to estimate. The RSAC concluded[110] that effective PTC systems could prevent certain types of collisions and derailments–an estimated 40 to 60 main line accidents per year. With an estimated annual accident number of about 1,450,[111] this would amount to at most a four percent reduction. According to a 2012 review study conducted for the US Congress,[112] PTC is expected to prevent less than two percent of the railroad collisions and derailments that occur annually. The majority of these accidents occur in rail yards, which are generally less severe.

The FRA estimates that there would be $90 million in annual safety benefits with the full implementation of PTC.[113] These safety benefits are calculated by estimating accident costs related to fatalities and injuries, equipment damage, track and off-track damages, hazardous material cleanup, evacuations, wreck cleanup, freight loss, and freight delay. In another FRA study,[114] in one ten-year period (between 1987 and 1997), an annual average of seven fatalities, 22 injuries, $20 million in property damages, and

[106] Peters and Friteli 2012.
[107] FRA 2009.
[108] AAR 2015c.
[109] Railroad Safety Advisory Committee 1999.
[110] Railroad Safety Advisory Committee 1999.
[111] Based on Table 9.
[112] Peters and Friteli 2012.
[113] Roskind 2009.
[114] Railroad Safety Advisory Committee 1999.

evacuations of 150 people due to potential hazardous material release could have been prevented by PTC. Note that these accidents would not have included any crude-by-rail accidents because of the time period involved. Since crude-by-rail makes up only a portion of all freight rail transport in the US (an estimated three percent),[115] it cannot be assumed that these types of reductions could all be attributed to crude-by-rail accidents.

Another study conducted for the industry group AAR,[116] the main purpose of which was to evaluate the effects of single-person crews,[117] also assessed the benefits of PTC, as summarized in Table 34. The results indicate that for a two-person crew, the reduction in accidents was estimated to be 80.3%. [The analytical results with respect to crew number are shown in Table 36.]

Table 34: Annual Accident Frequency Analysis with and without PTC[118]

Train Accident Scenario	Expected Annual Accidents		Reduction in Accidents with PTC
	Two-Person Crew w/o PTC	Two-Person Crew + PTC	
Accidents due to Violations	11	0.1	99.1%
Accidents due to Selected Route Integrity Failures	13	2.4	81.5%
Accidents due to Rollaways	3	3.0	0.0%
Grade Crossing Accidents/Failure to Sound Horn	2	0.2	90.0%
Accident Totals	**29**	**5.7**	**80.3%**

PTC Assumptions for HES and LES

The factors to consider in applying the potential reduction in accident rates for PTC to this current analysis are:

- The probability that PTC will be present on all main line tracks transited by crude-by-rail traffic in Washington State; and
- The actual effectiveness of PTC in reducing accidents.

PTC should be present on all main line tracks in Washington State by 2018. The completion of wayside detector controls in May 2016 allows for the complete installation of PTC by BNSF Railway. According to FRA, as of February 2016, BNSF Railway has targeted this to be completed by the beginning of 2018.[119]

For the purposes of this analysis, different assumptions were made for the Lower Estimate Spills (LES) and Higher Estimate of Spills (HES):

- For the HES, it was assumed that PTC will not be present on any main line tracks in Washington, or if it is present, it may not be fully functional or effective in reducing accidents, so that there would be *no* accident-reducing effect of PTC on any type of accident; and

[115] See Figure 7 and Figure 8.
[116] ICF Incorporated 2015.
[117] Two-person crews are traditional in the US.
[118] ICF Incorporated 2015.
[119] http://www.fra.dot.gov/Media/File/0798

- For the LES, it was assumed that PTC will be implemented in early 2018, as per the FRA target schedule, and that the accident reductions would vary from two to 80 percent.

The wide range of effectiveness (2–80%) for the LES is based on the two studies[120] previously described that came up with significantly different conclusions. For the LES it was considered that the range of effectiveness was somewhere in that large range. However, as described below, it was also assumed that PTC would be working together with other factors, including wayside detectors and track upgrades, to determine the actual effectiveness in reducing crude-by-rail accidents.[121]

Prevention of Derailments through Wayside Detectors[122]

A key prevention component in minimizing derailments is the extent to which the subject railroad employs monitoring equipment to detect anomalies with a train's operation, its equipment, or other factors that could affect the safe passage of a train. In Washington, BNSF Railway's extensive distribution of such equipment (*i.e.*, wayside detectors) is important in preventing derailments.

The nationwide wayside detector system is a technology that allows railroads to prevent damage and accidents before they happen. Positioned along 140,000 miles of railroad in the nation, seven kinds of wayside detectors monitor the wheels of passing trains and alert rail car operators to potential defects enabling them to schedule appropriate maintenance in a safe, timely, and cost-effective manner. There are eight types of wayside detectors in operation, as summarized in Table 35. The advanced wayside detector system installation project was completed in Washington State as of May 2016, according to Washington DOT.[123]

Table 35: Types of Wayside Detectors in Operation in the US

Wayside Detector Type	Function
Acoustic Bearing Detector (TADS-ABD)	Uses acoustic signatures to evaluate the sound of internal bearings and identify those likely to fail in the near term.
Railway Bearing Detector (RailBAM™)	Detects faulty wheel bearings as trains pass by.
Truck Bogie Optical Geometry Inspection (TBOGI)	Measures performance of a rail car's axle and wheel suspension ("truck") with laser-based monitoring system.
Truck Performance Detectors (TPD)	Assesses performance of rail car suspension systems or trucks on curved track by measuring each wheel's lateral forces at major segments of track containing 4°–6° of curvature.
Wheel Impact Load Detector (WILD)	Identifies rail wheels worn or damaged into an out-of-round shape before they can damage track
Wheel Profile Measurement System (WPMS)	Evaluates complete rail profile by capturing laser images and detecting worn wheel treads or flanges.
Hot Box Detector	Measures the temperature of journal bearings on passing rail cars.[124]
Dragging Detector	Detects loose components and dragging under freight cars.[125]

[120] Peters and Friteli 2012; ICF Incorporated 2015.
[121] In the actual modeling simulations, the adjustment factors are weighted on the low end, meaning that it is assumed that is more likely that the value is on the lower end of this range rather than the higher end.
[122] See also Etkin *et al.* 2015a.
[123] http://www.wsdot.wa.gov/projects/rail/advancedsignal/
[124] There are more than 6,000 hot box detectors on 140,000 miles of track in North America.
[125] More than 1,000 dragging equipment detectors are installed on the North American freight rail network.

There are no definitive studies that provide a reliable quantification of accident reduction rates with wayside detectors.[126] According to the industry group AAR, since the wayside detector system was developed in 2004, the broken wheel and accident rate has dropped over 20 percent.[127] No specific study was cited by AAR to make this assertion, however the data in Table 9, which is collected by the federal agency FRA, does show a 33 percent reduction in derailments and a nearly 25 percent reduction in overall accidents after 2004. Whether this reduction in accidents is solely attributable to wayside detectors, other factors, or a combination of factors cannot be concluded from this data.

Other components in minimizing derailments include track condition, track inspection, operating protocols and maintenance policies. BNSF Railway's main line corridors in the state of Washington over which loaded crude by rail trains operate are FRA Class 4 tracks, maintained to allow Amtrak passenger trains to operate at a maximum speed of 79 mph, and freight trains to operate at a maximum speed of 60 mph. BNSF Railway restricts loaded unit bulk trains that exceed 100 tons per operative brakes to 45 mph, which applies to crude-by-rail unit trains system-wide. In high-populated areas (High Threat Urban Areas, HTUA), an emergency USDOT order restricts unit trains carrying crude oil to 40 mph.[128]

Wayside Detector Assumptions for HES and LES

There are two important factors to consider in applying the potential reduction in accident rates of wayside detectors to this current analysis:

- The probability that wayside detector systems are fully operational in Washington State and by BNSF Railway; and
- The actual effectiveness of wayside detectors in reducing accident rates.

For the purposes of this analysis, different assumptions were made for the Lower Estimate of Spills (LES) and Higher Estimate of Spills (HES):

- For the HES, it was assumed that there would be no accident-reducing effect of wayside detectors, because they would not be fully implemented and/or their effectiveness could not be quantified; and
- For the LES, it was assumed that the wayside detector system would be fully operational in conjunction with the necessary PTC components, and that the effectiveness for reducing accidents was 20 percent.

Mandated Two-Person Crews

In April 2014, the FRA announced its intention to issue a proposed rulemaking requiring two-person crews on crude-by-rail trains.[129] Currently, over 99 percent of US trains operate with two federally-certified crew members, but this regulation would make this mandatory. FRA issued a Notice of Proposed Rulemaking (NPRM) in November 2015. It is currently under Office of Management and Budget (OMB)

[126] McWilliams 2015.
[127] http://freightrailworks.org/wp-content/uploads/safety2.pdf
[128] Effective 1 July 2014.
[129] https://www.fra.dot.gov/eLib/details/L04999

review. The NRPM had the support of the Railroad Workers United,[130] United Transportation Union, and the Brotherhood of Locomotive Engineers and Trainmen,[131] though some railroads were lobbying against this regulatory change, citing advancements with automated safety systems (*e.g.*, PTC).[132] At an FRA hearing on 15 July 2016, the agency heard two sharply contrasting arguments on the proposed two-person crew mandate–one from freight management and the other from labor.[133]

The industry group AAR reported that a review of FRA train accident data found no evidence that trains with one-person crews had accidents at a higher rate than with two-person crews. AAR supports a position of "continued flexibility in determining minimum crew size.[134] A 2015 study conducted for AAR concluded that PTC rather than crew size would significantly reduce accidents. Their fault tree analysis results are summarized in Table 36.

Table 36: Results of Annual Accident Frequency Analysis on Positive Train Control Tracks[135]

Train Accident Scenario	Expected Annual Accidents		
	Traditional Two-Person Crew w/o PTC	One-Person Crew + PTC	Two-Person Crew + PTC
Accidents due to Violations	11	0.1	0.1
Accidents due to Selected Route Integrity Failures	13	2.5	2.4
Accidents due to Rollaways	3	0.3	3.0
Grade Crossing Accidents with Failure to Sound Horn	2	0.2	0.2
Accident Totals	**29**	**3.1**	**5.7**

Their analysis did not include evaluating the effect of one- or two-person crews *without* PTC. The study makes a noteworthy conclusion that, "Train accidents due to rollaways decrease by a factor of 10 with the removal of a second person from the cab due to fewer potential situations and additional care taken when the sole operator leaves the cab." The researchers explained:

> *Two particular accident scenarios [for rollaway accidents] were identified that would be different for traditional operations today versus under the future cases. These involved instances in which: 1) the train was intentionally stopped to either move a hand operated switch or 2) to inspect the train after an emergency brake or detector stop. Regardless of why the train was stopped, the concern is if the train starts to roll away and the engineer in the cab must stop the train before an accident occurs. In general this will only happen if the train has not been properly secured and the slope is sufficient for the train to start to roll. In the future one-person crew case, there is no engineer in the cab, so the operator on the ground must get back into the cab to stop the train or the onboard system must stop the train.*[136]

[130] http://railroadworkersunited.org/whats-wrong-with-single-employee-train-operations/
[131] Etkin *et al.* 2015a.
[132] https://www.up.com/media/train-crew/index.htm
[133] The arguments are summarized in Vantuono 2016.
[134] https://www.aar.org/policy/crew-size-regulations
[135] ICF Incorporated 2015.
[136] ICF Incorporated 2015.

This conclusion is counter to that of the Canadian Transportation Safety Board and others that analyzed the Lac-Mégantic accident in which the train became a rollaway after the single operator left. [See Chapter 10 of this report.] The Sheet Metal, Air, Rail, and Transportation Workers Union (SMART) has stated that, in the experience of its members, two-person crews are vital to safe operations.[137]

Given that two-person crews are already the predominant operating practice in the US, and because this is likely to become part of rulemaking, it was assumed in this study that two-person crews will be part of future crude-by-rail operating practice in Washington State. With disagreement on the benefits of two-person crews, it is difficult to assign an adjustment for this factor in the analysis. Also, since this has already been standard practice for some time, it will not likely affect accident rates in the future. However, in conjunction with PTC (as per Table 36), it was assumed that there would be a reduction in accidents.

Two-Person Crew Assumptions for HES and LES

Given that there is no clear evidence that two-person crews either prevent or increase the likelihood of accidents and this issue is still under debate, no adjustments for two-person crews were made for either the HES or LES. At present, two-person crews are standard practice.

Track Upgrades and Operating Speeds

In a series of studies conducted at the Rail Transportation and Engineering Center at the University of Illinois at Urbana-Champaign,[138] the following conclusions were reached on reductions of rail accidents, primarily derailments, with safety enhancements:

- Track upgrades significantly reduce derailment rates (see Table 37);
- Broken wheel and accident rate down by 20 percent since 2004 due to wayside detectors;[139] and
- Integrated risk management systems that focus on reducing broken rails and broken wheels can significantly reduce derailments

Improvements or upgrades to railroad track are likely to prevent or reduce the occurrence of certain types of track-related derailment accidents. At the same time, because these upgrades will allow for trains to travel at higher speeds, they may also increase the risk of certain types of equipment failures that are more likely to occur at higher speeds. Derailments at higher speeds also tend to involve more cars.[140] Train derailments are less likely to occur on higher FRA track classes, as shown in Table 37.

Table 37: Derailment Rates by FRA Track Class for Freight Trains[141]

FRA Class	Freight Train Speed (mph)		Derailments per Million Freight Train Miles	Derailments per Billion Freight Car Miles[142]
	Maximum for Class	Average Speed at Time of Derailment[143]		

[137] http://utulocal60.com/2013/11/25/two-person-train-crews/
[138] Liu *et al.* 2010, 2013a, 2013b; 2014.
[139] http://archive.freightrailworks.org/wp-content/uploads/safety2.pdf. This conclusion is based on industry data, but this is supported by the reductions in accident rates shown in the government data in Table 9.
[140] Liu *et al.* 2011a, 2011b.
[141] Anderson and Barkan 2004 and Liu *et al.* 2011a.
[142] Freight car mile = freight car traveling one mile. Train-miles treat whole trains with multiple cars as one unit.

X and 1	10	7.7	48.54	720.1
2	25	16.9	6.06	92.7
3	40	25.0	2.04	31.5
4	60	33.2	0.53	7.8
5	80	37.4	0.32	4.9
All Classes	**-**	**25.7**	**1.00**	**14.8**

Equipment-related accidents increase somewhat in FRA track classes 4 and 5. However, the end result is that with track class upgrades, there is an overall risk reduction, though the severity does increase with track class. This means that in the less likely event that there is a derailment, the actual number of cars derailed would be expected to be higher. This may be due to the higher speed rather than track condition, however. The overall relationship between FRA Track Class and derailment risk is shown in Figure 29.

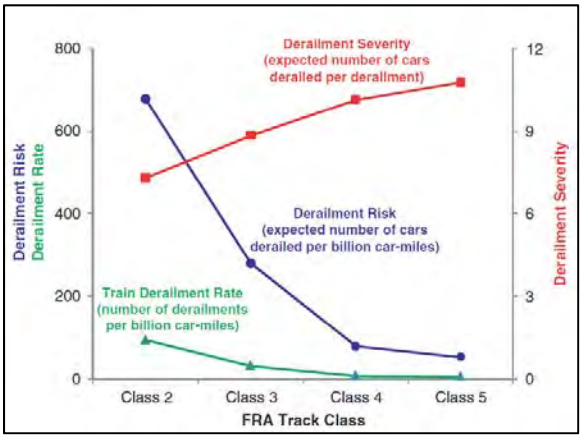


Figure 29: Relationship between Track Class, Derailment Rate, and Derailment Severity[144]

Track Upgrade and Operating Speed Assumptions for HES and LES

The important factors to consider in applying the potential accident reduction rate for track upgrades in this current analysis are:

- The degree to which track upgrades will have been completed when crude-by-rail traffic from Shell PSR, and other proposed future facilities, transits the tracks in Washington;
- The types of accidents that may be affected by track conditions; and
- The effectiveness of track upgrades in reducing accident rates.

The track upgrade adjustment is based on the assumption of upgrades from Class 3 to Class 4, which has been going on nationwide for at least a dozen years in heavily used rail corridors, even before crude-by-rail transport levels increased in the last four years. It is impossible to know exactly how much track has been upgraded from Class 3 to Class 4 to date in Washington State.[145] Publicly available information on track/infrastructure upgrades indicate that in its 2014 Capital Expenditure Plan, BNSF allocated $2.3

[143] Liu *et al.* 2011a.
[144] Liu *et al.* 2011a.
[145] There are some data on track upgrades in the 2015 Marine & Rail Oil Transportation Study (Etkin et al. 2015b).

billion in upgrades and maintenance to existing track infrastructure, which includes physical infrastructure expansion in the Northern Corridor, of which $230 million went to replacing 60 miles of rails, replacing 1,300 ties, and surfacing/undercutting 1,200 track miles.[146] In 2015, BNSF spent $550 million in track upgrades in Washington State. Additionally, in 2016 through mid-2017, BNSF has claimed that it will be completing an additional $220 million in track upgrades.

Based on the data in Table 37, it is assumed that an upgrade from track classes 3 to 4 would result in about 75 percent fewer derailments per train. Without more detailed information on the specific manner in which these track upgrades have occurred and will continue to be made over the next year, it is impossible to make any accurate predictions with regard to how much of the 75 percent reduction can be applied to future rail accidents. To be conservative, one could conjecture that track improvements are at least half done, though probably much more, which might reduce the actual efficacy of the track upgrade safety factor to about 37.5 percent at present. However, with each year, the reduction rate would increase as more upgrades are made to the existing rail infrastructure. Also, the assumption that the starting point is zero with the beginning of crude-by-rail transport is also dubious since these rail upgrades have been occurring for some time already. In addition, continuing track maintenance over the next decades is also assumed in this analysis. This may not necessarily be the case.

There are about 1,645 miles of freight rail track, of which most may be used for crude-by-rail transport. However, not all of these tracks are necessarily at FRA Track Class 3 and in need of upgrading to Class 4. In fact, four of the mainline corridors in Washington are currently classified as FRA Track Class 4 already [See Figure 30 and Table 38 for reference.]: Sand Point, ID, to Spokane (called "The Funnel"); Spokane to Vancouver, WA, via Pasco; Spokane to Everett via Stevens Pass; and Vancouver, WA, to Blaine and Vancouver, BC, via Seattle and Everett ("I-5 Corridor").[147]

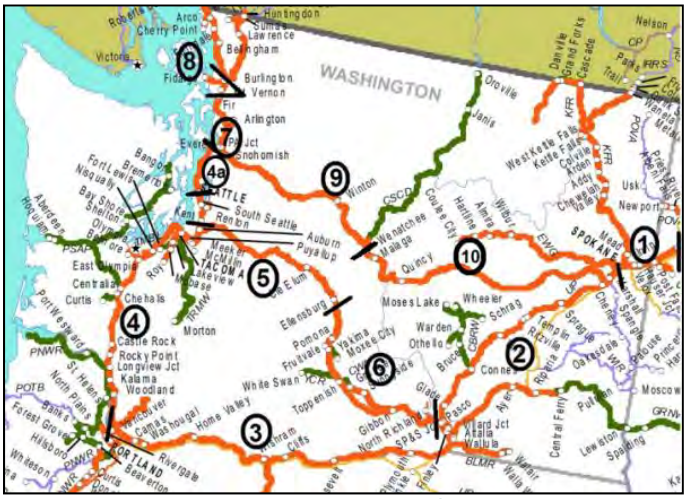


Figure 30: Crude-by-Rail Transport Route Subdivisions[148]

[146] Etkin et al. 2015b.
[147] Etkin et al. 2015b.
[148] Partially based on Etkin *et al.* 2015a.

Table 38: Segments of CBR Routes		
Segment	**Subdivision/Corridor**	**End Points**
1	Kootenai-Spokane Subdivision	Sand Point, Idaho, to Spokane
2	Lakeside Subdivision	Spokane to Pasco
3	Fallbridge Subdivision	Pasco to Vancouver
4	Vancouver-Seattle Subdivision	Vancouver to Seattle
4a	Seattle Scenic Subdivision	Seattle to Everett
5	Stampede Subdivision	Auburn to Ellensburg
6	Yakima Valley Subdivision	Ellensburg to Pasco
7	Bellingham Subdivision	Everett to Mt. Vernon
8	Anacortes	Mt. Vernon to Anacortes
9	Stevens Pass Subdivision (Scenic)	Everett to Wenatchee
10	Stevens Pass Subdivision (Columbia River)	Wenatchee to Spokane

The one exception is Stampede Pass, which is maintained at Class 4 condition but operated at a maximum freight train speed of 49 mph. (An FRA Class 4 designation allows freight trains to operate at speeds up to 60 mph.) [149] Note that crude-by-rail trains are generally operated at maximum speeds of 40 mph.

For the purposes of this analysis, different assumptions were made for the Lower Estimate of Spills (LES) and Higher Estimate of Spills (HES):

- For the HES, it was assumed that there is no benefit to track upgrades because these enhancements are privately initiated projects with no associated regulatory driver or public involvement t and
- For the LES, it was assumed that the track upgrades will have been completed and that the accident reduction rate varies from a conservative 37.5 percent to a high of 75 percent. The conservative estimate would also cover the possibility that some tracks are not completely upgraded.

For operating speed adjustments, for both HES and LES it was assumed that if the loaded crude-by-rail trains are traveling at the maximum speed of 40 mph, there would be no increase in derailments.[150]

Lateral Stability with Crude-by-Rail Unit Trains

Crude-by-rail unit trains are different from mixed cargo (manifest) trains in that all of the cars are relatively identical in size and shape. Unit trains are believed to have a greater lateral stability than manifest trains. This hypothesis was tested in a study conducted by TÜV Rheinland Mobility Rail Sciences for the Port of Vancouver, Washington. The Port of Vancouver requested that TÜV Rheinland evaluate the derailment risk of a proposed route exiting BNSF Railway Fallbridge Subdivision at MP 10.69 into the port (Figure 31).[151]

[149] Etkin et al. 2015b.
[150] Based on Table 37 where average speed at derailment is 25.7 mph (Anderson and Barkan 2004; Liu *et al.* 2011a.)
[151] TÜV Rheinland Mobility Rail Sciences Division 2014; Etkin *et al.* 2015a.

Figure 31: BNSF Railway Fallbridge Subdivision Tracks into Port of Vancouver[152]

As part of this study, the researchers analyzed the derailment probability for a 120-car crude-by-rail unit train with three locomotives at the head end and two at the rear end. The in-train force analysis indicated that the maximum in-train longitudinal forces observed in all nominal and braking simulation scenarios were well within industry and AAR- recommended limits. The lateral-to-vertical ratio (L/V) is the lateral (side-to-side) force pushing outward against the rail compared to the vertical force pushing downward on the top of the rail (Figure 32). The tendency for the rail to tip and/or move laterally, or for the wheel to climb the rail increases as the L/V ratio increases so that:

- L/V = 1.29, wheel may climb new rail;
- L/V = 0.82, wheel lift impending;
- L/V = 0.75, wheel may climb worn rail; and
- L/V = 0.64, rail overturn force starts (unrestrained rail may overturn).

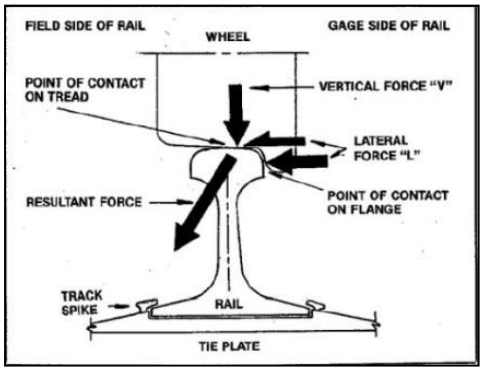


Figure 32: Lateral to Vertical Force Relationship between Rail and Wheel[153]

The results of the analyses of the crude-by-rail unit train, as shown in Table 39, indicate that all individual wheel L/V ratios were well under the maximum allowable values for the industry. Overall, TÜV Rail Sciences concluded that the proposed operation and track configuration was well within industry safety standards, and thus represented a low risk of derailment.

[152] TÜV Rheinland Mobility Rail Sciences Division 2014.
[153] From: TÜV Rheinland Mobility Rail Sciences Division 2014.

Table 39: Vehicle Dynamic Results–Loaded Tanker Cars[154]					
Parameter	**Industry Standard**	**In-Train Force**	**As-Designed Tack**	**Class I Cross Level Dip**	**Class 2 Cross Level Dip**
Maximum Individual Wheel L/V Ratio	Maximum 0.82[155] 1.00[156]	300 Kips Buff	0.43	0.59	0.57
		300 Kips Draft	0.34	0.52	0.50
		None	0.39	0.56	0.54
Minimum % Wheel Unloading	Minimum 10.0%	300 Kips Buff	83.86	56.96	59.42
		300 Kips Draft	90.60	68.37	70.75
		None	90.87	62.09	64.75
Maximum Axle Sum L/V Ratio	Maximum 1.50	300 Kips Buff	0.76	0.91	0.89
		300 Kips Draft	0.67	0.84	0.83
		None	0.73	0.88	0/86
Maximum Truck Side L/V Ratio	Maximum 0.60	300 Kips Buff	0.32	0.39	0.38
		300 Kips Draft	0.33	0.32	0.31
		None	0.30	0.36	0.35

Effect of Speed on Lateral Stability on Curves

Rail tracks inevitability have sharp curves as they are restricted to the landform. "Tight" curves are defined as those with a radius of 500 to 1,000 meters (1,640 to 3,280 feet). When a heavy-haul rail car is negotiating curved tracks with low speeds, the phenomenon of the "hunting motion" (also called "hunting oscillation") occurs. Hunting motion or hunting oscillation is the back and forth swaying of the train on the rails as it "hunts" for equilibrium. Due to the hunting motion on the curved tracks, the interaction force between the wheel and the rail is significantly enhanced, the performance of the negotiation is severely deteriorated, the rail is sharply worn, the rail life is clearly shortened, which may cause the vehicle may derail on curved track. For this reason, hunting motion on curved track has been studied extensively. [157]

One analysis resulted in the conclusion that the maximum speed on a curve with a radius of 600 meters (1,968.5 feet) is 76.4 km/h or 47.5 mph.[158] This result reiterates the importance of speed reductions in curvy areas. The overall maximum speed of 45 mph for crude-by-rail trains (or 40 mph in HTUAs) would cover the problem. But even slightly higher speeds could cause significant lateral shifts (Figure 33).

[154] TÜV Rheinland Mobility Rail Sciences Division 2014.
[155] Industry recommended maximum allowable L/V ratio = 0.82
[156] AAR Chapter XI Standard maximum allowable L/V ratio = 1.00.
[157] For example, Lee and Cheng 2005; Cheng and Lee 2005; Dukkipati and Swamy 2001.
[158] Wang and Liu 2012.

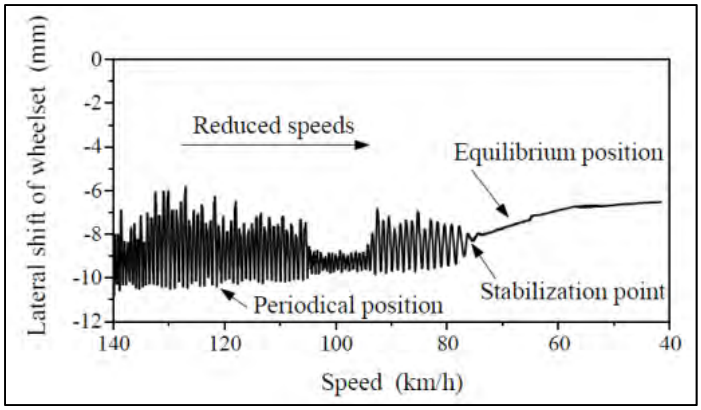


Figure 33: Wheelset Lateral Shift vs. Speeds of Heavy-Haul Vehicles on Curved Track[159]

Lateral Stability Assumptions for HES and LES

Given the findings of the research studies on lateral stability (with and without curves), it was assumed that there would be no net increase (or decrease) in accidents with crude-by-rail unit trains. For both the HES and LES no adjustment was made for this particular factor.

Sloshing of Partially-Filled Rail Tank Cars

"Sloshing" of liquid cargo in tank cars has been brought up by some groups as an issue of concern for crude-by-rail transport. The concern is that the oil in partially-filled cars moves back and forth in waves causing more lateral (side-to-side) strain on tracks, both harming the tracks and increasing the likelihood for derailment.[160] Longitudinal (in the direction of the train movement or track, not from side to side) sloshing has also been an issue of concern under certain circumstances, particularly with regard to braking.

Slosh in tank cars has been identified as a potential issue during transport at slower speeds. In particular, if a train were to stop quickly, there may be some longitudinal sloshing that could cause braking issues. This concern has led to the consideration of advanced brake signal propagation systems in unit trains carrying Class 3 flammable liquids.[161] In its May 2015 DOT/PHMSA Final Rule, Hazardous Materials: Enhanced Tank Car Standards and Operational Controls for High-Hazard Flammable Trains,[162] longitudinal sloshing (liquid movement in the direction the train is moving along the track) is mentioned as a potential contributing factor for derailments during the application of conventional air brakes (as opposed to ECP brakes). In addition to concerns about braking problems with longitudinal sloshing, there have been concerns about longitudinal sloshing causing undue wear on tracks, which may increase accidents. For example, Jason Lewis, Policy Advisor for the Washington Utilities and Transportation Commission, stated, "In the slowing down and speeding up, you will have a sloshing of the oil. That does

[159] Wang and Liu 2012. (Note 1 km/h = 0.62 mph).
[160] Ashtiani *et al.* 2015.
[161] *Federal Register* Vol. 80 No. 89, 8 May 2015, Pipeline and Hazardous Materials Safety Administration 49 CFR Parts 171, 172, 173, *et al.* Hazardous Materials: Enhanced Tank Car Standards and Operational Controls for High-Hazard Flammable Trains; Final Rule.
[162] 49 CFR Parts 171, 172, 173, 174, and 179: DOT Pipeline and Hazardous Materials Safety Administration Docket No. PHMSA-2012-0082 (HM-251) ROM 2137-AE91

put more pressure and strain on the track than what we've seen before. So we're more aware of potential risks because of that."[163]

A comprehensive review of existing engineering studies on sloshing was conducted for this analysis. According to various media reports, the FRA has been "studying" the sloshing effect in crude oil tank cars, including increases in sloshing due to required slower speeds, since early 2015.[164] However, no *recent* press releases, studies, or reports from the FRA on this specific topic were found.[165]

A 2009 study [166]conducted for the FRA concluded that the movement or sloshing of the fluid in tank cars during an impact event plays a significant role in force-time behavior, meaning it could increase the force involved in a collision. The study did not address the issue of whether sloshing would *cause* derailments or other accidents.

Partially-filled tanks in tank cars are prone to violent sloshing under certain motions. The large liquid movement creates highly localized impact pressure on tank walls that may in turn cause structural damage and may even create sufficient moment to affect the stability of the vehicle that carries the container. When a tank is partially filled with fluid, a free surface is present. Then, rigid body acceleration of the tank produces a subsequent sloshing of the fluid.[167]

Structural and fatigue analyses on tank cars have indicated that fluid sloshing exerts pressure on head walls, end walls, and side walls within the tanks themselves.[168] There are no quantitative assessments of the degree to which this might increase the likelihood of a release from tank cars upon impact. Other studies on "sloshing" have focused on the effects of liquid movement within tank cars with respect to pressure build-up and internal forces on parts of the tank car shells, but not in reference to any increased risk of derailment or other accidents.[169]

There have been no definitive conclusions on the degree to which sloshing may increase the likelihood of derailments. In fact, there have been conflicting results. One technical engineering study indicated that sloshing tends to increase the possibility of wheel/rail separation, thereby *increasing* the probability of derailments.[170] This study found that the normal contact force of the wheelset of the rear bogie[171] becomes irregular with sloshing, as shown in Figure 34. According to this same study, the speed at which a rigid-body (non-fluid-containing) car would derail on tangent track is 201 mph. For a fluid-containing car, the derailment speed is 134 mph. If the track is curved, the derailment speed for the fluid-containing car is 78 mph. (Note that these speeds exceed the typical and recommended speeds for crude-by-rail unit trains.)

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[163] http://www.opb.org/news/article/oil-train-tank-cars-getting-safer-what-about-tracks/
[164] For example: http://www.bloomberg.com/news/articles/2015-03-13/speed-limits-may-not-stop-fiery-oil-spills-u-s-rail-chief-says; http://www.railwayage.com/index.php/blogs/david-thomas/fra-freezes-on-tank-car-sloshing-doe-oil-volatility-bombshell-drops-like-a-dud.html?channel=
[165] As of 31 August 2016.
[166] Jeong et al. 2009.
[167] Celebi and Akyildiz 2002.
[168] Jimin et al. 2009.
[169] Tang et al. 2008a; Tang et al. 2008b; Barkan et al. 2000.
[170] Wang et al. 2014.
[171] A bogie on a train car is the chassis; it bears the load of the freight car, transmits the traction and braking forces, steers the car in a safe manner, and smooths out track irregularities.

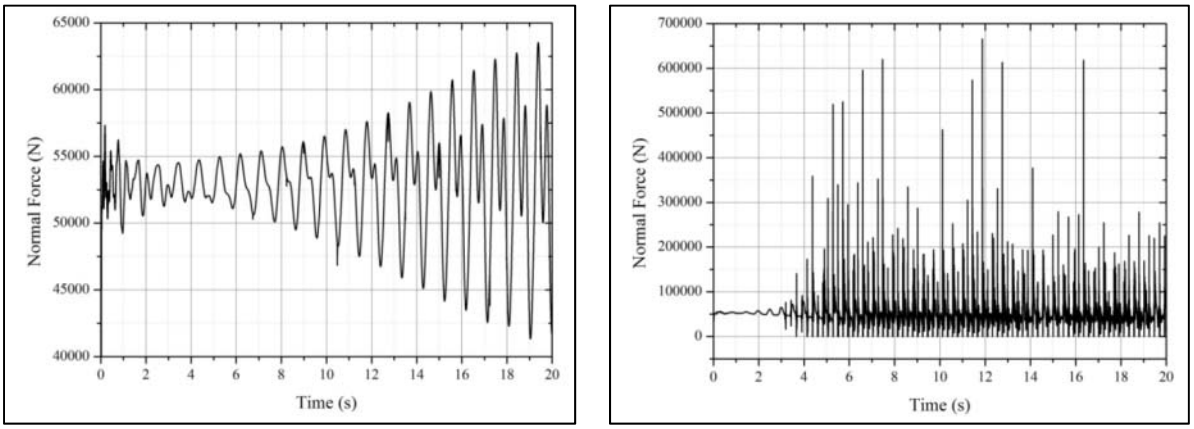


Figure 34: Normal Force Contact on Wheel of Rear Wheelset on Bogie–Rigid Car vs. Fluid Car[172]

A different engineering study[173] evaluated the running dynamic effects for partially-filled tank cars by modeling the various curve geometries, train speeds, and fill levels to analyze derailment and rollover (overturning) risks. This included longitudinal, lateral, and yaw[174] sloshing. The researchers concluded that sloshing can "significantly increase" the risk of *tanker truck* rollover, whereas its influence on the risk of derailment was "minor," because the running safety against flange climb derailment is only marginally affected by fluid sloshing even on "S-curves." Note that most of the past research studies on sloshing effects have been conducted on *tanker trucks*, not specifically on rail tank cars, which behave differently on tracks than tanker trucks do on roadways.

Another older study on partially-filled tanks indicated that neglecting fluid slosh in a partially-filled tank car could lead to an under-estimation of derailment potential by 18 to 25 percent.[175] The fluid slosh movements may affect wheel-rail contact loads, according to one group of researchers.[176] This research team's study, however, concluded that the fluid slosh in partially-filled tank cars yield an additional *dampening* effect on the lateral dynamics of the tank car (Table 40 and Figure 35).

[172] Wang et al. 2014.
[173] Gialleonardo et al. 2013.
[174] Yaw movements are twists or oscillations around a vertical axis (relative to the track).
[175] Abramson 1966.
[176] Ashtiani et al. 2015.

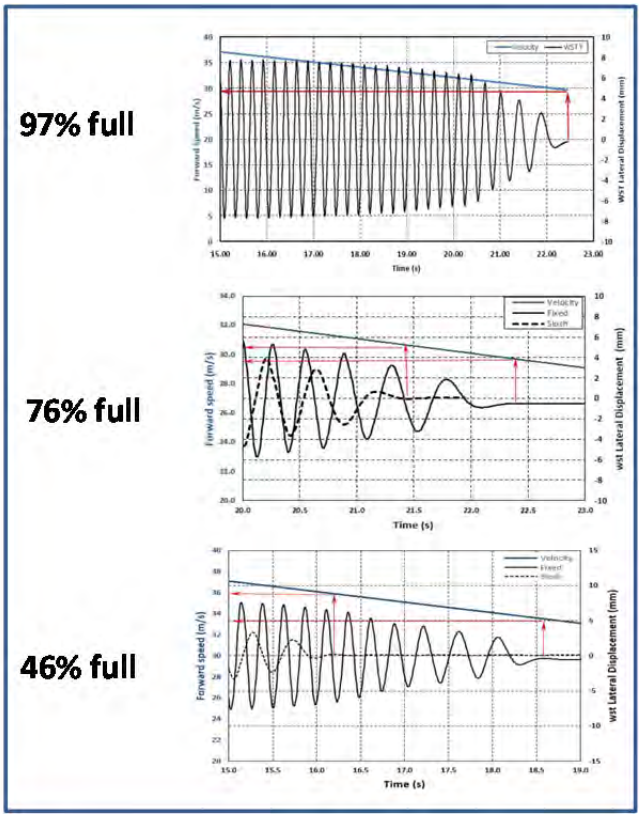


Figure 35: Variation in Lateral Oscillation of Leading Wheelset to Identify Critical Speed[177]

Table 40: Change in Critical Speed in Lateral Hunting with Liquid Sloshing[178]

Tank Car Condition				Critical Speed by Cargo Type				Increase in Critical Speed with Slosh
				Solid Rigid		Liquid		
Load State	Cargo	Specific Gravity	Total Cargo Mass (tons)	m/s	mph	m/s	mph	
97% Full	**Fuel**	**0.80**	**71.8**	29.5	66.0	29.5	66.0	0
76% Full	**Water**	**1.00**	**74.3**	29.7	66.4	30.6	68.5	1.03
46% Full	**Sulfuric acid**	**1.80**	**74.5**	33.5	74.9	36.0	80.5	1.07
Empty	**n/a**	**n/a**	**n/a**	23.0	51.4	23.0	51.4	0

The net effect is that the train is actually *more stable* on the tracks due to lateral sloshing. The 97 percent-filled tank car containing fuel essentially acted the same as a car with rigid cargo. There was a negligible effect of liquid slosh in high-fill levels. Lateral liquid cargo movement within a partially-filled tank car could thus yield a *beneficial* influence on the wheelset hunting, thereby stabilizing the cars on the track. Consequently, a partially-filled tank car can result in a relatively higher critical hunting velocity compared to that of a car with an equivalent rigid cargo. In other words, the fluid slosh within a tank of a railway wagon essentially acts as an absorber against the lateral hunting motions.

[177] (a) 97% full fuel tanker; (b) 76% full water tanker; (c) 46% filled tanker of sulfuric acid (Ashtiani *et al.* 2015).
[178] Ashtiani *et al.* 2015.

With respect to crude-by-rail tank cars, it would appear to be highly unlikely that the tank cars would ever been transported only partially-filled as this would not be cost-efficient. While there would always be some room in the car for liquid expansion and to accommodate the different densities of the oils (e.g., very light Bakken crude vs. much more dense diluted bitumen), it would not be less than 90 percent full.

Sloshing Assumptions for HES and LES

To develop estimates of effects of sloshing on accident rates for crude-by-rail unit trains for the HES and LES, it was necessary to make some broad assumptions since the data do not indicate any direct effects that would increase accidents.

First, for HES, it was conservatively assumed that there would be an increase in accidents due to sloshing, because this factor has been anecdotally cited as a possible causal factor for recent crude-by-rail accidents, though there are no specific definitive technical studies at this time to support this contention. The only estimate that would be potentially applicable in this regard would be the 18 to 25 percent underestimate on derailment potential for partially-filled tank cars, [179] though it would be very unlikely that partially-filled tank cars would be transported due to economic and practical considerations. For HES, to be most conservative in the modeling by hypothetically maximizing the potential accident rate, it was assumed there would be a 25 percent increase in accidents due to sloshing. This assumes that the crude-by-rail tank cars would be filled to less than 90-percent capacity, which is very unlikely to be the case. When transporting crude oil in trains it is most economical to fill the cars to the greatest capacity feasible while taking into account expansion space and maximum allowable tank car weight.

For LES, it was assumed that there would be no increase or decrease in accident rates, based on a review of available data, which indicated no effect of sloshing.

Effect of Train Length on Accidents

Another commonly-cited concern about crude-by-rail trains is that, with 100 to as many as 120 cars, they are longer than other freight trains and that this length increases the likelihood of an accident. The maximum length of a freight train is determined by the capacity of the locomotives, weight limitations, and coupler strength. Typically, US Class 1 railroad freight trains range from 80 to 120 cars, though they can be as long as 200 cars.[180] The average freight car number for trains involved in main line accidents during 1975–2015 was 74.5, and from 2000–2015 was 77.6 cars.[181] As such, crude-by-rail unit trains that are 102 cars long, as the ones that would transit to the Shell PSR would be, or even the longer 120-car trains that may be expected at other Washington State crude-by-rail facilities, are longer than the average length of freight trains, but not outside of maximum lengths relative to other freight trains.

Train length does, however, have an effect on the probability of accidents, according to at least one study. Table 41 shows the results of an analysis of freight trains that vary from 10 to 150 rail cars with respect to accident rates. In the end, the study conclusions were that running fewer, longer trains would reduce the overall number of accidents as opposed to running a higher number of shorter trains. The increase in accidents with a 100-car (or 102-car) train compared with a more standard 80-car freight train of the past

[179] Abramson 1966.
[180] Furtado 2013; USDOT/FRA 2005.
[181] Based on analysis of FRA accident data.

amounts to 12.4 percent. The increase in accidents with a 120-car train is estimated to be 24.7 percent, based on the data in Table 41.

Table 41: Modeled Effect of Train Length on Probability of Accidents[182]

Average Train Length (cars)	Corresponding Probability of Accident for Individual Train
10	0.00193
20	0.00214
30	0.00235
40	0.00256
50	0.00277
60	0.00298
70	0.00319
80	0.00340
90	0.00361
100	0.00382
110	0.00403
120	0.00424
130	0.00445
140	0.00466
150	0.00487

The adjustments for train lengths (12.4 percent and 24.7 percent increases to historical rail accident rates for 100- or 102-car trains and 120-car trains, respectively) are not related to any time-dependent implementation in the modeling. The existing crude-by-rail traffic has trains of 100 to 120 cars already. The assumptions for car length were applied in the modeling based on the stated train length of 102 cars for Shell ARUF and on variable ranges of car lengths for the other facilities.

Train Length Assumptions for HES and LES

Since the increased train length of crude-by-rail unit trains that are or would be in use for transport to the various Washington State facilities would tend to *increase* rather than decrease the accident rate, over the baseline of accident rates calculated from more typical 80-car freight trains in the historical data, it was assumed that this increase should be applied to both HES and LES.

The longer crude-by-rail trains in currently in operation and expected in the future are in comparison to more typical 80-car freight trains carrying other commodities. Accidents involving more typical 80-car trains that carried a variety of cargo other than oil were used to calculate the baseline accident rate. Longer trains that are to be (and are being) used for crude-by-rail transport may be expected to have more frequent accidents due to their increased lengths. This has nothing to do with the numbers of trains that would be used for crude-by-rail transport. The accident rate is calculated on a per-train-mile based on historical data involving mostly 80-car freight trains. Now, there are much longer trains out there transporting crude by rail. The accident rate is expected to be higher. If one were only considering crude-by-rail trains as the basis for the accident rate estimate and there was a finite and constant volume of oil to

[182] Schafer and Barkan 2008.

be transported, taking that same amount of oil and putting it into fewer longer trains, rather than more shorter trains, there would likely be a reduction in accidents and spills. But, this is not the methodology being used in the calculation in this report. The increase in accidents with a 100-car (or 102-car) train compared with a more standard 80-car freight train of the past amounts to 12.4 percent. The increase in accidents with a 120-car train is estimated to be 24.7 percent. For HES, the maximized accident rate would be assumed. For LES, adjustments appropriate to crude-by-rail transport were made, regardless of whether they increased or decreased the rate. The purpose of the LES is to incorporate, to the extent possible and based on the available research data, the aspects of crude-by-rail transport that would affect the overall freight rail accident rate.

Calculation of Accident Probability Adjustments for CBR Transport

The adjustments to accident probability for crude-by-rail transport that were *considered* in this analysis are summarized in Table 42. *Actual* adjustments applied in the analysis are shown in Table 43. *Note that this refers only to the probability that there would be an accident (e.g., derailment), not that there would necessarily be a spill as a result of the accident. That probability depends on tank car characteristics, accident type, speed, and other factors. That analysis is handled separately in Chapter 6.*

Table 42: Considered Adjustments to Rail Accident Probability for HES and LES

Accident Factor for CBR Unit Trains	Higher Estimate of Spills (HES)		Lower Estimate of Spills (LES)	
	Assumptions	**Potential Adjustments from Baseline Accident Rate**	**Assumptions**	**Potential Adjustments from Baseline Accident Rate**
Enhanced ECP Braking	ECP brakes not fully in use	0%	ECP brakes fully in use and effective in reducing accidents	0.007–3.7% reduction
Positive Train Control	PTC not implemented	0%	PTC fully implemented	2–80% reduction
Wayside Detectors	Wayside detectors not fully implemented	0%	Wayside detectors operational and effective	20% reduction
Two-Person Crews	Already in effect; benefit or detriment unclear	0%	Already in effect; benefit or detriment unclear	0%
Reduced Speed	40 mph operating speed	0%	40 mph operating speed	0%
Lateral Stability	No adjustment needed (unrelated to sloshing)	0%	No adjustment needed (unrelated to sloshing)	0%
Track Upgrades	Upgrades not completed or fully maintained	0%	Upgrades completed and fully maintained	37.5–75% reduction
Sloshing	Sloshing increases accident rate	25% increase	Sloshing does not increase accident rate on >90%-full cars	0%
Train Length 100/102 cars	Length increases accident rate for 100- or 102-car trains.	12.4% increase	Length increases accident rate for 100 or 102-car trains.	12.4% increase
Train Length 120 cars	Length increases accident rate for 120-car trains.	24.7% increase	Length increases accident rate for 120-car trains.	24.7% increase

The safety measures shown in Table 42, especially PTC, track upgrades, and wayside detectors, would work together in the prevention of rail accidents, as some have been for some time already to reduce accidents from the historical rates. The reduction factors of PTC, track upgrades, and wayside detectors, therefore, are not truly independent from one another. For this reason the reduction rates cannot be simply added together to calculate an additive reduction factor.

The factor that has been attributed with the greatest potential reduction in accidents is PTC, which is estimated to prevent anywhere from two to 80 percent of accidents.[183] Wayside detectors work together with PTC to prevent accidents. The wayside detectors provide information to the PTC system so that trains can be stopped or controlled to prevent an accident when irregularities are detected. For this reason, wayside detectors have *not* been separately added in to the adjustment factor. Their benefit is assumed to be largely related to the way in which they interact with the PTC system.

Likewise, track upgrades include, to some extent, the installation of wayside detectors and other components of PTC. There are also some aspects of track upgrades from FRA Class 3 to FRA Class 4 that involve replacing, repositioning, shoring up, and repairing track to allow for safe operation of trains at greater speeds.

If one assumes that track upgrades, which are largely already in place in Washington State, is the baseline of adjustment factors (a 75 percent reduction factor to be applied to *historical* accident rates), the additional benefits of PTC may increase that somewhat. Any accidents not already prevented by the track upgrades per se may be prevented by the full implementation of PTC (incorporating wayside detectors). And, if one assumes that track upgrades even without fully-implemented PTC is indeed at least half effective, a minimum effectiveness of 37.5 percent can be assumed.

The factor that can reasonably be considered independent is enhanced braking, which may have a minimal (0.007 percent) to 3.7 percent reduction in accidents. This is an aspect of the train rather than on the track infrastructure and rail operating system overall. The ECP braking factor can then be considered an additive factor in this analysis. However, it is possible that ECP braking may not be implemented depending on decisions that are pending with FRA. This is possibility is considered in the HES.

However, the greater lengths of the crude-by-rail trains (from 100 to as many as 120 cars) have been shown to *increase* the likelihood of an accident over more typical 80-car freight trains.[184] For the 100- (or 102-) car train, the probability of accidents is estimated to increase by 12.4 percent; for the 120-car trains, the probability is estimated to increase by 24.7 percent. These increases in accidents somewhat counteract the reductions realized by the various safety measures. The increase in accident rates due to longer trains is taken into account in both the LES and HES calculations. The two train lengths were applied to Shell PSR trains (102 cars) and to all other facilities (ranging from 100 to 120 cars), respectively.

The adjustment factors for rail accidents are summarized in Table 43, Figure 36, and Figure 37 . For LES, since a range of values was considered in the modeling, both the highest and lowest reduction factors were included as per Table 42.

Table 43: Applied Adjustment Factors for Crude-by-Rail Accident Rates

Train Length	Adjustments to Baseline Accident Rate	
	Higher Estimate of Spills	Lower Estimate of Spills (LES)[186]

[183] Peters and Friteli 2012; ICF Incorporated 2015.
[184] Schafer and Barkan 2008.
[186] LES-minimum, 100-102 car adjustment = 12.4% (train length)–(0.007% + 37.5%) [ECP braking minimum + PTC/wayside detector/train upgrade minimum). LES-maximum, 100-102 car adjustment = 12.4% (train length)–

	(HES) [185]	Minimum	Maximum
100-102 cars	37.4% increase	25.1% decrease	71.3% decrease
120 cars	49.7% increase	12.8% decrease	59.0% decrease

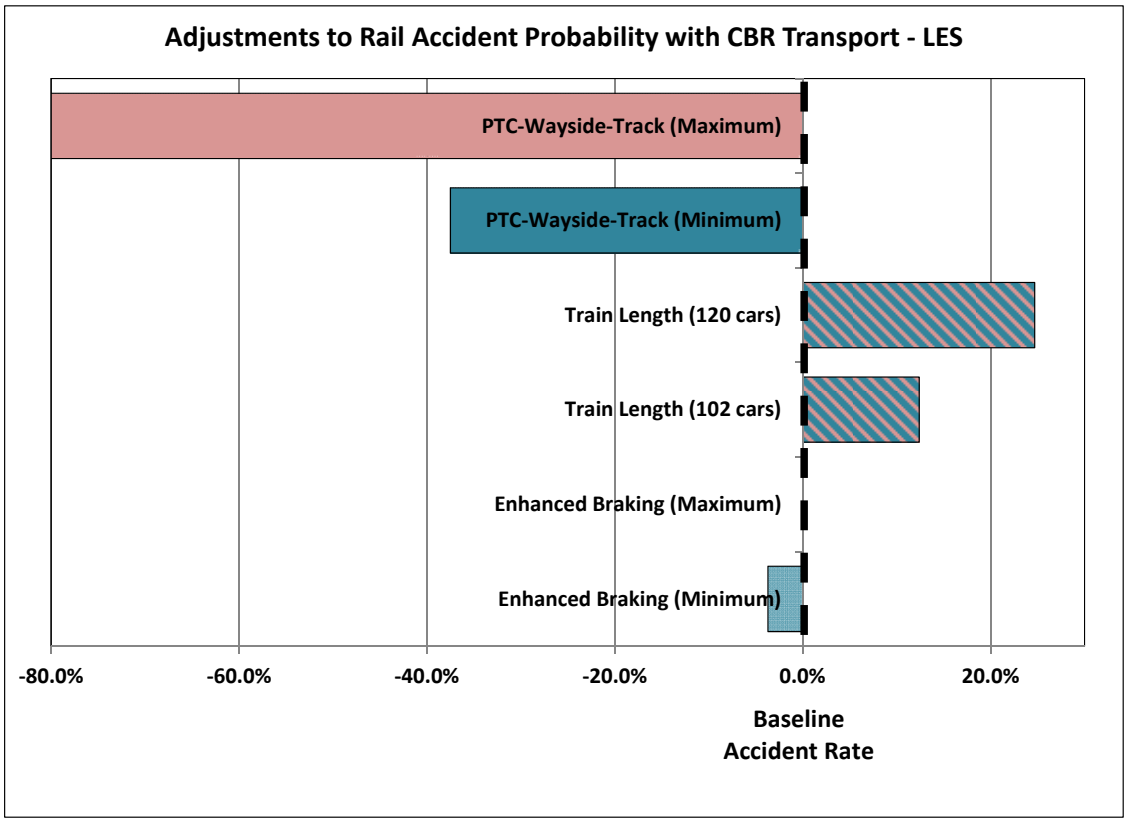


Figure 36: Adjustments to Rail Accident Probability for Crude-by-Rail Transport (LES)

(3.7% + 80%) [ECP braking maximum + PTC/wayside detector/train upgrade maximum]. LES-minimum, 120 car adjustment = 24.7%% (train length)–(0.007% + 37.5%) [ECP braking minimum + PTC/wayside detector/train upgrade minimum). For LES-maximum, 120-car adjustment = 24.7% (train length)–(3.7% + 80%) [ECP braking maximum + PTC/wayside detector/train upgrade maximum).

[185] HES 100-102 car adjustment = 25% (sloshing) + 12.4% (train length). 120 car adjustment = 25% (sloshing) + 24.7% (train length).

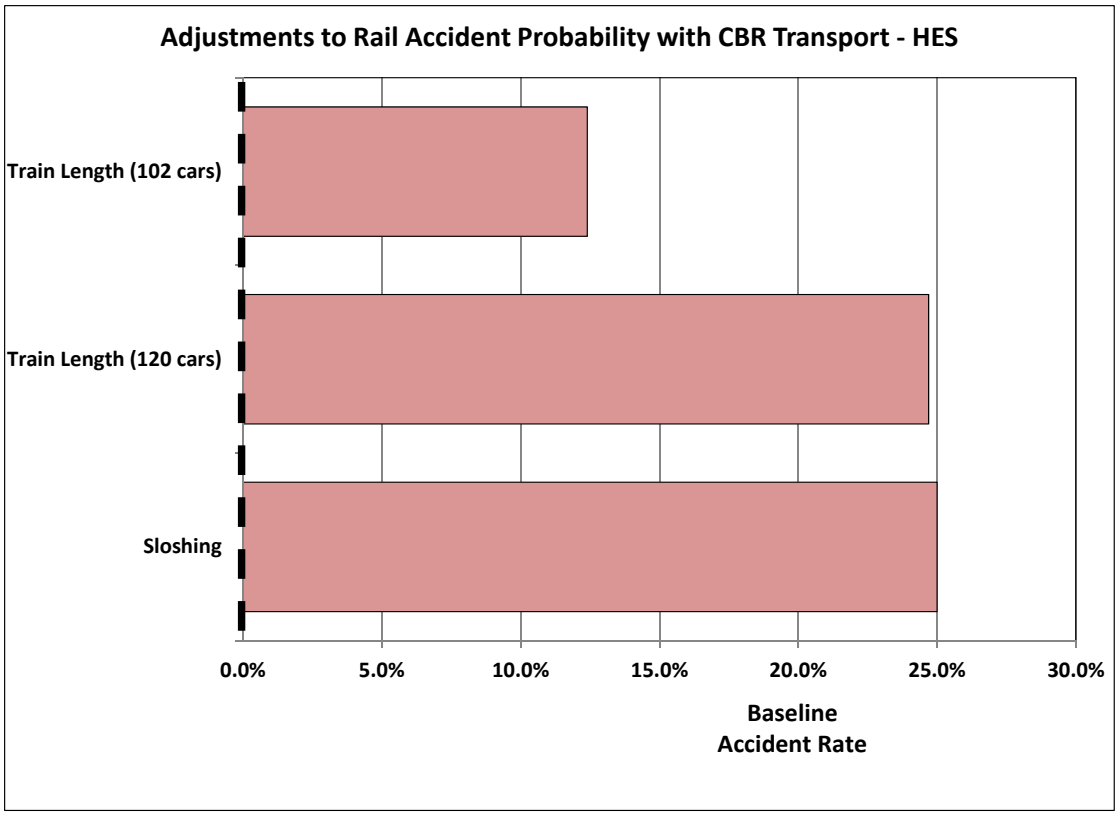


Figure 37: Adjustments to Rail Accident Probability for Crude-by-Rail Transport (HES)

It should be noted that the rail accident probability adjustment factors considered and applied for the LES and HES are applied to all accident types (derailments, collisions, fire/explosion, highway-rail crossing, and miscellaneous categories). This differs from the approach to the spill probability analysis discussed in Chapter 7 for which there is one different adjustment factor applied based on accident type.

The reasoning behind this approach is that for the accident probability the vast majority of accidents involve prevention factors that would probably be encompassed in by various portions of the PTC-wayside detector-track upgrade component of the adjustment.[187] There are no definitive studies that would provide specific quantitative means to apportion the adjustments based on accident type.

In a *qualitative* manner, one might assume, for example, that fires and explosions[188], which make up less than two percent of all incidents, would not be affected by PTC-wayside detector-track upgrade factors, ECP braking, or sloshing. Sloshing may really only affect derailments, which make up 79 percent of rail accidents.

[187] For reference, see Table 11, for example.
[188] Accidents in which fire and/or explosion is the primary *cause* of the incident, not the *result* of an accident.

Chapter 6: Analysis of Baseline Rail Release Probability

Rail accidents involving hazmat tank cars, such as those used to transport crude oil, do not necessarily result in the release or spillage of any hazardous materials. The next phase of the probability analysis involved determining the release probability in the event of an accident involving crude-by-rail tank cars.

Release Probability with Hazmat Tank Cars

To determine the probability of a spill or release from tank cars, an analysis of 3,589 rail accidents[189] involving loaded tank cars was conducted with the results shown in Table 44 and Figure 38.[190]

In the 3,589 accidents, there were a total of 11,352 hazmat cars damaged or derailed with 2,418 releasing material. In nearly two-thirds (66.2 percent) of accidents involving hazmat cars, there is no release from damaged or derailed cars. The spillage probability depends on the type of accident and the time period.

The cumulative distribution of percentage of hazmat cars with releases in each accident is shown in Figure 39, and summarized in Table 45.

Table 44: Percent of Damaged/Derailed Loaded Hazmat Car with Release

Accident Type	Percent Hazmat Cars with Release[191]				
	1975–1984	1985–1994	1995–2004	2005–2015[192]	1975–2015
Collision	27.9%	32.1%	12.1%	13.1%	**19.5%**
Derailment	26.5%	22.3%	14.9%	19.4%	**21.5%**
Fire/Explosion[193]	50.0%	100.0%	-	-	**60.0%**
Highway-Rail Crossing	27.7%	24.4%	5.9%	6.8%	**17.0%**
Miscellaneous	8.8%	22.9%	14.0%	47.1%	**19.1%**
Total	**26.4%**	**22.6%**	**14.6%**	**19.0%**	**21.3%**

[189] From national FRA data from 1975 through 2015.
[190] This follows the methodology in Etkin *et al.* 2015b.
[191] Total number of loaded hazmat cars damaged and/or derailed that released materials during that time period.
[192] Data are current through 30 November 2015. 2015 data are pro-rated to 11 months.
[193] The 60% release rates from hazardous material tank cars are for tank cars carrying all kinds of materials (such as anhydrous ammonia, ethanol, other chemicals). Notice that there have been no incidents recorded after 1994 in which there had been an accident caused by fire in which there was any release from a hazmat car, by the way. The data only show a few accidents that occurred during 1975-1994 (PRIOR to crude-by-rail) in which there was an accident caused by fire and/or explosion in which there was any release from the tank car. During 1975-2015, there were 10 fire/explosion-caused accidents (out of 3,589–or 0.3% of the total accidents in which there were hazmat tank cars) involving trains that had hazmat cars that were damaged or derailed. All the accidents occurred before 1994. No accidents of this type between 1995 and 2015.) Note that the fire/explosion may have occurred in the locomotive (or another freight car). There were a few (1-5) hazmat cars on each of the trains involved (this was before unit trains). In each 10 of the incidents one (1) hazmat car was damaged or derailed. Of those damaged/derailed cars, 60% released material. This does *not* mean that there is a 60% chance of spilled oil igniting during a crude-by-rail accident.

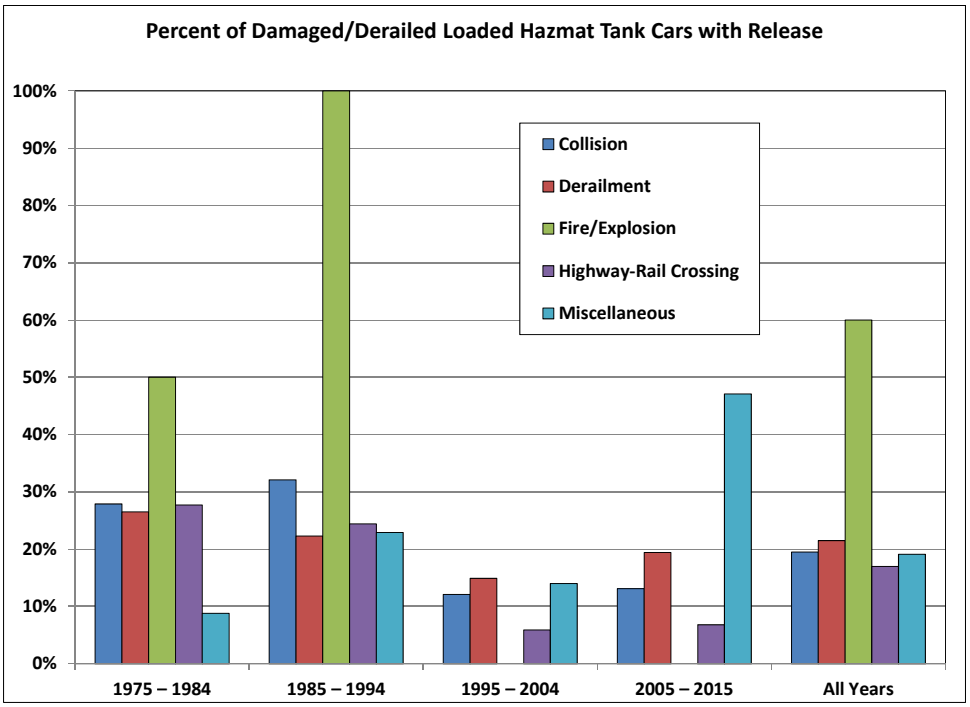


Figure 38: Percent Damaged/Derailed Loaded Hazmat Tank Cars with Release[194]

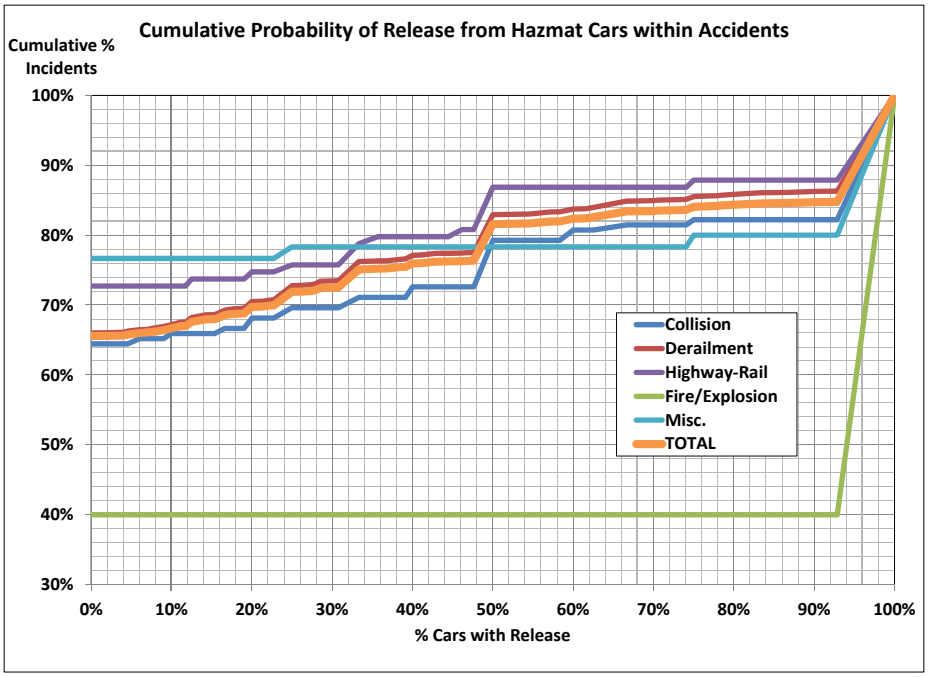


Figure 39: Cumulative Probability of Release Percent from Hazmat Cars (1975–2015)[195]

[194] Analysis based on FRA data.
[195] Based on analyses of FRA data. This is the distribution of percentages of hazmat cars with releases, considering each individual accident.

Table 45: Cumulative Probability of Release Percent from Hazmat Cars (1975–2015)[196]						
Percentile (% Accidents)	**% Cars with Release**					
	Collision	**Derailment**	**Hwy-Rail**	**Fire/Explosion**	**Misc.**	**All Accidents**
60th	0%	0%	0%	0%	0%	0%
65th	0%	0%	0%	0%	0%	0%
70th	31%	19%	0%	0%	0%	23%
75th	49%	32%	20%	0%	0%	33%
80th	59%	49%	36%	0%	75%	49%
90th	100%	100%	100%	100%	100%	100%
95th	100%	100%	100%	100%	100%	100%
99th	100%	100%	100%	100%	100%	100%

[196] Based on analyses of FRA data. This is the distribution of percentages of hazmat cars with releases, considering each individual accident.

Chapter 7: Adjustments to Spill Probability for Crude-by-Rail

The probability that there would be spillage in the event of a rail accident needs to be adjusted for the particular circumstances of future CBR transport to the Shell PSR and other facilities.

Studies on Reductions in Spillage Probability with New Tank Car Designs

Hazardous material release accidents decreased significantly between 1980 and 1993, and then remained relatively steady until another drop in 2008 (Figure 40). Overall there has been a 90 percent decrease in spillage with improvements in tank car safety design, as well a substantial reduction in accidents.[197] Much of this reduction in spillage may be attributable to the reduction in accidents. [Compare this reduction to overall accident reductions in Figure 21.] The calculated reduction percentage depends on the specific time period analyzed. An analysis[198] on data from 1985 – 2004 showed an 85 percent reduction in the release rate and a 44 percent decrease in the accident rate.

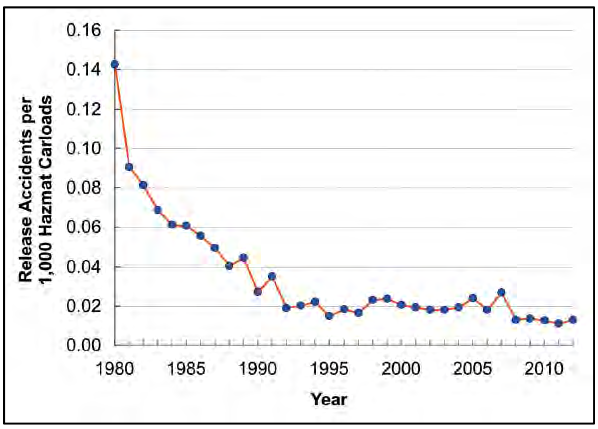


Figure 40: Release Accidents from Rail Hazmat Cars (1980–2012)[199]

PHMSA/DOT Estimations of Tank Car Design Safety Increases

A significant emphasis has been placed on reducing the likelihood of spillage from crude-by-rail trains with the implementation of safer tank car designs, emphasizing an increase in wall thickness.[200] The effectiveness of the new tank car designs were estimated and modeled by PHMSA, as shown in Table 46, based on the specifications in Table 47.

Table 46: Effectiveness of Newly Constructed Tank Car Options Relative to DOT-111[201]

Tank Car[202]	Total	Head Puncture	Shell Puncture	Thermal Damage	Top Fittings	Bottom Outlet Valve
PHSMA/FRA (DOT-117)	55%	21%	17%	12%	4%	<1%
AAR 2014 Design	51.3%	21%	17%	12%	1.3%	<1%

[197] Barkan *et al.* 2013.
[198] Barkan 2008a.
[199] Barkan *et al.* 2013.
[200] Wall (tank) thickness is inversely related to the probability of release (Barkan 2008a; Hughes *et al.* 1998).
[201] *Federal Register* Vol. 79, No. 108 (August 1, 2014), Part III Department of Transportation, Pipeline and Hazardous Materials Safety Administration (49 CFR § 171, 172, 173, 174, 179) pp. 45,016–45,079.
[202] For specifications, see Table 47.

Enhanced CPC-1232	41.3%	19%	9%	12%	1.3%	0%

Table 47: Summary of Options for Tank Car Standards (Post October 1, 2015)

Feature	PHMSA/FRA	AAR 2014	Enhanced CPC-1232
Wall Thickness	9/16”	9/16”	7/16”
AAR/TC-128 Grade B Steel	Required by rule	Required by rule	Required by rule
Full Head Shield, ½ inch	Required by rule	Required by rule	Required by rule
Thermal Protection[203]	Required by rule	Required by rule	Required by rule
Reclosing Pressure Relief Device	Required by rule	Required by rule	Required by rule
Jacket[204]	Required by rule	Required by rule	Required by rule
Bottom Outlet Handle[205]	Required by rule	Required by rule	Required by rule
Top Fittings Protection	TIH 9 mph rollover	AAR App. E 10.2.1	AAR App. E 10.2.1
Braking[206]	ECP Brakes	DP or EOT	DP or EOT
286,000 GRL[207] **Authorized**	Required by rule	Required by rule	Required by rule

Other Studies on Tank Car Release Rates

In another analysis conducted by the industry group AAR in conjunction with the Railway Supply Institute (RSI) as part of the RSI-AAR Railroad Tank Car Safety Research and Test Project, the conditional probability of release for various types of tank cars were found to be as shown in Table 48.

Table 48: Conditional Probability of Release by Tank Car Type[208]

Car Category	Additional Features[209]					Conditional Probability of Release	
	Shell	Jacket	HHS	FHHS	TFP	Any Volume	>2.4 bbl
DOT-111 (Legacy)	7/16”					26.6%	19.6%
	7/16”	✓				12.8%	8.5%
CPC-1232	1/2”		✓		✓	13.2%	10.3%
	7/16”	✓		✓	✓	6.4%	4.6%
	1/2”	✓		✓	✓	5.2%	3.7%
DOT-117	9/16”	✓		✓	✓	4.2%	2.9%

Taking the data in Table 48, the calculated reductions in probabilities of release (spillage) from the newer design tank cars are shown in Table 49. Note that the two values highlighted in pink are actually *increases in probability*. This means that the jacketed ½”-CPC-1232 is actually *more* likely to release oil than the jacketed DOT-111 car.

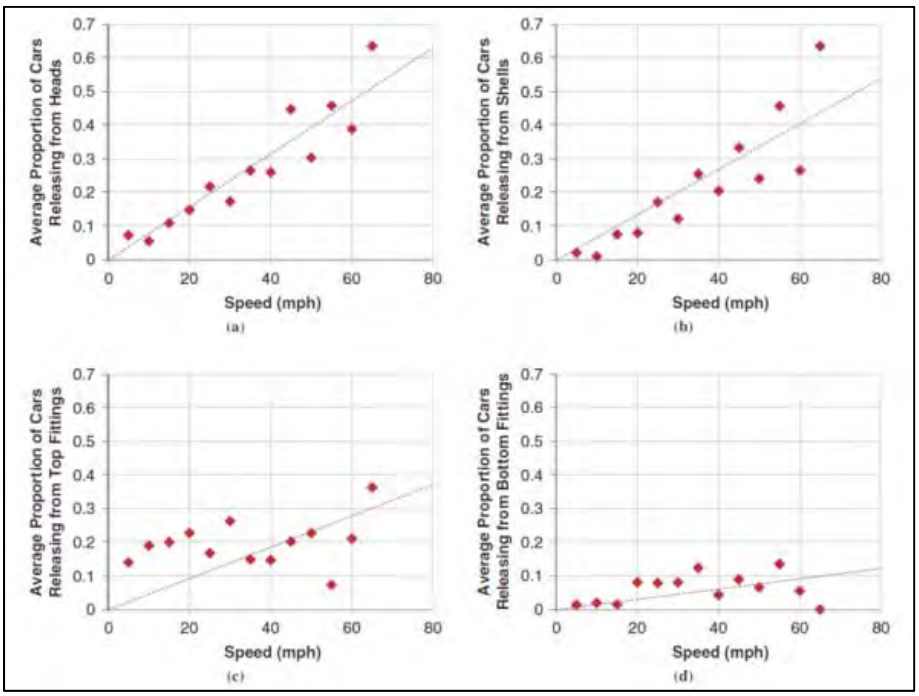
[203] In accordance with 49 CFR §179.18.
[204] Minimum 11-gauge jacket constructed from A1011 steel and weathertight.
[205] Bottom outlet handle removed or designed to prevent unintended actuation during train accident.
[206] ECP = electronically-controlled pneumatic brakes; DP = distributed power; EOT = end of train device.
[207] Gross rail load.
[208] API/AAR 2014; Treichel 2014; Barkan et al. 2015. Probability that there will be a release or spill from a tank car given an accident.
[209] HHS = half-height head shield; FHHS = full-height head shield; TFP = top-fittings protection.

Table 49: Estimated Reductions in Release Probability with Newer Tank Cars									
Car Category	**Additional Features[210]**					**Estimated Reduction in Release Probability Compared with DOT-111**			
	Shell	**Jacket**	**HHS**	**FHHS**	**TFP**	**DOT-111 Non-Jacketed**		**DOT-111 Jacketed**	
						Any Volume	**>2.4 bbl**	**Any Volume**	**>2.4 bbl**
CPC-1232	1/2”		✓		✓	50.4%	47.4%	-3.1%	-21.2%
	7/16”	✓		✓	✓	75.9%	76.5%	50.0%	45.9%
	1/2”	✓		✓	✓	80.5%	81.1%	59.4%	56.5%
DOT-117	9/16”	✓		✓	✓	84.2%	85.2%	67.2%	65.9%

Another study estimated the reduction in the average probability of release from tank cars that meet the specifications of the DOT-117 car to be 85 percent compared with the probability of release from the current non-jacketed DOT-111 car.[211] In addition, the enhanced design is expected to considerably reduce the likelihood of secondary failures caused by fire.

Train Speed as Factor in Determining Release Probability

Train speed affects the probability that a derailment will result in spillage from tank cars, as in Figure 41. The reduction in release rate due to speed reduction varies by impact type (head, shell, top, or bottom) from about 10 percent to 35 percent.



[210] HHS = half-height head shield; FHHS = full-height head shield; TFP = top-fittings protection.
[211] Barkan *et al.* 2015.

Figure 41: Average Proportion of Tank Cars Releasing Material in Accident by Speed[212]

In another study, the probability distribution of the numbers of cars releasing material at two speeds was analyzed (Figure 42). At a slower speed, fewer cars would be expected to release material. The probability of a multi-car release reduces by 22 percent to a probability of 0.32, and the mean number of tank cars releasing reduces by 25 percent to 1.38 cars. The study assumes 10 tank cars on an 82-car train.

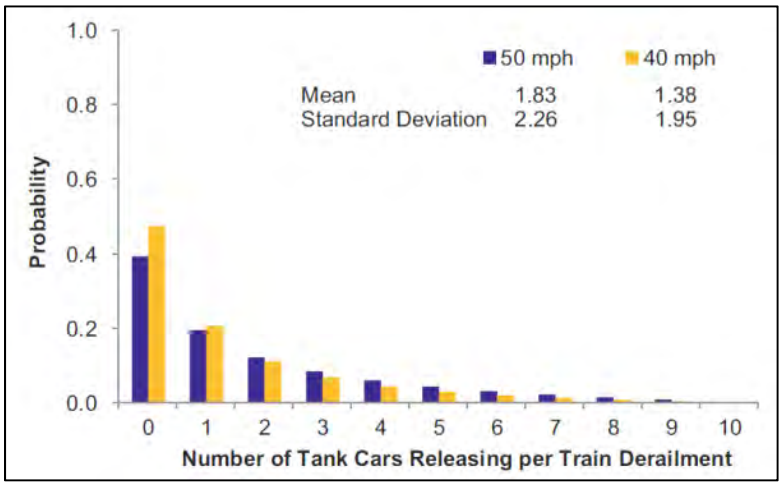


Figure 42: Estimated Probability Distribution of Derailed Tank Cars Releasing by Speed[213]

Thermal Protection

In early April 2015, the National Transportation Safety Board (NTSB)[214] issued a Safety Recommendation for thermal protection systems for tank cars, which neither the DOT-111 nor the CPC-1232 designs have. This thermal protection is intended to limit the heat flux to the tank car containers when exposed to fire. According to NTSB:

> *Appropriately designed thermal protection systems will prevent a rapid increase in the temperature of the lading and commensurate increase in vapor pressure in the tank, and are intended to limit the volume of materials required to be evacuated through the pressure relief device, thereby limiting dangerous over-pressurization of the tank.*
>
> *Exposing a bare steel, flammable-liquid filled tank car to a large pool fire from product released in an accident can result in tank failure from a thermal tear in the tank that was not otherwise breached in a derailment. When the tank is exposed to heat from a pool fire, the internal pressure increases while the strength of the tank decreases. The tank will rupture if the pressure relief device cannot sufficiently relieve internal pressure. The resulting thermal tear in the shell material suddenly releases built-up pressure, ejecting vapor and liquid to ignite in a violent fireball eruption. Research studying accidents involving tank cars has shown that use of tank cars with thermal protection and a jacket will significantly reduce the amount of product released in*

[212] Kawprasert and Barkan 2010; a) Releases from heads; b) releases from shells; c) releases from top fittings; d) releases from bottom fittings (see Figure 9).
[213] Liu *et al.* 2014; Assumes an 82-car train with 10 unjacketed DOT-111 tank cars.
[214] http://www.ntsb.gov/safety/safety-recs/recletters/R-15-014-017.pdf

accidents.[215] *PHMSA estimates that jacketed CPC-1232 tank cars with thermal protection systems could provide an 18 percent reduction in lading loss in accidents relative to comparable accidents involving non-jacketed CPC-1232 tank cars.*[216]

NTSB made the following safety recommendations to PHMSA:

- **R-15-14**: Require that all new and existing tank cars used to transport all Class 3 flammable liquids to be equipped with thermal protection systems that meet or exceed the thermal performance standards outlined in Title 49 *CFR*179.18(a) and are appropriately qualified for the tank car configuration and the commodity transported
- **R-15-15**: In conjunction with thermal protection systems called for in safety recommendation R-15-14, require that all new and existing tank cars used to transport all Class 3 flammable liquids to be equipped with appropriately sized pressure relief devices. Those devices must allow the release of pressure under fire conditions to ensure thermal performance that meets or exceeds the requirements of Title 49 *CFR* 179.18(a), and minimizes the likelihood of energetic thermal ruptures.
- **R-15-16**: Require an aggressive, intermediate progress milestone schedule, such as a 20-percent yearly completion metric over a 5-year implementation period, for the replacement or retrofitting of legacy DOT-111 and CPC-1232 tank cars to appropriate tank car performance standards. Those standards include equipping these tank cars with jackets, thermal protection, and appropriately sized pressure relief devices.
- **R-15-17:** Establish a publicly available reporting mechanism that reports at least annually, progress on retrofitting and replacing tank cars subject to thermal protection system performance standards as recommended in safety recommendation R-15-16.

Availability of DOT-117 Tank Cars

According to Shell, the company would own and use DOT-117 specification tank cars[217] at the Shell PSR.

The assumption of the DOT-117 tank cars depends upon the practice of the individual operators of the trains and on the availability of these tank cars for all of the current and potential future crude-by-rail traffic in Washington State. While all newly-constructed tank cars are required to meet the DOT-117 specifications by 1 October 2015, the timeline for retrofitting of older tank cars (as shown in Table 5) would allow for some non-compliant tank cars to be in use until mid-2025. Some of the interim retrofitted designs do provide better protection against spillage than DOT-111 cars (Table 46), but are not quite as effective as the DOT-117 design.

When the PHSMA/DOT regulations regarding tank cars were released in May 2015, industry experts warned that there may be significant shortages of DOT-117 tank cars while manufacturers try to meet the sudden high demand.[218] Some have predicted that there may be shortages of newly-built tank cars that

[215] Safety Performance of Tank Cars in Accidents: Probabilities of Lading Loss, Report RA-05-02, Railway Supply Institute and Association of American Railroads Safety Research and Test Project (January, 2006).
[216] *Calculating Effectiveness Rates of Tank Car Options*, PHMSA Docket PHMSA-2012-0082.
[217] http://shellraileis.com/
[218] Thomas 2015.

meet the DOT-117 specifications or that can be retrofitted according to the DOT timetable (see Table 5).[219] Based on the retrofitting timetable, a large portion of the existing unjacketed and jacketed DOT-111 tank cars would have to be removed from service in early 2018 until the required modifications could be carried out. According to the Railway Supply Institute Committee on Tank Cars, the retrofitting process could result in capacity shortfalls, which could have significant impacts on the availability of tank cars.[220] There is a possibility that there may not always be sufficient DOT-117 cars to meet the demands for all of the future crude-by-rail traffic in Washington State.

Release Probability Assumptions for HES and LES

For the calculation of release probabilities from tank cars involved in accidents, two major factors needed to be considered:

- The universal availability and usage of newer design DOT-117 tank cars;
- The degree to which the DOT-117 tank cars would decrease the probability of release;
- The degree to which reduced operating speed would reduce tank car release probabilities; and
- The degree to which thermal protection would reduce the probability of releases related to thermal damage or thermal tears.

Again, in keeping with the intent to provide both a Lower Estimate of Spills (LES) and a Higher Estimate of Spills (HES), two different sets of assumptions were applied.

For the Lower Estimate of Spills (LES), it was assumed that DOT-117 tank cars would be available at the onset of the project, and that the release rate from tank cars involved in accidents would be reduced by tank car design, thermal protection, and reduced operating speeds. As with the accident rate adjustments, a minimum and maximum reduction factor was estimated. For the LES, reductions in release probability related to tank car design (thicker shell, fittings) other than thermal protection were applied to the baseline release rates from accidents caused by impact (derailments, collisions, highway-rail crossing accidents, and miscellaneous). Thermal protection release reductions were only applied to accidents caused by fire and/or explosion.

The adjustments to release probability from tank cars are based on reduced train speed and tank car design. Reduced speed regulations are largely in place at this time, and one can have a reasonable assumption that these regulations will be enforced in actual practice. However, it is possible, as in all traffic situations, that an individual operator may intentionally or inadvertently operate a train at an unsafe speed. This could lead to an accident and possible spill. Excessive speed would most likely be prevented by PTC, which would be completely in place in 2018. Reductions in release probability due to reduced train speed were assumed to be concurrent with reductions related to tank car design based on the assumption that testing of tank car release rates for newer designs would have incorporated a concomitant application of the speed restrictions for HHFTs. For this reason, it was not included as a separate reduction factor.

[219] For example: http://blogs.oliverwyman.com/rail/2015/01/20/publication-of-new-tank-car-regulations-delayed/ ; http://www.railwayage.com/index.php/regulatory/dot-117-tank-car-rule-debuts-with-some-controversy.html
[220] Neels and Berkman 2014.

For the Higher Estimate of Spills (HES), it was assumed that there would be a delay in the availability of DOT-117 tank cars. The universal availability of DOT-117 cars is in question, according to various news reports. There are also delays in retrofitting existing cars that could affect fleet compositions for the next few years. In order to conservatively maximize the estimate of crude-by-rail spills, it was assumed that DOT-111 cars would not be universally available, or, alternatively, as another conservative assumption, that the DOT-117 or DOT-117R cars that are employed do not provide the protection to reduce releases upon impact. It was also assumed that release rates from tank cars involved in accidents would be the same as those of DOT-111 tank cars, i.e., with no reduction in releases related to tank car design or thermal protection. It was assumed that reduced speed would also not have an effect on release rates.

Table 50 summarizes the probabilities that were *considered* in making adjustments to tank car release probabilities in the analysis.

Table 50: Considered Adjustments to Tank Car Release Probability

Release Probability Factor	Higher Estimate of Spills (HES)		Lower Estimate of Spills (LES)		
	Assumptions	Adjustments to Baseline Tank Car Release Rate	Assumptions	Adjustments to Baseline Tank Car Release Rate	
				Minimum	Maximum
Tank Car Design	DOT-111 tank car release rate applied	0%	DOT-117 tank car release rate applied[221]	43% reduction	72.2% reduction
Operating Speed	No release reduction with reduced speed	0%	Release rate reduced due to lower operating speeds[222, 223]	10% reduction	35% reduction
Thermal Protection	No release reduction with thermal protection	0%	Thermal protection reduces releases due to fire/explosion[224, 225,226]	12% reduction	12% reduction

[221] For impact-related accidents (derailments, collisions, highway-rail crossing accidents, miscellaneous).
[222] Kawprasert and Barkan 2010 (Figure 41).
[223] See Figure 42.
[224] Reduction applied only to accidents caused by fire/explosion.
[225] *Federal Register* Vol. 79, No. 108 (August 1, 2014), Part III Department of Transportation, Pipeline and Hazardous Materials Safety Administration (49 CFR § 171, 172, 173, 174, 179) pp. 45,016–45,079.
[226] See Table 46.

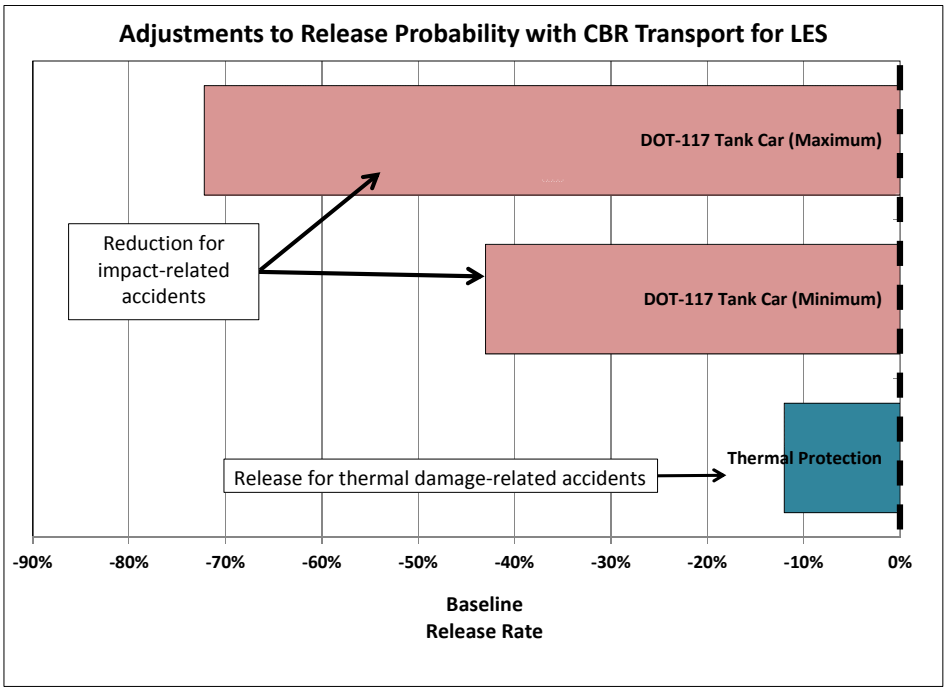


Table 51 and Figure 43 summarize the adjustments to spill probability that were applied in the final crude-by-rail spill probability analysis. There was no release probability adjustment applied for the HES.

Table 51: Applied Adjustments to Tank Car Release Probability

Release Probability Factor	Higher Estimate of Spills (HES)		Lower Estimate of Spills (LES)		
	Assumptions	Adjustments to Baseline Tank Car Release Rate	Assumptions	Adjustments to Baseline Tank Car Release Rate	
				Minimum	Maximum
Total Adjustment Applied to Impact Accident Rate		0%	**Total Adjustment Applied to Impact Accident Rate**	43% reduction	72.2% reduction
Total Adjustment Applied to Fire/Explosion Accident Rate		0%	**Total Adjustment Applied to Fire/Explosion Accident Rate**	12% reduction	12% reduction

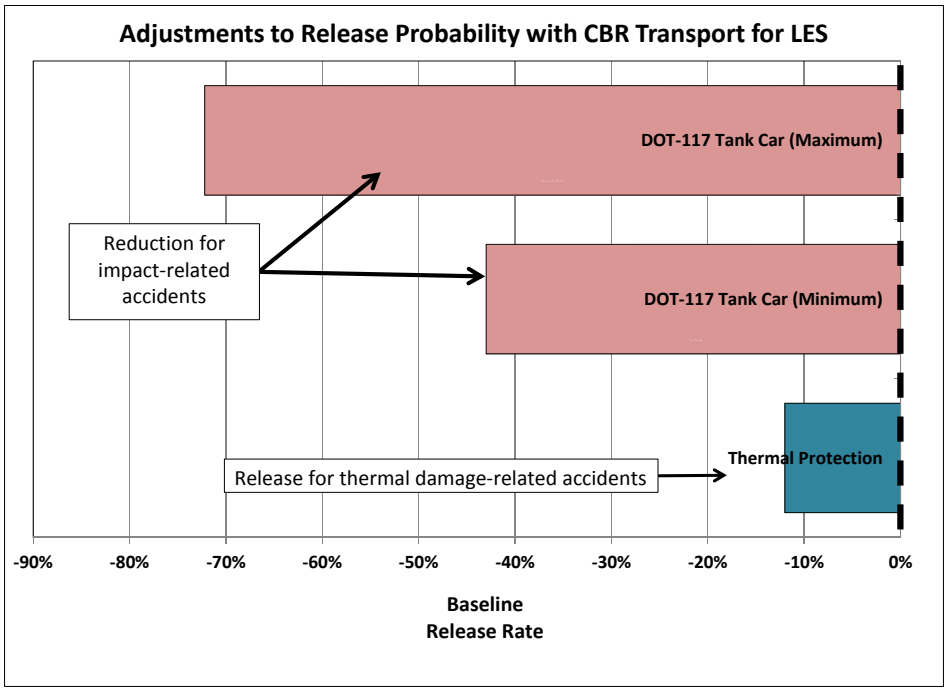


Figure 43: Applied Adjustments to Release Probability with Crude-by-Rail Transport–LES

Chapter 8: Spill Volume Analysis

The probability of the release from an individual hazmat car needs to be multiplied by the number of cars involved in the accident to derive the total volume spilled in the accident.

Numbers of Cars Involved in Transit Accidents

When a rail accident occurs in transit, there are varying numbers of freight cars that may be involved. An analysis of the numbers of freight cars involved in derailments and other accidents was conducted. Based on the FRA accident data,[227] probability distributions of numbers of cars involved per event are shown by accident type in Table 52. [These are national data.] The probability distributions of number of cars and percentage of total cars are shown in Figure 44 and Figure 45. Accidents in all accident categories in which no freight cars are involved are assumed to be those in which only locomotives are involved.

Table 52: Damaged/Derailed Freight Cars Involved in National Transit Accidents (1975–2015)[228]

Percentile	Number of Cars Involved per Transit Accident by Accident Type					
	Collision	Derailment	Hwy-Rail	Fire/Explosion	Misc.	All Accidents
	N = 3,106	N =43,656	N = 4,456	N = 872	N = 2,390	N = 54,480
% accidents with 0 cars	50.1%	2.5%	85.6%	97.2%	82.9%	17.1%
10th	0	1	0	0	0	0
20th	0	2	0	0	0	1
25th	0	2	0	0	0	1
30th	0	3	0	0	0	1
40th	0	4	0	0	0	3
50th (Median)	0	5	0	0	0	4
60th	2	7	0	0	0	6
70th	3	9	0	0	0	8
75th	4	10	0	0	0	9
80th	5	12	0	0	0	11
90th	8	18	3	0	2	16
95th	13	24	10	0	6	22
99th	27	37	23	7	21	36
Worst Case	58	122	80	43	66	122

The numbers of cars involved in accidents were evaluated based on accident type and time frame, with results shown in Table 53. For each type of accident there are many factors that determine the number of cars involved. For example, for highway-rail crossing accidents, a disproportionate number of accidents involve large vehicles, such as tractor-semitrailers, but the vehicle size does not affect derailment severity. Several studies indicate that the speed of the vehicle and train are important factors with derailments more likely to occur at higher vehicle speeds and lower train speeds.[229]

[227] This follows the methodology in Etkin *et al.* 2015b.
[228] FRA accident data on freight trains of at least 20 freight cars on main line track (54,480 accidents).
[229] For example, Chadwick *et al.* 2011, 2013.

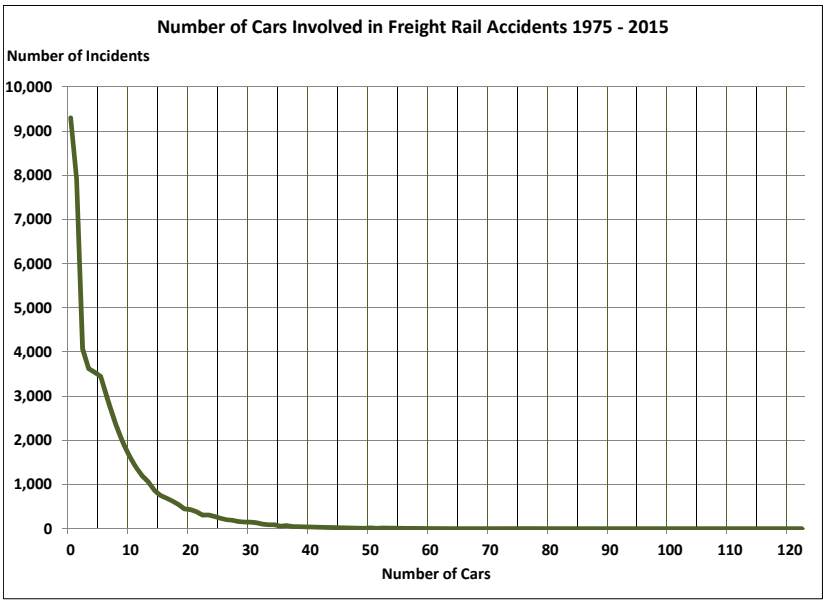


Figure 44: Numbers of Cars Involved in Main Line Freight Transit Accidents (1975–2015)

Table 53: Damaged/Derailed Freight Cars Involved in Transit Accidents by Type and Time[230]

Time Frame	Statistic	Number of Freight Cars Involved per Transit Accident					
		Collision	Derailment	Hway-Rail	Fire/Explosion	Misc.	All
1975–1984	% 0 cars	53.3%	2.2%	76.5%	97.7%	86.5%	12.5%
	Average	2.6	7.4	2.0	0.3	0.7	6.6
	Maximum	58	81	52	43	38	81
	Accidents	1,622	25,712	1,309	597	891	30,131
1985–1994	% 0 cars	46.5%	2.8%	81.8%	94.5%	78.5%	17.2%
	Average	3.2	8.4	2.0	0.3	1.4	7.0
	Maximum	33	88	80	16	61	88
	Accidents	587	7,586	874	109	456	9,612
1995–2004	% 0 cars	43.8%	2.9%	90.0%	97.9%	75.1%	21.6%
	Average	3.5	8.4	0.8	0.1	1.5	6.6
	Maximum	55	81	32	6	66	81
	Accidents	507	5,968	1,016	48	514	8,053
2005–2015	% 0 cars	50.5%	3.6%	94.1%	97.5%	88.3%	31.7%
	Average	2.8	8,2	0.5	0.3	0.7	5.7
	Maximum	41	122	46	27	39	122
	Accidents	390	4,390	1,257	118	529	6,684
All Years 1975–2015	% 0 cars	50.1%	2.5%	85.6%	97.2%	82.9%	17.1%
	Average	2.9	7.8	1.3	0.3	1.0	6.6
	Maximum	58	122	80	43	66	122
	Accidents	3,106	43,656	4,456	872	2,390	54,480

[230] FRA accident data on freight trains of at least 20 freight cars on main line track (54,480 accidents).

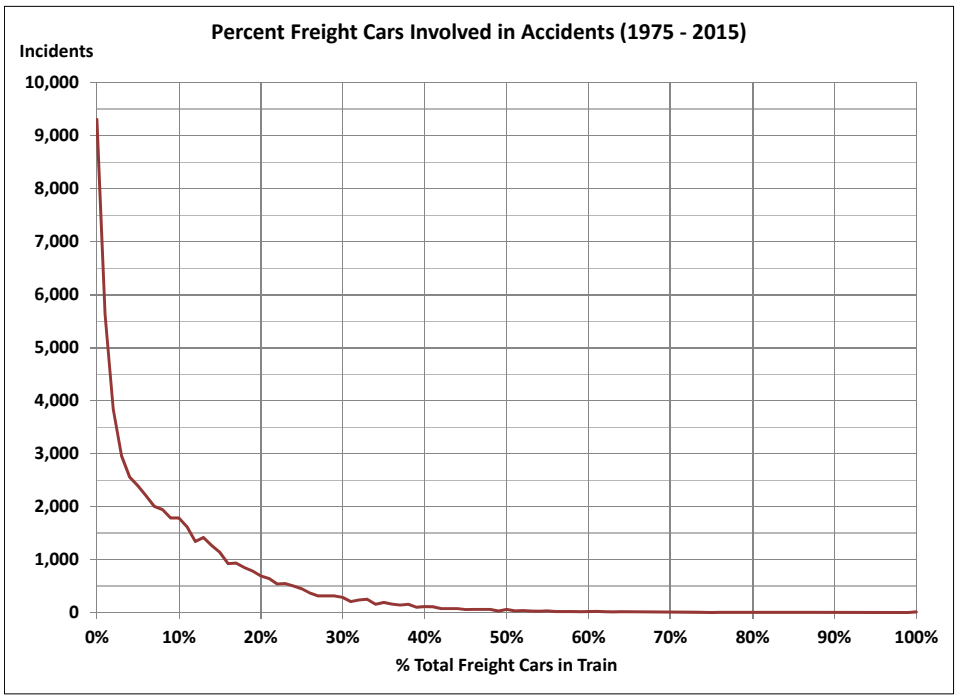


Figure 45: Distribution of Percent Freight Cars Involved in Transit Accidents (1975–2015)

The issue of numbers of cars released in derailments has been studied extensively by various rail technology researchers who made assumptions that there would be a hyper-geometric distribution of tank cars derailed if they were randomly placed on a train or that the position on the train would affect the probability and number of derailed cars.[231] Cars in front of the middle of a train are more likely to derail in a broken-rail-caused derailment than the cars at the very front or towards the end (Figure 46).

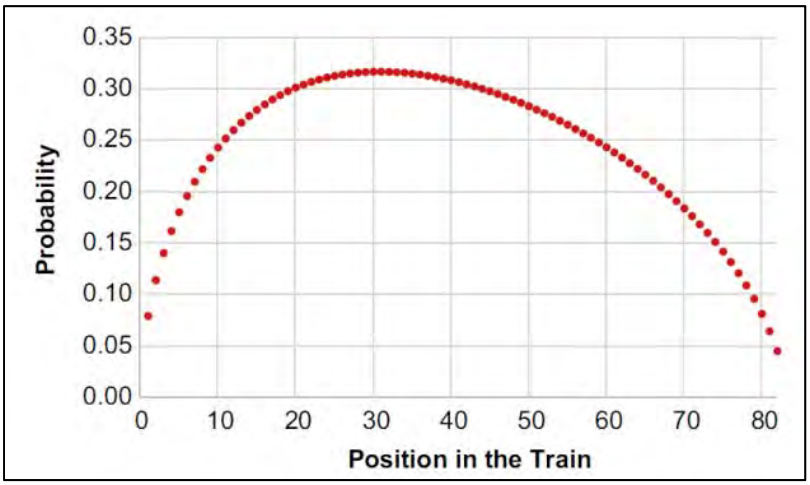


Figure 46: Derailment Profile for Broken-Rail Derailment with 82-Car Train[232]

[231] Glickman *et al.* 2007; Bagheri 2009; Bagheri *et al.* 2011; Liu *et al.* 2014.
[232] Liu *et al.* 2014.

A more relevant study that would be analogous to the results in Figure 44, Table 52, and Table 53 estimated the distribution of numbers of derailed cars.[233] For an 82-car train with 10 conventional, non-jacketed DOT-111 tank cars, the estimated [modeled] Poisson binomial probability distribution of the number of tank cars that derailed per derailment accident is shown in Figure 47. The analysis was conducted on only the hypothetical 10 tank cars on the train. It is unclear whether this can be extrapolated to a 100-car crude-by-rail unit train based on the percentage of cars rather than the total number of cars.

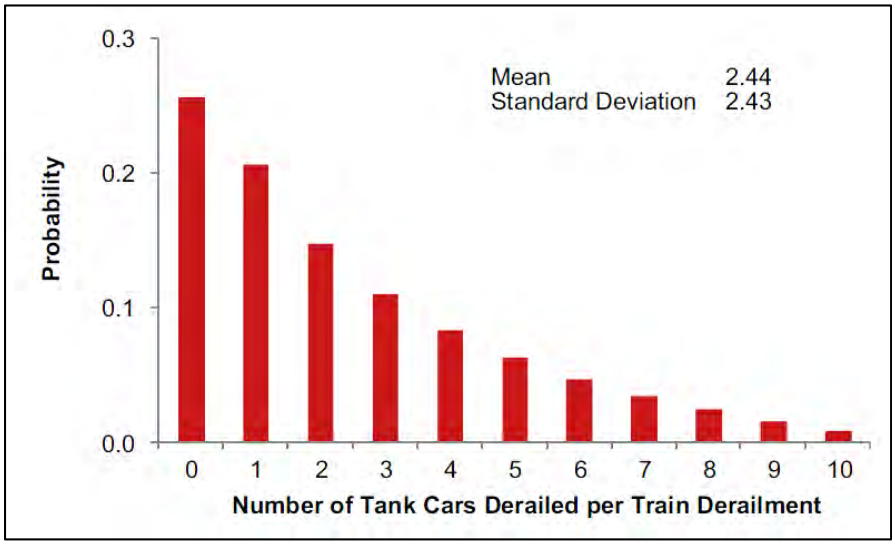


Figure 47: Modeled Distribution of Numbers of Tank Cars Derailed per Derailment[234]

Train Speed Effect on Derailment Car Number

Speed is an important factor in determining the number of cars that derail in an accident. One study[235] examined the average numbers of cars that derail based on track class and speed, as summarized in Table 54 and Figure 48 for FRA Class 4 Track.[236]

Table 54: FRA Class 4 Track Derailment Accidents by Derailed Number and Speed[237]

Speed	Cars Derailed (% Accidents)						Average Car Number
	1–5	6–10	11–15	16–20	21–25	>25	
1–10 mph	71.1%	19.9%	5.7%	1.4%	0.5%	1.4%	**4.8**
11–25 mph	50.9%	25.3%	15.0%	5.8%	1.7%	1.4%	**6.9**
26–40 mph	41.7%	15.1%	16.9%	11.3%	7.2%	7.9%	**10.2**
> 40 mph	44.6%	10.9%	11.2%	8.9%	6.8%	17.7%	**10.9**
Total	**48.7%**	**16.0%**	**12.6%**	**7.9%**	**5.0%**	**9.7%**	**9.7**

[233] Liu *et al.* 2014.
[234] Liu *et al.* 2014.
[235] Anderson and Barkan 2005.
[236] Track classified by FRA with respect to maximum speed for track condition as 60 mph for freight, 80 mph for passenger. This is the dominant class for main-line track used in passenger and long-haul freight service.
[237] Anderson and Barkan 2005.

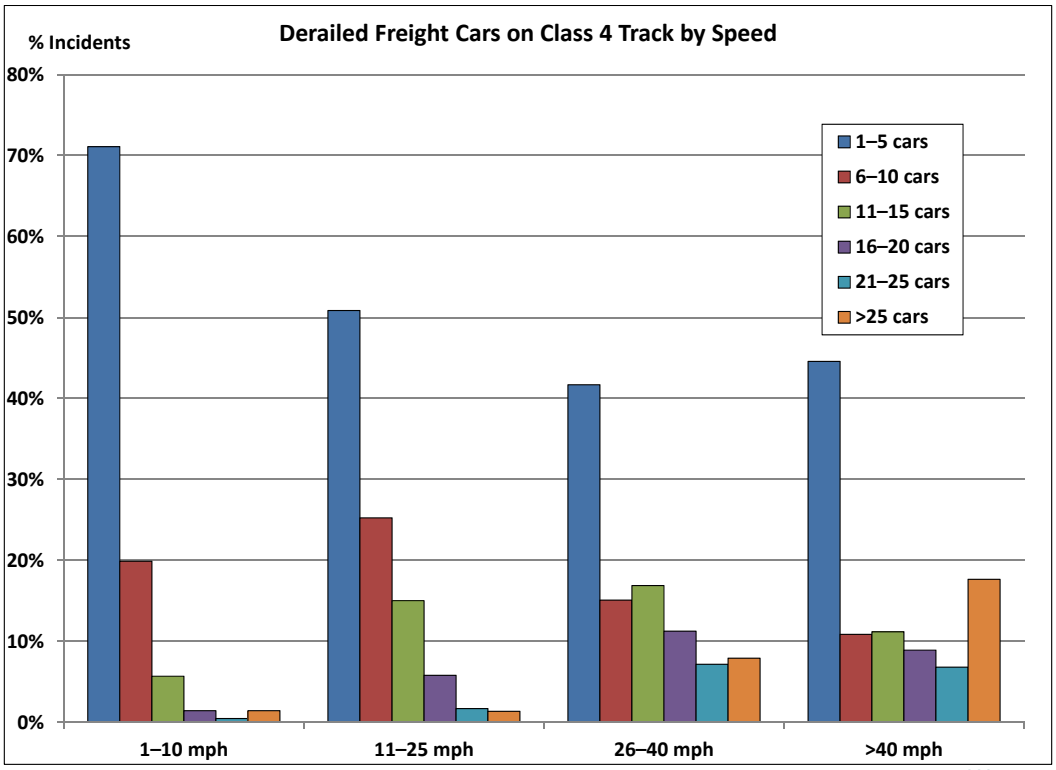


Figure 48: Frequency Distributions of Derailed Cars on FRA Class 4 Track by Speed[238]

Numbers of Rail Cars Involved in Within-Facility Accidents

Rail-related accidents within facility may occur during loading/unloading (transfer operations) or while moving along rails within the facility grounds. Out of the 4,776 within-facility accidents reported to FRA (Table 27), 83 percent were derailments, 6.5 percent were collisions, 9 percent were attributed to miscellaneous causes, 0.2 percent were caused by fires or explosions, and 0.9 percent were related to vehicle-rail crossing accidents (within facilities). The accidents typically occur while the trains are stationary or while moving at a low speed (the average speed of the accidents reported to FRA was 6 mph). The Washington State accident data showed that an average of 2.9 freight cars involved per event. The average speed was calculated to be 6.7 mph.

The breakdown of car numbers by accident type for the national data is summarized in Table 55.

Table 55: Car Numbers Involved in Within-Facility National Rail Accidents (1975–2015)

Statistic	Number Cars					
	Collision	Derail	Fire/ Explosion	Hwy-Rail	Misc.	Total
Avg. Cars Involved	1.2	4.4	0.7	0.9	0.7	**3.8**
Avg. % Total Train Cars[239]	7.4%	16.7%	10.7%	0.8%	4.4%	**14.8%**
Avg. % Hazmat Cars Damaged	0.1%	0.4%	0.0%	2.4%	0.2%	**0.4%**

[238] Based on Anderson and Barkan 2005

[239] Total car number averaged 50 cars. Freight trains are often divided into smaller sections during maneuvers to facilitate transfer operations and to rearrange cars.

Distribution of Percent Release per Tank Car

When a tank car is breached, the entire contents may not necessarily be released to the environment. The amount released depends specifically on the size of the puncture or tear in the tank, its location, the orientation of the car (upright, at an angle or on its side or end), the volume of fluid in the tank, as well as the characteristics of the fluid (*e.g.*, its viscosity and pour point) at the prevailing environmental conditions (primarily air temperature). These same factors affect outflow from tankships due to accidents (*e.g.*, groundings, collisions).

A literature review revealed four studies that mention the distribution of release percentages. One study mentioned that in one-third of cases, only 5 percent of the tank car contents is released, and that in one-third of cases, 80 to 100 percent is released. Presumably, the remaining one-third releases between 5 and 80 percent.[240] A second study evaluated the release rates of tank cars with the results shown in Figure 49.[241] (Tank-caused accidents involve damage to the head and shell; non-tank-caused accidents involve damage to other tank car components, principally the top and bottom fittings.)

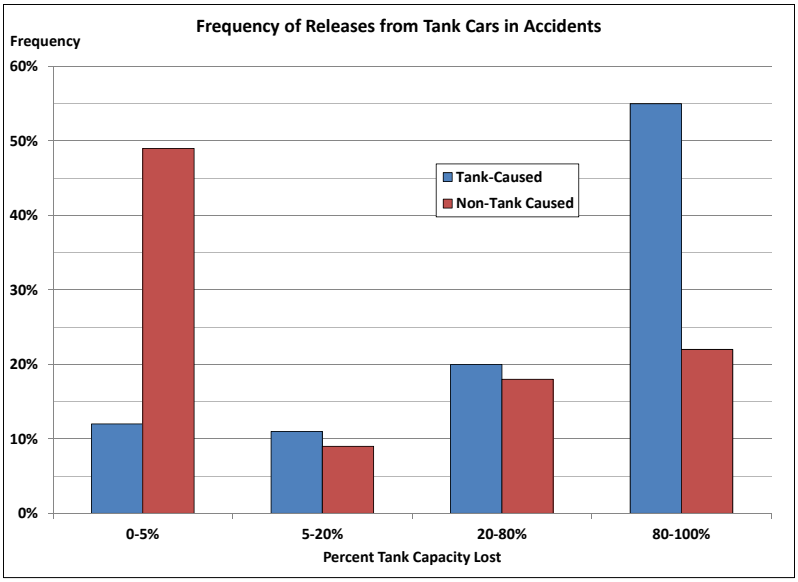


Figure 49: Frequency of Releases of Different Volumes[242]

A third study combined conditional probability of release with percentage release (Figure 50–Figure 52). The analyses indicated that the conditional probability of release (*i.e.*, a spill in the event of a derailment) was 0.117 for tank-related causes and 0.207 for non-tank-related causes for DOT-111 tank cars, and that 62 percent and 32.1 percent of the tank capacity would be lost, respectively. Multiplying these values together netted a 7.25 percent average tank capacity release risk for tank-caused accidents and 6.65 percent for non-tank-caused accidents. With an average tank capacity for DOT-111 cars of 717.7 bbl, this

[240] Treichel *et al.* 2006.
[241] Saat and Barkan 2005.
[242] Based on Anderson and Barkan 2004.

would mean an average release risk per derailment of 52 bbl and 48 bbl, respectively, depending on whether the release occurred due to tank- or non-tank-related causes.

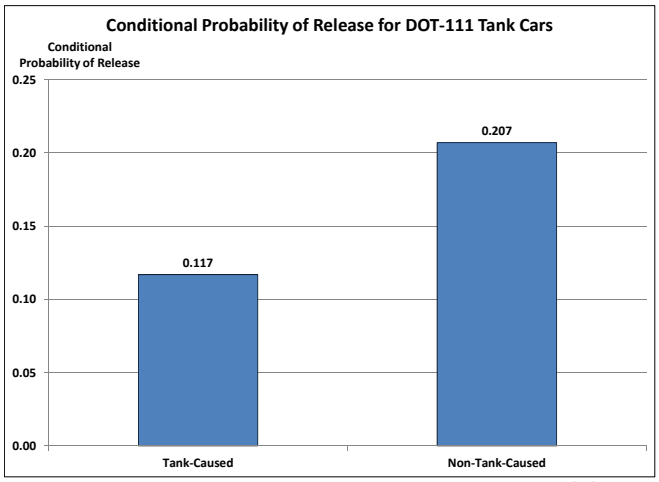


Figure 50: Conditional Probability of Release for DOT-111 Tank Cars[243]

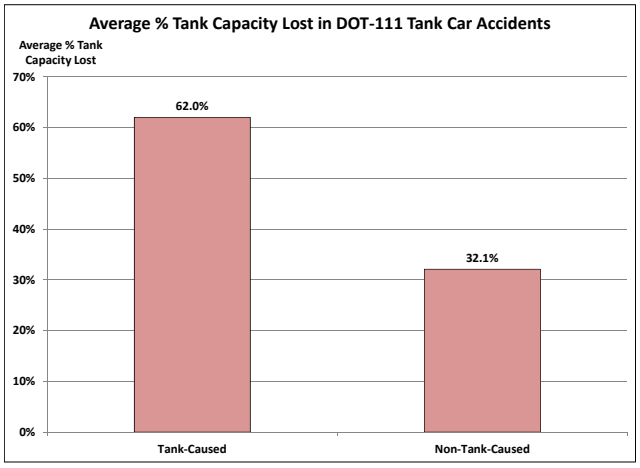


Figure 51: Average Percent Tank Capacity Lost in DOT-111 Tank Car Accidents

[243] Saat and Barkan 2005.

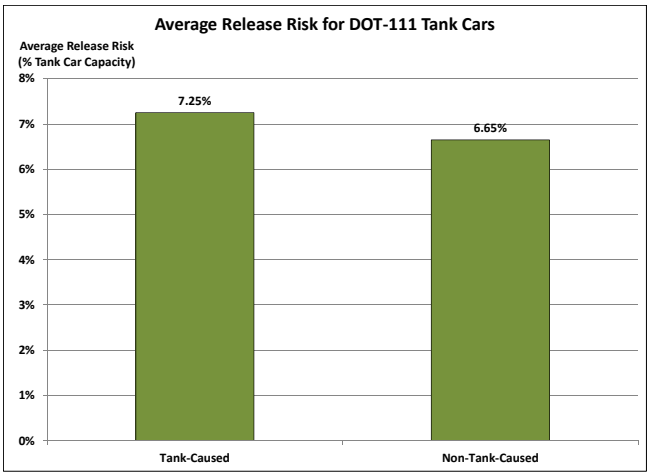


Figure 52: Average Release Risk for DOT-111 Tank Car Accidents

The fourth study assumed a Poisson binomial probability distribution of the number of tank cars that would release material assuming there were 10 tank cars (Figure 53).[244]

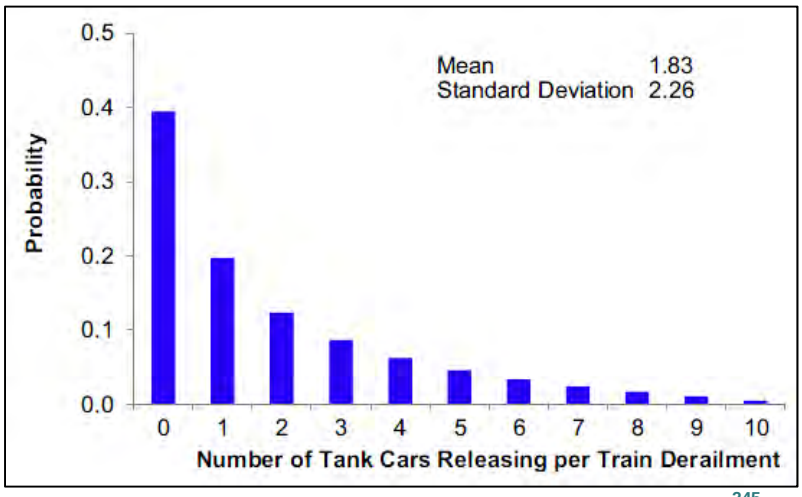


Figure 53: Estimated Probability Distribution of Derailed Tank Car Numbers[245]

Variable volumes of release (or percentages of tank capacity lost) are relevant in the evaluation of spill volumes and the analysis of effects of spills of the liquid cargo (*i.e.*, Bakken crude oil in the case of the Shell PSR). If the spilled oil ignites, it is highly likely that the remaining oil in a breached tank car not completely emptied of its contents will be involved in the resulting fire despite the fact that it did not technically spill out of the tank car. [*Combustion of spilled Bakken crude oil is analyzed in another report.*[246]]

[244] Liu *et al.* 2014.
[245] Liu *et al.* 2014; assumes 10 DOT-111 tank cars in an 82-car train.
[246] Risknology 2016.

Crude Oil Volumes Carried in Tank Cars

The percentage of release from individual tank cars and the numbers of tank cars involved, in combination with the amount of oil contained in each tank car, will determine the total amount of oil released to the environment.

The actual volume of crude oil in each tank car may vary depending on:

- The type of oil and its density (specific gravity or °API);[247]
- The capacity of the tank car based on its model design;
- The degree to which each tank car is filled (to allow for air space); and
- The total weight limit allowed per tank car (gross rail load).

Capacities of various tank car designs are shown in Table 56. The tank capacity is not necessarily the amount of Bakken crude that would be contained in an individual car, because there is a maximum total gross weight (the empty tank car plus its cargo) that is allowed. This weight, called the gross rail load (GRL) is set by regulations. The GRL for North American free interchange is set at 263,000 pounds (131.5 short tons). The GRL for heavy axle load weight for North American Class I railroads is currently set at 286,000 pounds. (143 short tons), which puts a load of 36 tons per axle for a typical four-axle freight car. This weight limit exists regardless of the commodity being carried.

Table 56: Capacity of Tank Car Designs[248]

Tank Car Type	Typical Tank Full Capacity (bbl)[249]	Maximum Total Gross Rail Load (lbs)[250]
DOT-111 (Non-Jacketed)	717.7	263,000
DOT-111 (Jacketed)	607.1	263,000
CPC-1232 (Jacketed)	675.5	286,000
DOT-117	675.5	286,000

Typically, the nominal capacity (also called "light weight" or "tare weight") of a tank car is about 66,000 pounds (33 tons), which allows for 220,000 pounds (110 tons) of cargo. The volume depends on the density of the commodity. In the case of Bakken crude, with a density of 0.808 (°API of 43.67) at 60°F, 110 tons is the equivalent of 776.8 bbl. However, this exceeds the tank capacity of the tank cars, as shown in Table 56. (The reason for the discrepancy is that Bakken crude oil is particularly light.) A fully-loaded DOT-117 or CPC-1232 tank car filled to a 675.5-barrel capacity weighs 70.6 tons.[251]

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[247] Density, mass per unit volume of the oil, determines its buoyancy in water. Density is commonly expressed in grams per cubic centimeter (g/cm3) or in ºAPI. The units are related as: $^{o}API = (141.5/sp.gr.) - 131.5$. A low ºAPI oil has a high density and specific gravity, and a high ºAPI oil has a low density and specific gravity. A heavy oil is one with an ºAPI gravity less than 20°. Oil density increases with weathering (evaporation of volatile hydrocarbon components) and decreasing temperature (see Etkin 2015a).

[248] Based on data provided by Railway Supply Institute.

[249] Actual capacity will depend on the specific design features.

[250] The change in regulatory gross rail load (GRL) from 263,000 to 286,000 was made in 2003 and is not unique to tank cars but applies to all rail cars (Barkan 2008a; AAR 2003; Barkan *et al.* 2015).

[251] One frequently-cited concern voiced in public comments and media coverage about CBR is that CBR trains are "heavier" than other freight trains. This extra weight is alleged to cause additional stress on existing infrastructures,

Regardless of the tank capacity, tank cars of crude oil are generally loaded to allow for air space so the oil can expand due to temperature differences during transport. Older tank cars (unjacketed DOT-111) generally are loaded with 690 barrels of Bakken crude oil.[252] For the newer DOT-117 tank cars, the expected loading volume is 650 barrels. This takes into account a 4 percent expansion space.

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such as damaging trestles, bridges, and rails, as well as increasing the likelihood of an accident. In actuality, CBR trains and individual tank cars with Bakken crude are considerably lighter than other freight cars or tank cars carrying other commodities. Water is approximately 20 percent heavier than Bakken crude oil.

[252] The unjacketed DOT-111 cars involved in the Lac-Mégantic accident (see Figure 65) contained about 672.22 bbl each.

Chapter 9: Crude-by-Rail Accident/Release Probability Modeling

The analyses of rail accidents and spills, as well as the various adjustments based on specific crude-by-rail factors all inform the inputs for the final spill probability modeling–one for loaded crude-by-rail unit trains and one for empty trains. The basic fault-tree models are solved with a Monte Carlo simulation approach. This allows for distributions of values and uncertainties to be incorporated into the analysis rather than solely static values. The calculations are made in accident and spill frequencies per train-mile. The train-miles vary based on the numbers of trains expected.

This process estimates the likelihood that there will be a spill of any magnitude. It does not determine the volumes of spillage. That process is described in Chapter 10.

Accident and Spill Probability Model (CBR-SpillRISK)

For loaded crude-by-rail trains, there are five types of accidents that could lead to the release or spillage of crude oil cargo. In order for a spill to occur from any one of these accident types, three events need to occur:

- The tank cars on the train need to be loaded with crude oil and be in transit;
- An accident needs to occur; and
- A breach needs to occur in at least one tank car to cause the release of oil.

The probabilities of the events leading to spillage due to a particular type of accident are multiplied together. The probabilities of release by any of the accident types are then added together to derive the total probability of spillage from the loaded trains (Figure 54). The probability is calculated on a per train-mile basis. The number of loaded crude-by-rail train-miles is multiplied by the probability to derive the total number of annual spills expected.

The probability or frequency calculations are conducted with Equation 10 through Equation 16:

Equation 10
$$P(spill)_i = P(accident)_i \cdot P(release)_i$$

Equation 11
$$P(spill)_{derail} = P(derail) \cdot P(release)_{derail}$$

Equation 12
$$P(spill) = \sum P(accident)_i \cdot P(release)_i$$

Equation 13
$$P(spill)_{collision} = P(collision) \cdot P(release)_{collision}$$

Equation 14
$$P(spill)_{fire} = P(fire) \cdot P(release)_{fire}$$

Equation 15
$$P(spill)_{cross} = P(hway\,cross) \cdot P(release)_{cross}$$

Equation 16
$$P(spill)_{misc} = P(misc) \cdot P(release)_{misc}$$

An analogous procedure is followed for empty trains. In this case, the spillage would only come from locomotives. In this case, the empty train-mile numbers are applied (Figure 55).

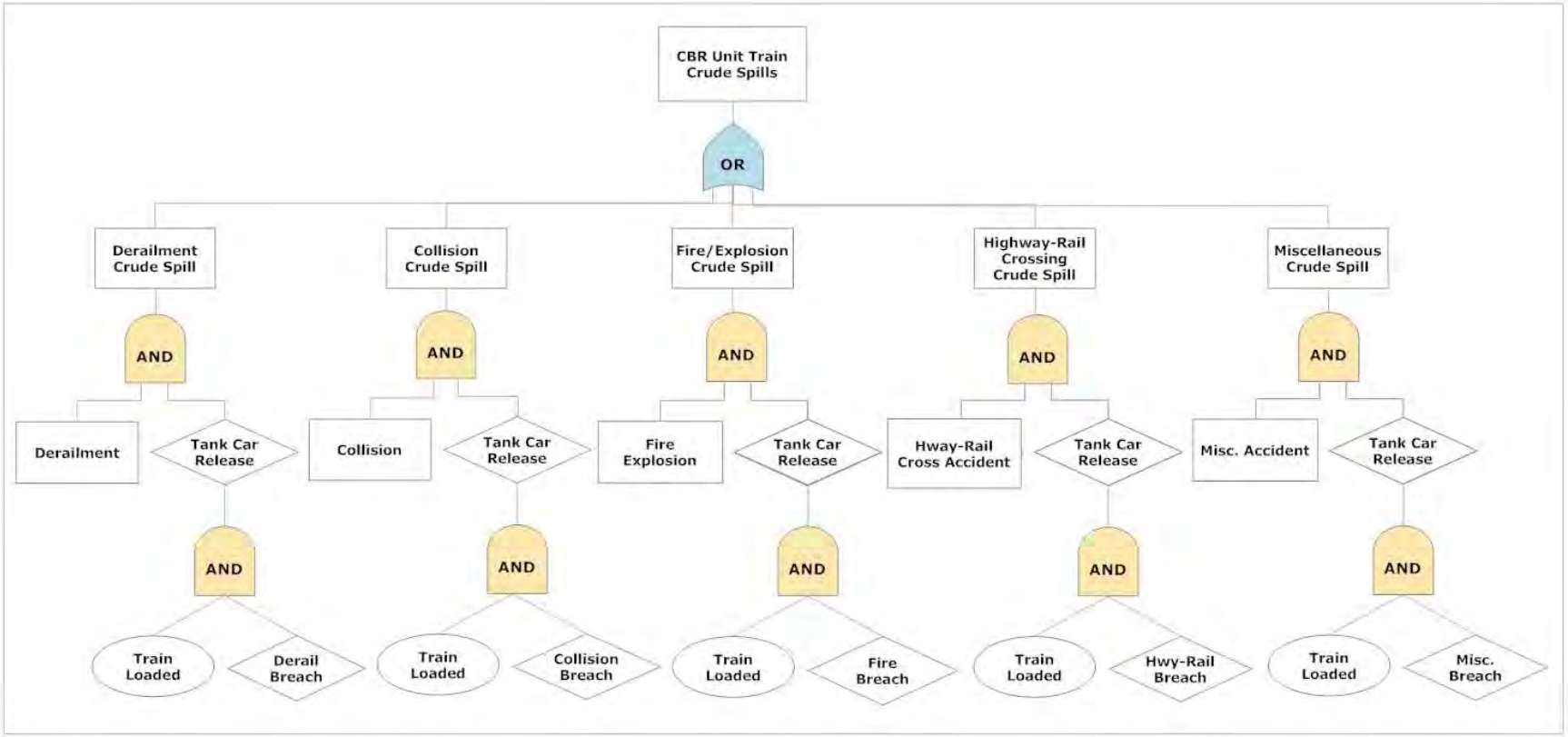


Figure 54: Fault Tree Model Setup for Crude-by-Rail Crude Spill Events (Loaded Trains)

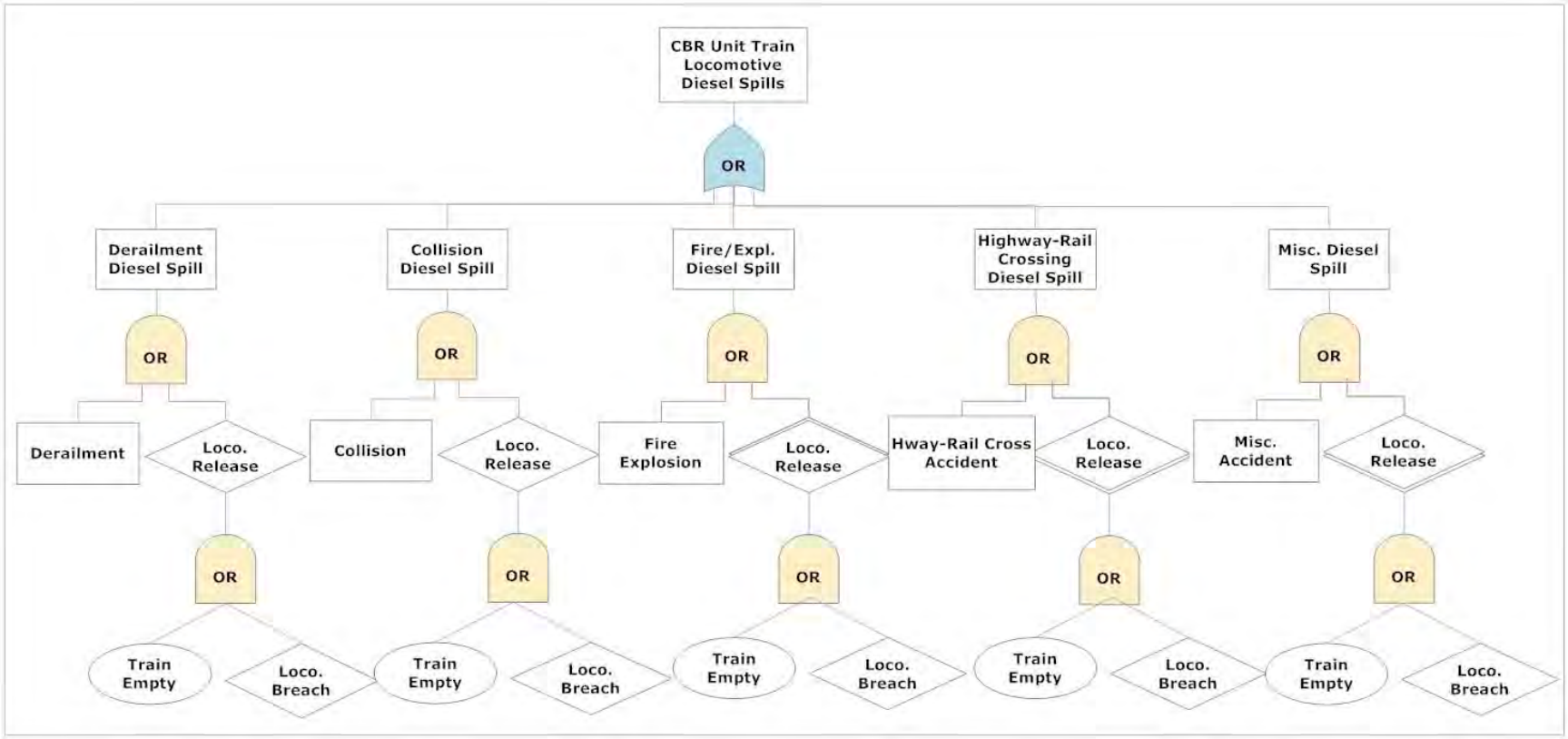


Figure 55: Fault Tree Model Setup for Crude-by-Rail Diesel Spills (Empty Trains)

Crude-by-Rail-Specific Probability Adjustments for CBR-SpillRISK

The adjustments to accident probability and to release probability were applied differently to the Lower Estimate of Spills (LES) (Table 42 and Table 43) and the Higher Estimate of Spills (HES) (Table 50). The application of the adjustments for accident rates are summarized in Figure 56 and Figure 57.

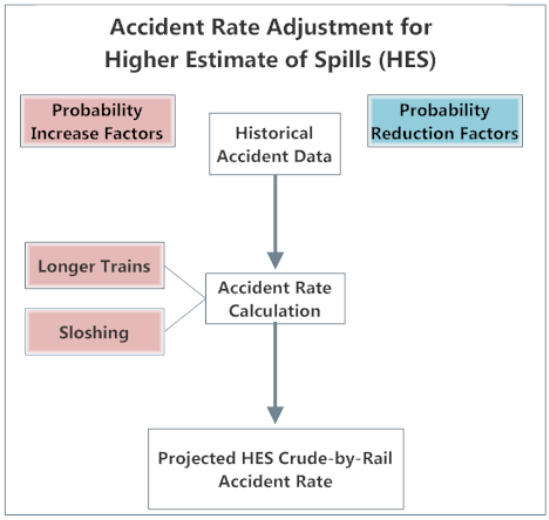


Figure 56: Adjustments to Historical Rail Accident Probability for Crude-by-Rail Rate for HES

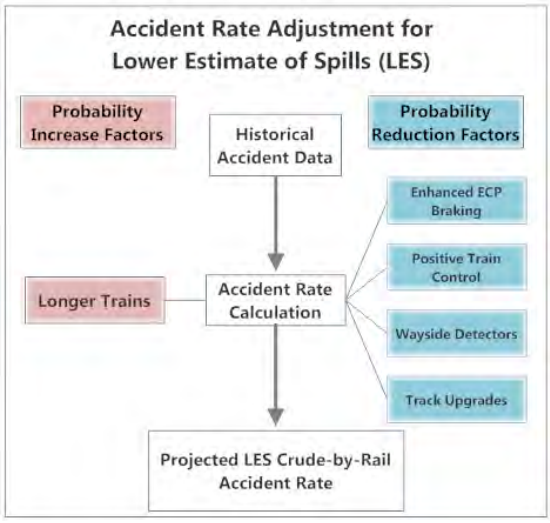


Figure 57: Adjustments to Historical Rail Accident Probability for Crude-by-Rail Rate for LES

The adjustments for the release rate from tank cars for the LES to take into account safety enhancements are summarized in Figure 58. These adjustments include those shown in Table 50. Note that there were no adjustments made to historical release rates for the HES, because it was assume that the release rate would be that for the older DOT-111 cars.

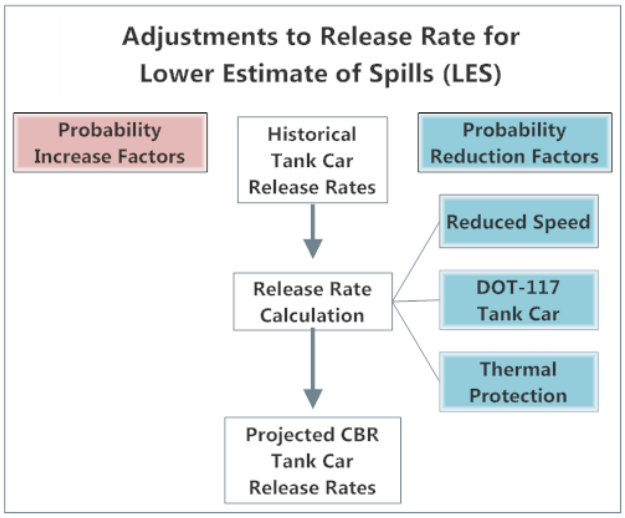


Figure 58: Adjustments to Hazmat Tank Car Release Rate for Crude-by-Rail for LES

HES Probability Inputs CBR-SpillRISK with Crude-by-Rail Adjustments

The rail accident-related inputs into the Monte Carlo simulation of the loaded crude-by-rail unit train spillage (CBR-SpillRISK) model for the Higher Estimate of Spills (HES) were as summarized in Table 57 for loaded trains and for locomotives on empty trains.

Table 57: CBR-SpillRISK Model Rail Accident Inputs with Adjustments (Loaded Trains): HES

Accident Type	Accident Probability Per Million Train-Miles						Distribution Type[253]
	Pre-Adjustment		Adjustment		Adjusted		
	Low	High	Train Length (cars)	Multiplier[254]	Low	High	
Derailment	0.6620	1.1100	102 (Shell PSR)	1.374	0.9096	1.5251	Log-normal
			120 (statewide)	1.497	0.9910	1.1000	
Collision	0.0612	0.1283	102 (Shell PSR)	1.374	0.0841	0.1763	Weibull
			120 (statewide)	1.497	0.0916	0.1921	
Fire/Explosion	0.0000	0.0338	102 (Shell PSR)	1.374	0.0000	0.0464	Uniform
			120 (statewide)	1.497	0.0000	0.0506	
Hway-Rail Cross	0.0541	0.1503	102 (Shell PSR)	1.374	0.0743	0.2065	Uniform
			120 (statewide)	1.497	0.0810	0.2250	
Miscellaneous	0.0639	0.1284	102 (Shell PSR)	1.374	0.0878	0.1764	Uniform
			120 (statewide)	1.497	0.0957	0.1922	

The pre-adjustment accident probabilities were derived from the highest and lowest accident rate values in Table 16 for accidents that occurred between 1985 and 2004,[255] prior to crude-by-rail transport with the

[253] Variable distribution for application in Monte Carlo analysis. Log-normal distribution: upper value is unlimited but values cannot fall below zero; natural logarithm of distribution is normal distribution; distribution positively skewed with most values being near lower limit. Weibull distribution: slightly positively skewed normal distribution. Uniform distribution: equal likelihood for all values in designated range.
[254] Based on Table 43.

accident numbers per million train-miles apportioned into accident with loaded and empty trains based on the data in Table 24.[256] The HES tank car release (spill) probability inputs into the CBR-SpillRISK model are in Table 59 for loaded trains and Table 60 for empty trains (locomotives).

Release probabilities are based on 1985–2015 data in Table 44 (analogous to DOT-111), with no adjustments to release probability as per Table 50.[257] Release probabilities were the same for all train lengths. There are no known estimates for release probability for locomotives. Since the fuel tanks on locomotives are typically about 20 percent the size of tank cars, it is assumed that they have a 20 percent chance of being breached relative to tank cars.

Table 58: CBR-SpillRISK Model Rail Accident Inputs with Adjustments (Empty Trains): HES

Accident Type	Accident Probability Per Million Train-Miles						Distribution Type
	Pre-Adjustment		Adjustment		Adjusted		
	Low	High	Train Length (cars)	Multiplier	Low	High	
Derailment	0.3116	0.5223	102 (Shell PSR)	1.374	0.4281	0.7176	Log-normal
			120 (statewide)	1.497	0.4665	0.7819	
Collision	0.0288	0.0604	102 (Shell PSR)	1.374	0.0396	0.0830	Weibull
			120 (statewide)	1.497	0.0431	0.0904	
Fire/Explosion	0.0000	0.0159	102 (Shell PSR)	1.374	0.0000	0.0218	Uniform
			120 (statewide)	1.497	0.0000	0.0238	
Hway-Rail Cross	0.0254	0.0708	102 (Shell PSR)	1.374	0.0349	0.0973	Uniform
			120 (statewide)	1.497	0.0380	0.1060	
Miscellaneous	0.0300	0.0604	102 (Shell PSR)	1.374	0.0412	0.0830	Uniform
			120 cars (statewide)	1.497	0.0449	0.0904	

[255] None of the accident data applied in the analysis involve crude-by-rail transport specifically. The purpose of using the 1985-2004 time frame for accident rate is that it is higher than the more recent time frame of 2005-2015 in which there are already a number of safety enhancements that have changed accident rates for freight trains (not only for crude-by-rail). The 1975-1984 time period was not included because there were extraordinarily high accident rates at that time that are not relevant to overall current practice.

[256] The calculations for the low and high pre-adjustment accident rates were taken from the lowest and highest accident rates in Table 16 for 1985–1994 and 1995–2004 by accident type, e.g., for derailments, the lowest accident rate was 0.9736 (Washington 1995–2004). That rate was then apportioned between loaded and empty trains based on percentages in Table 24. 0.9736 was multiplied by 70% for loaded trains, and 30% for empty trains. The resulting accident probability values for loaded trains appear in Table 57 and for empty trains in Table 58.

[257] The pre-adjustment probabilities of release were derived from the values in Table 44. (The percentages were converted into decimals.) The highest values for the time periods 1985–2015 were selected, e.g., for derailments the 14.9% percent damaged cars was assumed to be the lower probability that a tank car would have a breach (and spill its contents). The 22.3% value was used for the higher release probability. For the locomotive releases, 20% of these values were applied based on the assumption that since fuel tanks on locomotives are typical about 20% the size of tank cars, they might have a 20% chance of being breached.

Table 59: CBR-SpillRISK Release Probability Inputs with Adjustments (Loaded Trains): HES						
Accident Type	**Release Probability Per Accident**					**Distribution Type**
	Pre-Adjustment		**Adjustment Multiplier**	**Adjusted**		
	Low	**High**		**Low**	**High**	
Derailment	0.1490	0.2230	1.000	0.1490	0.2230	Log-normal
Collision	0.1210	0.3210	1.000	0.1210	0.3210	Weibull
Fire/Explosion	0.5000	1.0000	1.000	0.5000	1.0000	Uniform
Hway-Rail Cross	0.0590	0.2440	1.000	0.0590	0.2440	Log-normal
Miscellaneous	0.1400	0.4710	1.000	0.1400	0.4710	Log-normal

Table 60: CBR-SpillRISK Release Probability Inputs with Adjustments (Empty Trains): HES						
Accident Type	**Release Probability Per Accident**					**Distribution Type**
	Pre-Adjustment		**Adjustment Multiplier**	**Adjusted**		
	Low	**High**		**Low**	**High**	
Derailment	0.0298	0.0446	1.000	0.0298	0.0446	Log-normal
Collision	0.0242	0.0642	1.000	0.0242	0.0642	Weibull
Fire/Explosion	0.1000	0.2000	1.000	0.1000	0.2000	Uniform
Hway-Rail Cross	0.0118	0.0488	1.000	0.0118	0.0488	Log-normal
Miscellaneous	0.0280	0.0942	1.000	0.0280	0.0942	Log-normal

CBR-SpillRISK Modeling Spill Probability Results for HES

The expected crude-by-rail spill probability distributions per million train-miles as calculated by CBR-SpillRISK (100,000 simulations) are described in Table 61 for loaded crude-by-rail rains with 102 cars (Shell PSR) and in Table 62 for loaded crude-by-rail trains with 120 cars (other facilities in the state). The results for empty crude-by-rail trains (*i.e.*, spills from locomotives only) are shown in Table 63 for the Shell PSR and Table 64 for other facilities.

Table 61: HES Expected Crude-by-Rail Spill Probabilities per Train-Mile (Loaded)–Shell PSR						
Statistical Parameter[258]	**Annual Frequency per Million Train-Miles**					
	Derailment	**Collision**	**Fire/ Explosion**	**Hwy-Rail**	**Misc.**	**Total**
Mean	0.16489	0.01486	0.01835	0.02124	0.00238	**0.22172**
Median	0.16116	0.01411	0.01765	0.01962	0.00232	**0.21486**
Standard Deviation	0.01669	0.00307	0.01135	0.00996	0.00061	**0.04168**

Table 62: HES Expected Crude-by-Rail Spill Probabilities per Train-Mile (Loaded)–Statewide						
Statistical Parameter	**Annual Frequency per Million Train-Miles**					
	Derailment	**Collision**	**Fire/ Explosion**	**Hwy-Rail**	**Misc.**	**Total**
Mean	0.17148	0.01598	0.01901	0.02313	0.00549	**0.23509**
Median	0.16749	0.01520	0.01827	0.02133	0.00536	**0.22765**

[258] Mean = average; median = 50th percentile (half more than this value, half less). Standard deviation is a measure of how spread out the numbers are around the mean.

Standard Deviation	0.06539	0.00318	0.01176	0.01052	0.00197	**0.09282**

Table 63: HES Expected Crude-by-Rail Spill Probabilities per Train-Mile (Empty)–Shell PSR

Statistical Parameter	Annual Frequency per Million Train-Miles					
	Derailment	Collision	Fire/ Explosion	Hwy-Rail	Misc.	Total
Mean	0.01457	0.00186	0.00163	0.00201	0.00279	**0.02286**
Median	0.01402	0.00179	0.00157	0.00186	0.00273	**0.02197**
Standard Deviation	0.00362	0.00036	0.00101	0.00092	0.00070	**0.00661**

Table 64: HES Expected Crude-by-Rail Spill Probabilities per Train-Mile (Empty)–Statewide

Statistical Parameter	Annual Frequency per Million Train-Miles					
	Derailment	Collision	Fire/ Explosion	Hwy-Rail	Misc.	Total
Mean	0.01488	0.00200	0.00179	0.00218	0.00304	**0.02389**
Median	0.01413	0.00193	0.00171	0.00202	0.00297	**0.02276**
Standard Deviation	0.00428	0.00038	0.00110	0.00099	0.00076	**0.00751**

The results in Table 61 through Table 64 provide the number of spills per million train-miles. To calculate the number of spills, the train-mileage needed to be taken into account as in Equation 17.

Equation 17

$$frequency_{spills} = \frac{spills}{year} = \frac{spills}{train-mile} \cdot \frac{train-miles}{year}$$

The train-miles for all of the Washington crude-by-rail facilities (current and proposed) were calculated in Table 8 (Chapter 2). The values incorporated into the spill probability analysis are shown in Table 65.

Table 65: HES Crude-by-Rail Train-Miles for Statewide and Shell PSR

CBR Facilities	Annual Million Train-Miles	
	Loaded Trains	Empty Trains
Current Facilities Only	0.7434	0.5494
All Future Facilities Except Shell PSR (Excluding Current)	1.0961	1.2244
All Future Facilities Including Shell PSR (Excluding Current)	1.3024	1.3904
All Facilities Except Shell PSR (Including Current)	1.8395	1.7738
Shell PSR Only	0.2063	0.1660
All Facilities with Shell PSR (Including Current)	2.0458	1.9398

Based on the crude-by-rail train-miles in Table 65, the expected frequencies of spills (*of any volume*) are shown in Table 66 for loaded trains and Table 67 for empty trains (locomotive diesel fuel spills).[259]

[259] Note that these spills may be of any size, from very small to large. The volume of spillage in these accidents is discussed in Chapter 10. Note also that the "Fire/Explosion" category refers to the original cause of the accident, not the outcome. The numbers shown under this category are not the expected fires or explosions that might occur with

Table 66: HES Expected Annual Frequency of Crude Spills of Any Volume for Loaded Trains				
Crude-by-Rail Facilities	**Accident Type**	**Statistic (Spills per Year)**		
		Mean	**Median**	**Standard Deviation**
Current Facilities Only	**Derailment**	0.12748	0.12451	0.04861
	Collision	0.01188	0.01130	0.00236
	Fire/Explosion	0.01413	0.01358	0.00874
	Hwy-Rail	0.01719	0.01586	0.00782
	Miscellaneous	0.00408	0.00398	0.00146
	Total	**0.17477**	**0.16924**	**0.06900**
All Future Facilities Except Shell PSR (Excluding Current)	**Derailment**	0.18796	0.18359	0.07167
	Collision	0.01752	0.01666	0.00349
	Fire/Explosion	0.02084	0.02003	0.01289
	Hwy-Rail	0.02535	0.02338	0.01153
	Miscellaneous	0.00602	0.00588	0.00216
	Total	**0.25768**	**0.24953**	**0.10174**
All Future Facilities Including Shell PSR (Excluding Current)	**Derailment**	0.22334	0.21814	0.08516
	Collision	0.02081	0.01980	0.00414
	Fire/Explosion	0.02476	0.02379	0.01532
	Hwy-Rail	0.03012	0.02778	0.01370
	Miscellaneous	0.00715	0.00698	0.00257
	Total	**0.30618**	**0.29649**	**0.12089**
All Facilities Except Shell PSR (Including Current)	**Derailment**	0.31544	0.30810	0.12028
	Collision	0.02940	0.02796	0.00585
	Fire/Explosion	0.03497	0.03361	0.02163
	Hwy-Rail	0.04255	0.03924	0.01935
	Miscellaneous	0.01010	0.00986	0.00362
	Total	**0.43245**	**0.41876**	**0.17074**
Shell PSR Only	**Derailment**	0.03402	0.03325	0.00344
	Collision	0.00307	0.00291	0.00063
	Fire/Explosion	0.00379	0.00364	0.00234
	Hwy-Rail	0.00438	0.00405	0.00205
	Miscellaneous	0.00049	0.00048	0.00013
	Total	**0.04574**	**0.04433**	**0.00860**
All Facilities With Shell PSR (Including Current)	**Derailment**	0.35081	0.34265	0.13377
	Collision	0.03269	0.03110	0.00651
	Fire/Explosion	0.03889	0.03738	0.02406
	Hwy-Rail	0.04732	0.04364	0.02152
	Miscellaneous	0.01123	0.01097	0.00403
	Total	**0.48095**	**0.46573**	**0.18989**

a spill. A crude-by-rail unit train derailment that resulted in the release of oil that then ignited would be considered a derailment, not a fire/explosion accident. The topic of the resultant fires and explosions that may occur as a result of a rail accident is analyzed in a separate report (Risknology 2016).

Table 67: HES Expected Annual Frequency of Diesel Spills of Any Volume for Empty Trains				
Crude-by-Rail Facilities	**Accident Type**	**Statistic (Spills per Year)**		
		Mean	**Median**	**Standard Deviation**
Current Facilities Only	**Derailment**	0.00818	0.00776	0.00235
	Collision	0.00110	0.00106	0.00021
	Fire/Explosion	0.00098	0.00094	0.00060
	Hwy-Rail	0.00120	0.00111	0.00054
	Miscellaneous	0.00167	0.00163	0.00042
	Total	**0.01313**	**0.01250**	**0.00413**
All Future Facilities Except Shell PSR (Excluding Current)	**Derailment**	0.01822	0.01730	0.00524
	Collision	0.00245	0.00236	0.00047
	Fire/Explosion	0.00219	0.00209	0.00135
	Hwy-Rail	0.00267	0.00247	0.00121
	Miscellaneous	0.00372	0.00364	0.00093
	Total	**0.02925**	**0.02787**	**0.00920**
All Future Facilities Including Shell PSR (Excluding Current)	**Derailment**	0.02069	0.01965	0.00595
	Collision	0.00278	0.00268	0.00053
	Fire/Explosion	0.00249	0.00238	0.00153
	Hwy-Rail	0.00303	0.00281	0.00138
	Miscellaneous	0.00423	0.00413	0.00106
	Total	**0.03322**	**0.03165**	**0.01044**
All Facilities Except Shell PSR (Including Current)	**Derailment**	0.02639	0.02506	0.00759
	Collision	0.00355	0.00342	0.00067
	Fire/Explosion	0.00318	0.00303	0.00195
	Hwy-Rail	0.00387	0.00358	0.00176
	Miscellaneous	0.00539	0.00527	0.00135
	Total	**0.04238**	**0.04037**	**0.01332**
Shell PSR Only	**Derailment**	0.00242	0.00233	0.00060
	Collision	0.00031	0.00030	0.00006
	Fire/Explosion	0.00027	0.00026	0.00017
	Hwy-Rail	0.00033	0.00031	0.00015
	Miscellaneous	0.00046	0.00045	0.00012
	Total	**0.00379**	**0.00365**	**0.00110**
All Facilities With Shell PSR (Including Current)	**Derailment**	0.02886	0.02741	0.00830
	Collision	0.00388	0.00374	0.00074
	Fire/Explosion	0.00347	0.00332	0.00213
	Hwy-Rail	0.00423	0.00392	0.00192
	Miscellaneous	0.00590	0.00576	0.00147
	Total	**0.04634**	**0.04415**	**0.01457**

Table 68: HES Expected Return Years of Crude Spills of Any Volume for Loaded Trains				
Crude-by-Rail Facilities	**Accident Type**	**Statistic (Return Years)**		
		Mean	**Median**	**Standard Deviation**
Current Facilities Only	**Derailment**	7.84	8.03	20.57
	Collision	84.18	88.50	423.73
	Fire/Explosion	70.77	73.64	114.42
	Hwy-Rail	58.17	63.05	127.88
	Miscellaneous	245.10	251.26	684.93
	Total	**5.72**	**5.91**	**14.49**
All Future Facilities Except Shell PSR (Excluding Current)	**Derailment**	5.32	5.45	13.95
	Collision	57.08	60.02	286.53
	Fire/Explosion	47.98	49.93	77.58
	Hwy-Rail	39.45	42.77	86.73
	Miscellaneous	166.11	170.07	462.96
	Total	**3.88**	**4.01**	**9.83**
All Future Facilities Including Shell PSR (Excluding Current)	**Derailment**	4.48	4.58	11.74
	Collision	48.05	50.51	241.55
	Fire/Explosion	40.39	42.03	65.27
	Hwy-Rail	33.20	36.00	72.99
	Miscellaneous	139.86	143.27	389.11
	Total	**3.27**	**3.37**	**8.27**
All Facilities Except Shell PSR (Including Current)	**Derailment**	3.17	3.25	8.31
	Collision	34.01	35.77	170.94
	Fire/Explosion	28.60	29.75	46.23
	Hwy-Rail	23.50	25.48	51.68
	Miscellaneous	99.01	101.42	276.24
	Total	**2.31**	**2.39**	**5.86**
Shell PSR Only	**Derailment**	29.39	30.08	290.70
	Collision	325.73	343.64	1,587.30
	Fire/Explosion	263.85	274.73	427.35
	Hwy-Rail	228.31	246.91	487.80
	Miscellaneous	2,040.82	2,083.33	7,692.31
	Total	**21.86**	**22.56**	**116.28**
All Facilities With Shell PSR (Including Current)	**Derailment**	2.85	2.92	7.48
	Collision	30.59	32.15	153.61
	Fire/Explosion	25.71	26.75	41.56
	Hwy-Rail	21.13	22.91	46.47
	Miscellaneous	89.05	91.16	248.14
	Total	**2.08**	**2.15**	**5.27**

Table 69: HES Expected Return Years of Diesel Spills of Any Volume for Empty Trains				
Crude-by-Rail Facilities	**Accident Type**	**Statistic (Return Years)**		
		Mean	**Median**	**Standard Deviation**
Current Facilities Only	**Derailment**	122.25	128.87	425.53
	Collision	909.09	943.40	4,761.90
	Fire/Explosion	1,020.41	1,063.83	1,666.67
	Hwy-Rail	833.33	900.90	1,851.85
	Miscellaneous	598.80	613.50	2,380.95
	Total	**76.16**	**80.00**	**242.13**
All Future Facilities Except Shell PSR (Excluding Current)	**Derailment**	54.88	57.80	190.84
	Collision	408.16	423.73	2,127.66
	Fire/Explosion	456.62	478.47	740.74
	Hwy-Rail	374.53	404.86	826.45
	Miscellaneous	268.82	274.73	1,075.27
	Total	**34.19**	**35.88**	**108.70**
All Future Facilities Including Shell PSR (Excluding Current)	**Derailment**	48.33	50.89	168.07
	Collision	359.71	373.13	1,886.79
	Fire/Explosion	401.61	420.17	653.59
	Hwy-Rail	330.03	355.87	724.64
	Miscellaneous	236.41	242.13	943.40
	Total	**30.10**	**31.60**	**95.79**
All Facilities Except Shell PSR (Including Current)	**Derailment**	37.89	39.90	131.75
	Collision	281.69	292.40	1,492.54
	Fire/Explosion	314.47	330.03	512.82
	Hwy-Rail	258.40	279.33	568.18
	Miscellaneous	185.53	189.75	740.74
	Total	**23.60**	**24.77**	**75.08**
Shell PSR Only	**Derailment**	413.22	429.18	1,666.67
	Collision	3,225.81	3,333.33	16,666.67
	Fire/Explosion	3,703.70	3,846.15	5,882.35
	Hwy-Rail	3,030.30	3,225.81	6,666.67
	Miscellaneous	2,173.91	2,222.22	8,333.33
	Total	**263.85**	**273.97**	**909.09**
All Facilities With Shell PSR (Including Current)	**Derailment**	34.65	36.48	120.48
	Collision	257.73	267.38	1,351.35
	Fire/Explosion	288.18	301.20	469.48
	Hwy-Rail	236.41	255.10	520.83
	Miscellaneous	169.49	173.61	680.27
	Total	**21.58**	**22.65**	**68.63**

HES spill frequency results are in Table 70 and Table 71. For the Shell PSR, the HES for the average expected number of annual crude spills is 0.046, or one spill every 22 years.

Table 70: HES Crude Spill Frequencies for Crude-by-Rail Transport in Washington (Loaded Trains)				
Estimate	**Current**	**Shell PSR**	**Other Future**	**All Facilities**
Mean Annual Spill Frequency	0.17	0.046	0.26	0.48
Mean Return Period (Years)	6	22	3.9	2.1

Table 71: HES Diesel Spill Frequencies for Crude-by-Rail Transport in Washington (Empty Trains)				
Estimate	**Current**	**Shell PSR**	**Other Future**	**All Facilities**
Mean Annual Spill Frequency	0.013	0.0038	0.029	0.046
Mean Return Period (Years)	76	264	34	22

LES Probability Inputs CBR-SpillRISK with Crude-by-Rail Adjustments

The rail accident-related inputs into CBR-SpillRISK model for the Lower Estimate of Spills (LES) are in Table 72 and Table 73. Pre-adjustment accident rates are the highest and lowest rates in Table 16 for 1995–2015, a lower accident rate than applied for the HES. Accident numbers per million train-miles were apportioned into loaded and empty trains based on Table 24.[260] The LES tank car release (spill) probability inputs are in Table 74 for loaded trains and Table 75 for empty trains. Release probabilities are based on the data in Table 44 for 1985–2015, with adjustments based Table 50. There were no adjustments for locomotive spills because none of the changes to tank cars would affect those probabilities. Release probabilities were the same for 102- and 120-car trains. There are no known estimates for release probability for locomotives. Since the fuel tanks on locomotives are typically about 20 percent the size of tank cars, it was assumed that they have a 20 percent chance of being breached relative to tank cars.[261]

Table 72: CBR-SpillRISK Model Rail Accident Inputs with Adjustments (Loaded Trains): LES								
Accident Type	**Accident Probability Per Million Train-Miles**							**Distribution Type**
	Pre-Adjustment		**Adjustment**			**Adjusted**		
	Low	**High**	**Train Length (cars)**	**Multipliers**		**Low**	**High**	
				Min.	**Max.**			
Derailment	0.4403	0.7016	102 (Shell PSR)	0.749	0.287	0.1264	0.5255	Log-normal
			120 (statewide)	0.872	0.410	0.1805	0.6118	
Collision	0.0123	0.0946	102 (Shell PSR)	0.749	0.287	0.0035	0.0709	Weibull
			120 (statewide)	0.872	0.410	0.0050	0.0825	
Fire/Explosion	0.0000	0.0116	102 (Shell PSR)	0.749	0.287	0.0000	0.0087	Uniform
			120 (statewide)	0.872	0.410	0.0000	0.0101	
Hway-Rail Cross	0.0541	0.1338	102 (Shell PSR)	0.749	0.287	0.0155	0.1002	Uniform
			120 (statewide)	0.872	0.410	0.0222	0.1167	
Miscellaneous	0.0543	0.1284	102 (Shell PSR)	0.749	0.287	0.0156	0.0962	Uniform

[260] Calculations for low and high pre-adjustment accident rates were taken from lowest and highest accident rates in Table 16 between 1985 and 2015, e.g., for derailments, the lowest accident rate was 0.6475 (national 2005–2015). That rate was then apportioned between loaded and empty trains based on percentages in Table 24.

[261] Pre-adjustment release probabilities were derived from Table 44. (Percentages were converted into decimals.) Values for 1985–2015 were selected, e.g., for derailments the 14.9% was assumed to be the lower probability that a tank car would breach. 22.3% was used for the higher release probability.

			120 (statewide)	0.872	0.410	0.0223	0.1120	
			120 (statewide)	0.872	0.410	0.0105	0.0527	

Table 73: CBR-SpillRISK Model Rail Accident Inputs with Adjustments (Empty Trains): LES

Accident Type	Accident Probability Per Million Train-Miles							Distribution Type
	Pre-Adjustment		Adjustment			Adjusted		
	Low	High	Train Length (cars)	Multiplier		Low	High	
				Min.	Max.			
Derailment	0.2072	0.3302	102 (Shell PSR)	0.749	0.287	0.0595	0.2473	Log-normal
			120 (statewide)	0.872	0.410	0.0850	0.2879	
Collision	0.0058	0.0445	102 (Shell PSR)	0.749	0.287	0.0017	0.0333	Weibull
			120 (statewide)	0.872	0.410	0.0024	0.0388	
Fire/Explosion	0.0000	0.0055	102 (Shell PSR)	0.749	0.287	0.0000	0.0041	Uniform
			120 (statewide)	0.872	0.410	0.0000	0.0048	
Hway-Rail Cross	0.0254	0.0630	102 (Shell PSR)	0.749	0.287	0.0073	0.0472	Uniform
			120 (statewide)	0.872	0.410	0.0104	0.0549	
Miscellaneous	0.0256	0.0604	102 (Shell PSR)	0.749	0.287	0.0073	0.0452	Uniform

Table 74: CBR-SpillRISK Release Probability Inputs with Adjustments (Loaded Trains): LES

Accident Type	Release Probability Per Accident						Distribution Type
	Pre-Adjustment		Adjustment Multiplier		Adjusted		
	Low	High	Min.	Max.	Low	High	
Derailment	0.1490	0.2230	0.570	0.278	0.0414	0.1271	Log-normal
Collision	0.1210	0.3210	0.570	0.278	0.0336	0.1830	Weibull
Fire/Explosion	0.5000	1.0000	0.880	0.880	0.4400	0.8800	Uniform
Hway-Rail Cross	0.0590	0.2440	0.570	0.278	0.0164	0.1391	Log-normal
Miscellaneous	0.1400	0.4710	0.570	0.278	0.0389	0.2685	Log-normal

Table 75: CBR-SpillRISK Release Probability Inputs with Adjustments (Empty Trains): LES

Accident Type	Release Probability Per Accident						Distribution Type
	Pre-Adjustment		Adjustment Multiplier		Adjusted		
	Low	High	Min.	Max.	Low	High	
Derailment	0.0298	0.0446	1.0	1.0	0.0298	0.0446	Log-normal
Collision	0.0242	0.0642	1.0	1.0	0.0242	0.0642	Weibull
Fire/Explosion	0.1000	0.2000	1.0	1.0	0.1000	0.2000	Uniform
Hway-Rail Cross	0.0118	0.0488	1.0	1.0	0.0118	0.0488	Log-normal
Miscellaneous	0.0280	0.0942	1.0	1.0	0.0280	0.0942	Log-normal

CBR-SpillRISK Modeling Spill Probability Results for LES

The expected crude-by-rail spill probability distributions per million train-miles as calculated by CBR-SpillRISK (100,000 simulations) are in Table 76 for loaded crude-by-rail rains with 102 cars (Shell PSR)

and in Table 77 for loaded trains with 120 cars (other facilities). The results in Table 80–Table 83 provide the number of spills per million train-miles. Based on the crude-by-rail train-miles in Table 65, the expected frequencies of spills (*of any volume*) are in Table 80 for loaded trains and Table 81 for empty trains (locomotives). The results for empty crude-by-rail trains are in Table 78 for the Shell PSR and Table 79 for other facilities.

Table 76: LES Expected Crude-by-Rail Spill Probabilities per Train-Mile (Loaded)–Shell PSR

Statistical Parameter	Annual Frequency per Million Train-Miles					
	Derailment	Collision	Fire/ Explosion	Hwy-Rail	Misc.	Total
Mean	0.00992	0.00063	0.00289	0.00859	0.00447	**0.02650**
Median	0.00875	0.00046	0.00278	0.00735	0.00409	**0.02343**
Standard Deviation	0.00510	0.00058	0.00177	0.00538	0.00252	**0.01535**

Table 77: LES Expected Crude-by-Rail Spill Probabilities per Train-Mile (Loaded)–Statewide

Statistical Parameter	Annual Frequency per Million Train-Miles					
	Derailment	Collision	Fire/ Explosion	Hwy-Rail	Misc.	Total
Mean	0.01397	0.00079	0.00335	0.01032	0.00536	**0.03379**
Median	0.01139	0.00059	0.00323	0.00894	0.00491	**0.02906**
Standard Deviation	0.09878	0.00071	0.00206	0.00619	0.00286	**0.11060**

Table 78: LES Expected Crude-by-Rail Spill Probabilities per Train-Mile (Empty)–Shell PSR

Statistical Parameter	Annual Frequency per Million Train-Miles					
	Derailment	Collision	Fire/ Explosion	Hwy-Rail	Misc.	Total
Mean	0.00248	0.00031	0.00031	0.00160	0.00118	**0.00588**
Median	0.00227	0.00023	0.00030	0.00144	0.00116	**0.00540**
Standard Deviation	0.00097	0.00025	0.00019	0.00086	0.00053	**0.00280**

Table 79: LES Expected Crude-by-Rail Spill Probabilities per Train-Mile (Empty)–Statewide

Statistical Parameter	Annual Frequency per Million Train-Miles					
	Derailment	Collision	Fire/ Explosion	Hwy-Rail	Misc.	Total
Mean	0.00309	0.00237	0.00036	0.00193	0.00142	**0.00917**
Median	0.00266	0.00166	0.00035	0.00175	0.00140	**0.00782**
Standard Deviation	0.00412	0.00231	0.00022	0.00099	0.00060	**0.00824**

Table 80: LES Expected Annual Frequency of Crude Spills of Any Volume for Loaded Trains				
Crude-by-Rail Facilities	**Accident Type**	**Statistic (Spills per Year)**		
		Mean	**Median**	**Standard Deviation**
Current Facilities Only	**Derailment**	0.01039	0.00847	0.07343
	Collision	0.00059	0.00044	0.00053
	Fire/Explosion	0.00249	0.00240	0.00153
	Hwy-Rail	0.00767	0.00665	0.00460
	Miscellaneous	0.00398	0.00365	0.00213
	Total	**0.02512**	**0.02160**	**0.08222**
All Future Facilities Except Shell PSR (Excluding Current)	**Derailment**	0.01531	0.01248	0.10827
	Collision	0.00087	0.00065	0.00078
	Fire/Explosion	0.00367	0.00354	0.00226
	Hwy-Rail	0.01131	0.00980	0.00678
	Miscellaneous	0.00588	0.00538	0.00313
	Total	**0.03704**	**0.03185**	**0.12123**
All Future Facilities Including Shell PSR (Excluding Current)	**Derailment**	0.01819	0.01483	0.12865
	Collision	0.00103	0.00077	0.00092
	Fire/Explosion	0.00436	0.00421	0.00268
	Hwy-Rail	0.01344	0.01164	0.00806
	Miscellaneous	0.00698	0.00639	0.00372
	Total	**0.04401**	**0.03785**	**0.14405**
All Facilities Except Shell PSR (Including Current)	**Derailment**	0.02570	0.02095	0.18171
	Collision	0.00145	0.00109	0.00131
	Fire/Explosion	0.00616	0.00594	0.00379
	Hwy-Rail	0.01898	0.01645	0.01139
	Miscellaneous	0.00986	0.00903	0.00526
	Total	**0.06216**	**0.05346**	**0.20345**
Shell PSR Only	**Derailment**	0.00205	0.00181	0.00105
	Collision	0.00013	0.00009	0.00012
	Fire/Explosion	0.00060	0.00057	0.00037
	Hwy-Rail	0.00177	0.00152	0.00111
	Miscellaneous	0.00092	0.00084	0.00052
	Total	**0.00547**	**0.00483**	**0.00317**
All Facilities With Shell PSR (Including Current)	**Derailment**	0.02858	0.02330	0.20208
	Collision	0.00162	0.00121	0.00145
	Fire/Explosion	0.00685	0.00661	0.00421
	Hwy-Rail	0.02111	0.01829	0.01266
	Miscellaneous	0.01097	0.01004	0.00585
	Total	**0.06913**	**0.05945**	**0.22627**

Table 81: LES Expected Annual Frequency of Diesel Spills of Any Volume for Empty Trains				
Crude-by-Rail Facilities	**Accident Type**	**Statistic (Spills per Year)**		
		Mean	**Median**	**Standard Deviation**
Current Facilities Only	**Derailment**	0.00170	0.00146	0.00226
	Collision	0.00130	0.00091	0.00127
	Fire/Explosion	0.00020	0.00019	0.00012
	Hwy-Rail	0.00106	0.00096	0.00054
	Miscellaneous	0.00078	0.00077	0.00033
	Total	**0.00504**	**0.00430**	**0.00453**
All Future Facilities Except Shell PSR (Excluding Current)	**Derailment**	0.00378	0.00326	0.00504
	Collision	0.00290	0.00203	0.00283
	Fire/Explosion	0.00044	0.00043	0.00027
	Hwy-Rail	0.00236	0.00214	0.00121
	Miscellaneous	0.00174	0.00171	0.00073
	Total	**0.01123**	**0.00957**	**0.01009**
All Future Facilities Including Shell PSR (Excluding Current)	**Derailment**	0.00430	0.00370	0.00573
	Collision	0.00330	0.00231	0.00321
	Fire/Explosion	0.00050	0.00049	0.00031
	Hwy-Rail	0.00268	0.00243	0.00138
	Miscellaneous	0.00197	0.00195	0.00083
	Total	**0.01275**	**0.01087**	**0.01146**
All Facilities Except Shell PSR (Including Current)	**Derailment**	0.00548	0.00472	0.00731
	Collision	0.00420	0.00294	0.00410
	Fire/Explosion	0.00064	0.00062	0.00039
	Hwy-Rail	0.00342	0.00310	0.00176
	Miscellaneous	0.00252	0.00248	0.00106
	Total	**0.01627**	**0.01387**	**0.01462**
Shell PSR Only	**Derailment**	0.00041	0.00038	0.00016
	Collision	0.00005	0.00004	0.00004
	Fire/Explosion	0.00005	0.00005	0.00003
	Hwy-Rail	0.00027	0.00024	0.00014
	Miscellaneous	0.00020	0.00019	0.00009
	Total	**0.00098**	**0.00090**	**0.00046**
All Facilities With Shell PSR (Including Current)	**Derailment**	0.00599	0.00516	0.00799
	Collision	0.00460	0.00322	0.00448
	Fire/Explosion	0.00070	0.00068	0.00043
	Hwy-Rail	0.00374	0.00339	0.00192
	Miscellaneous	0.00275	0.00272	0.00116
	Total	**0.01779**	**0.01517**	**0.01598**

Table 82: LES Expected Return Years of Crude Spills of Any Volume for Loaded Trains				
Crude-by-Rail Facilities	**Accident Type**	**Statistic (Return Years)**		
		Mean	**Median**	**Standard Deviation**
Current Facilities Only	**Derailment**	96.25	118.06	13.62
	Collision	1,694.92	2,272.73	1,886.79
	Fire/Explosion	401.61	416.67	653.59
	Hwy-Rail	130.38	150.38	217.39
	Miscellaneous	251.26	273.97	469.48
	Total	**39.81**	**46.30**	**12.16**
All Future Facilities Except Shell PSR (Excluding Current)	**Derailment**	65.32	80.13	9.24
	Collision	1,149.43	1,538.46	1,282.05
	Fire/Explosion	272.48	282.49	442.48
	Hwy-Rail	88.42	102.04	147.49
	Miscellaneous	170.07	185.87	319.49
	Total	**27.00**	**31.40**	**8.25**
All Future Facilities Including Shell PSR (Excluding Current)	**Derailment**	54.98	67.43	7.77
	Collision	970.87	1,298.70	1,086.96
	Fire/Explosion	229.36	237.53	373.13
	Hwy-Rail	74.40	85.91	124.07
	Miscellaneous	143.27	156.49	268.82
	Total	**22.72**	**26.42**	**6.94**
All Facilities Except Shell PSR (Including Current)	**Derailment**	38.91	47.73	5.50
	Collision	689.66	917.43	763.36
	Fire/Explosion	162.34	168.35	263.85
	Hwy-Rail	52.69	60.79	87.80
	Miscellaneous	101.42	110.74	190.11
	Total	**16.09**	**18.71**	**4.92**
Shell PSR Only	**Derailment**	487.80	552.49	952.38
	Collision	7,692.31	11,111.11	8,333.33
	Fire/Explosion	1,666.67	1,754.39	2,702.70
	Hwy-Rail	564.97	657.89	900.90
	Miscellaneous	1,086.96	1,190.48	1,923.08
	Total	**182.82**	**207.04**	**315.46**
All Facilities With Shell PSR (Including Current)	**Derailment**	34.99	42.92	4.95
	Collision	617.28	826.45	689.66
	Fire/Explosion	145.99	151.29	237.53
	Hwy-Rail	47.37	54.67	78.99
	Miscellaneous	91.16	99.60	170.94
	Total	**14.47**	**16.82**	**4.42**

Table 83: LES Expected Return Years of Diesel Spills of Any Volume for Empty Trains				
Crude-by-Rail Facilities	**Accident Type**	**Statistic (Return Years)**		
		Mean	**Median**	**Standard Deviation**
Current Facilities Only	**Derailment**	588.24	684.93	442.48
	Collision	769.23	1,098.90	787.40
	Fire/Explosion	5,000.00	5,263.16	8,333.33
	Hwy-Rail	943.40	1,041.67	1,851.85
	Miscellaneous	1,282.05	1,298.70	3,030.30
	Total	**198.41**	**232.56**	**220.75**
All Future Facilities Except Shell PSR (Excluding Current)	**Derailment**	264.55	306.75	198.41
	Collision	344.83	492.61	353.36
	Fire/Explosion	2,272.73	2,325.58	3,703.70
	Hwy-Rail	423.73	467.29	826.45
	Miscellaneous	574.71	584.80	1,369.86
	Total	**89.05**	**104.49**	**99.11**
All Future Facilities Including Shell PSR (Excluding Current)	**Derailment**	232.56	270.27	174.52
	Collision	303.03	432.90	311.53
	Fire/Explosion	2,000.00	2,040.82	3,225.81
	Hwy-Rail	373.13	411.52	724.64
	Miscellaneous	**507.61**	**512.82**	**1,204.82**
	Total	78.43	92.00	87.26
All Facilities Except Shell PSR (Including Current)	**Derailment**	182.48	211.86	136.80
	Collision	238.10	340.14	243.90
	Fire/Explosion	1,562.50	1,612.90	2,564.10
	Hwy-Rail	292.40	322.58	568.18
	Miscellaneous	396.83	403.23	943.40
	Total	**61.46**	**72.10**	**68.40**
Shell PSR Only	**Derailment**	2,439.02	2,631.58	6,250.00
	Collision	20,000.00	25,000.00	25,000.00
	Fire/Explosion	20,000.00	20,000.00	33,333.33
	Hwy-Rail	3,703.70	4,166.67	7,142.86
	Miscellaneous	5,000.00	5,263.16	11,111.11
	Total	**1,020.41**	**1,111.11**	**2,173.91**
All Facilities With Shell PSR (Including Current)	**Derailment**	166.94	193.80	125.16
	Collision	217.39	310.56	223.21
	Fire/Explosion	1,428.57	1,470.59	2,325.58
	Hwy-Rail	267.38	294.99	520.83
	Miscellaneous	363.64	367.65	862.07
	Total	**56.21**	**65.92**	**62.58**

The mean spill probability (frequency) results based on the LES criteria are summarized for loaded trains in Table 84 and for empty trains (i.e., locomotive spills only) in Table 85. All spill causes (accident types)

were combined. *Note that these spills may be of any size, from very small to large. The volume of spillage in these accidents is discussed in Chapter 10.* The LES results indicate that for the Shell PSR, the average expected number of annual crude spills is 0.001, or one spill every 1,000 years.

Table 84: LES Crude Spill Frequencies for Crude-by-Rail Transport in Washington (Loaded Trains)

Estimate	Current	Shell PSR	Other Future	All Facilities
Mean Annual Spill Frequency	0.025	0.0055	0.037	0.069
Mean Return Period (Years)	40	180	27	14

Table 85: LES Diesel Spill Frequencies for Crude-by-Rail Transport in Washington (Empty Trains)

Estimate	Current	Shell PSR	Other Future	All Facilities
Mean Annual Spill Frequency	0.0050	0.00098	0.011	0.018
Mean Return Period (Years)	198	1,000	89	56

Summary of Project Annual Spill Frequencies

The two estimates of annual spill frequencies (or annual probabilities of spills) for the Shell PSR and the other current and potential future facilities are compared in Figure 59. The spill projections for Shell PSR alone are shown in Figure 60. *Note that these are spills of any size, not necessarily large spills.*

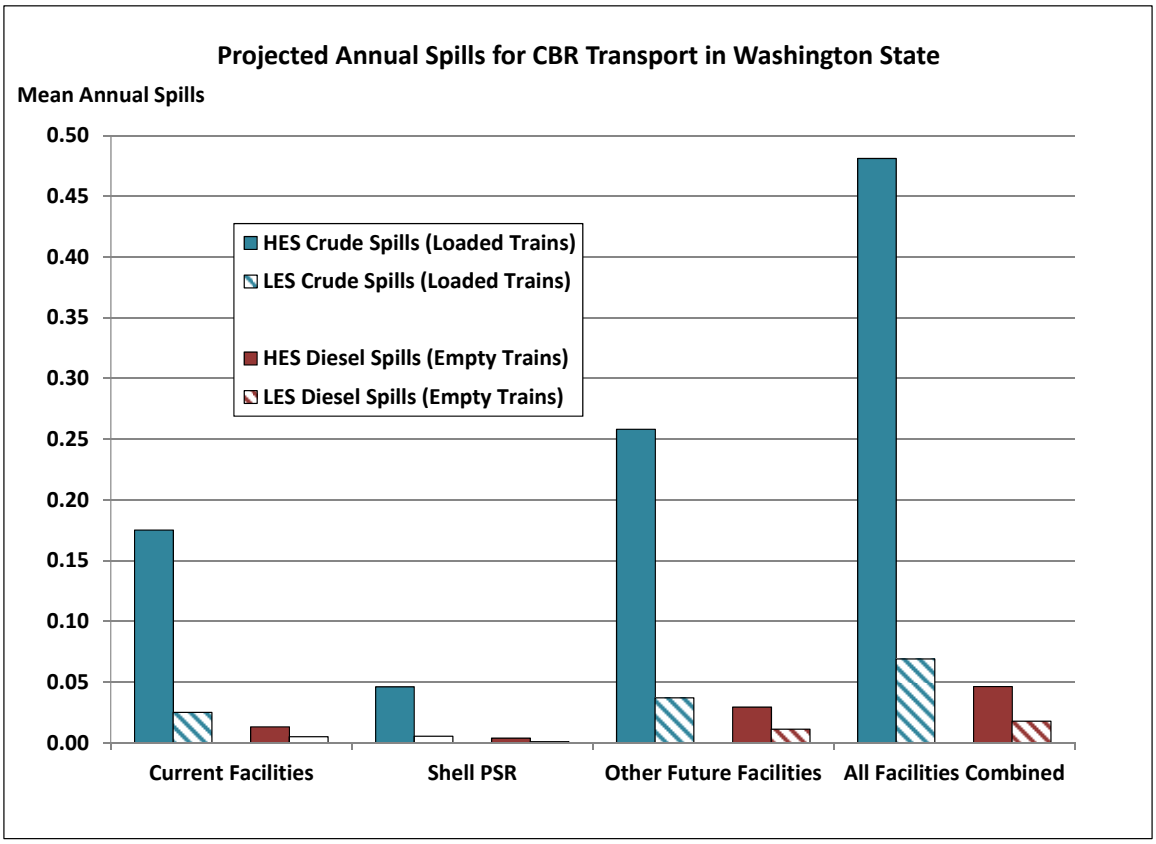


Figure 59: HES and LES Projected Annual Crude-by-Rail Spill Frequencies for All Facilities

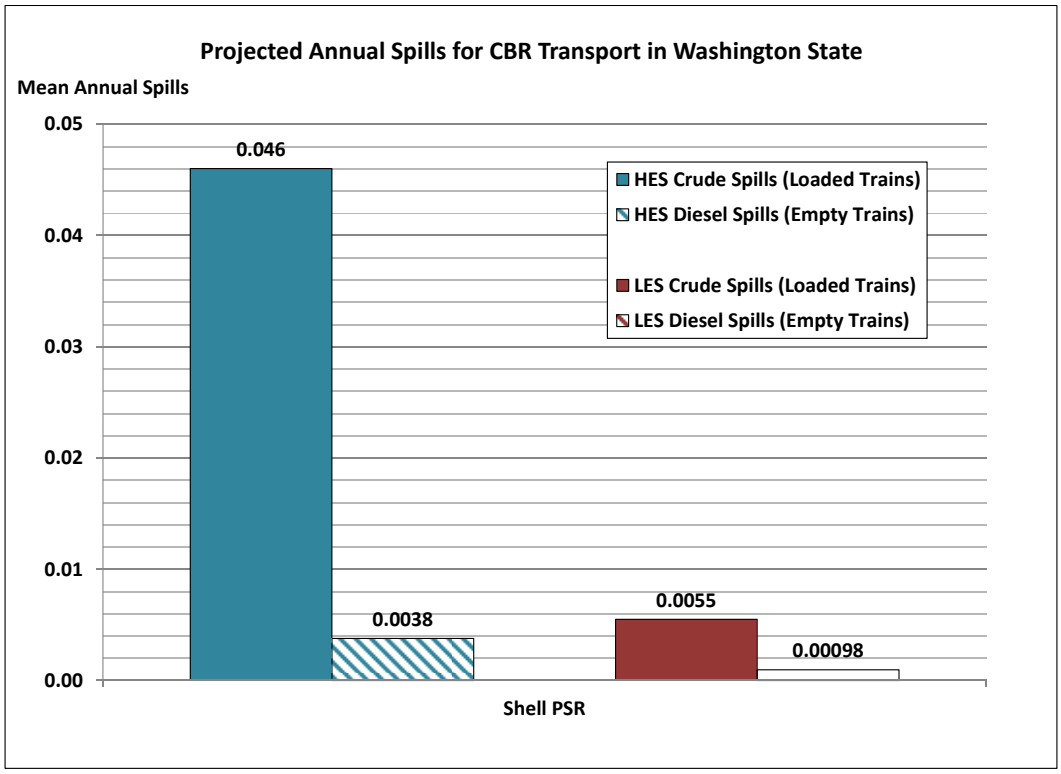


Figure 60: HES and LES Projected Annual Crude-by-Rail Spill Frequencies for Shell PSR

The relative increases in crude-by- rail spills that might occur with the proposed Shell PSR crude-by-rail transport project over various baseline spills are in Table 86, based on the HES methodology, and Table 87, based on the LES methodology. *Note that these are spills of any size, not necessarily large spills.*

Table 86: Relative Increase in Spill Frequency with Shell PSR Crude-by-Rail Traffic–HES

Facility Group	Estimated Baseline Annual Spills	Estimated Annual Spills with Shell PSR	Percent Increase
Current Facilities	0.175	0.221	26%
Other Future Facilities (w/o Shell PSR)	0.258	0.304	18%
Current + Other Future Facilities (w/o Shell PSR)	0.433	0.479	11%

Table 87: Relative Increase in Spill Frequency with Shell PSR Crude-by-Rail Traffic–LES

Facility Group	Estimated Baseline Annual Spills	Estimated Annual Spills with Shell PSR	Percent Increase
Current Facilities	0.0251	0.0306	22%
Other Future Facilities (w/o Shell PSR)	0.0370	0.0425	15%
Current + Other Future Facilities (w/o Shell PSR)	0.0621	0.0676	9%

Chapter 10: Crude-by-Rail Spill Volume Model (CBR-SpillRISK-V)

The second part of the modeling involved deriving the probability distribution of potential spill volumes. Assuming that a spill occurs, the volume can range from very small up to a much larger, or potentially worst-case, discharge. For a loaded crude-by-rail unit train, the maximum spillage is based on the number of tank cars and the volume to which each tank car is loaded. For HES, a tank car volume of 690 bbl was assumed (DOT-111 car), while for LES, a tank car volume of 650 bbl was assumed (DOT-117 car).

Spill Volume Model Design

The spill volume calculation involved determining the distribution of probabilities that varying numbers of tank cars will have releases in the event of an accident. The model, CBR-SpillRISK-V, was based on Equation 18.

Equation 18

$$Volume_{spill} = N_{total} \cdot P_{involvement} \cdot Volume_{car} \cdot \%Outflow$$

Where, N_{total} = total number of tank cars
$P_{involvment}$ = percent tank cars involved in accident (derailed or otherwise damaged)
$Volume_{car}$ = volume content of tank car
$\%Outflow$ = percentage of release of tank car contents

Spill Volume Inputs to CBR-SpillRISK-V with Adjustments

Each of the variables has a distribution of values associated with it, as shown in Table 88 for loaded trains. The primary difference between the Shell PSR and the All Crude-by-Rail Facilities category is that the Shell PSR crude-by-rail unit trains would be limited to 102 cars, whereas the other facilities may conceivably have train lengths of 100 to 120 cars.

Table 88: CBR-SpillRISK-V Inputs: Loaded Trains

Variable	Accident Type	Washington Statewide			Shell PSR Only		
		Value(s)		Distribution Type[262]	Value(s)		Distribution Type
		Low	High		Low	High	
Total Car Number	**-**	100	120	Uniform	102	102	Uniform
Volume/Car (bbl)	**-**	650	675.5	Log-normal	650	675.5	Log-normal
% Cars Involved[263]	**Derailment**	0%	100%	Log-normal	0%	100%	Log-normal
% Outflow/Car	**Derailment**	5%	100%	Triangular/min	5%	100%	Triangular/min
% Cars Involved	**Collision**	0%	50%	Log-normal	0%	50%	Log-normal
% Outflow/Car	**Collision**	5%	100%	Triangular/min	5%	100%	Triangular/min
% Cars Involved	**Fire/Explosion**	0%	20%	Log-normal	0%	20%	Log-normal
% Outflow/Car	**Fire/Explosion**	1%	100%	Triangular-max	1%	100%	Triangular-max
% Cars Involved	**Hway-Rail**	0%	10%	Log-normal	0%	10%	Log-normal
% Outflow/Car	**Hway-Rail**	5%	100%	Triangular-min	5%	100%	Triangular/min
% Cars Involved	**Misc.**	0%	50%	Log-normal	0%	50%	Log-normal

[262] Triangular with minimum skew means that most of the values are high and there is a tail towards the lower end. A maximum skew is the opposite with most of the values being low and a tail towards to higher end.
[263] Based on data in Table 52 and Table 53.

Table 88: CBR-SpillRISK-V Inputs: Loaded Trains							
Variable	**Accident Type**	**Washington Statewide**			**Shell PSR Only**		
		Value(s)		**Distribution**	**Value(s)**		**Distribution**
% Outflow/Car	**Misc.**	5%	100%	Triangular/min	5%	100%	Triangular/min

Input values for empty trains (*i.e.*, locomotive spills) are shown in Table 89. The inputs were the same for the PSR as for the other facilities because there would be no expected differences in the locomotives used and no particular effect of train length. The potential for variations in the number of locomotives was taken into account in the modeling. Since the locomotives are usually in groups with two or three at the front of the train and two or three toward the back of the train, it is unlikely that both ends of the train would be involved in an accident.

Table 89: CBR-SpillRISK-V Inputs: Empty Trains (Locomotives Only)				
Variable	**Accident Type**	**Value(s)**		**Distribution Type**
		Low	**High**	
Total Locomotive Number	-	4	6	Triangular
Volume/Locomotive (bbl)[264]	-	65	131	Uniform
% Locomotives Involved	**All Types**	20%	60%	Log-normal
% Outflow/Locomotive		1%	100%	Log-normal

CBR-SpillRISK-V Modeling Results

A total of 500,000 simulations of CBR-SpillRISK-V were run for each of the accident types based on the criteria in Table 88 for the Shell PSR and all current and proposed future crude-by-rail facilities statewide combined. All accident types (derailment, collision, fire/explosion, highway-rail, and miscellaneous) were combined based on the relative proportions of incident types during 2005–2015 (Table 12). These data were applied because these were determined to most closely represent the number of incidents that might be expected to be experienced in the future.

The primary difference between the Shell PSR and the All Crude-by-Rail Facilities category is that the proposed Shell PSR crude-by-rail unit trains would be limited to 102 cars, whereas the other facilities may conceivably have train lengths of 100 to 120 cars.

The HES estimate for the expected crude-by-rail spill volume probability distribution for loaded trains is described in Table 90 for the Shell PSR alone and for all current and proposed future crude-by-rail facilities statewide combined. The LES estimate is shown in Table 91. Because of the somewhat higher volume in a DOT-111 tank car compared with a DOT-117 car, the volumes for HES are somewhat higher. Figure 61 and Figure 62 show the distributions for the LES. The HES volumes are about six percent larger.

Note that locomotive spills can occur from loaded trains as well, but it is assumed that that spillage would be minor relative to the spillage of crude oil from tank cars. The largest predicted spill from a locomotive (290 bbl) is at about the 1st percentile of volume for crude oil.

[264] Typical diesel locomotive has a fuel capacity of 131 bbl. Low volume is based on half-full fuel tanks.

Table 90: Expected CBR Spill Volume per Incident (Loaded Trains)–HES				
Statistical Parameter	**Shell PSR Only**		**All Crude-by-Rail Facilities**	
	Spill Volume (bbl)	**Tank Car Equivalent[265]**	**Spill Volume (bbl)**	**Tank Car Equivalent**
Mean	11,144	16.2	11,945	17.3
Median	9,220	13.4	9,851	14.3
Standard Deviation	7,752	-	8,389	-
Mean Standard Error[266]	11	-	12	-
0% Percentile	264	0.4	277	0.4
10% Percentile	2,885	4.2	3,036	4.4
20% Percentile	4,229	6.1	4,478	6.5
30% Percentile	5,695	8.3	6,056	8.8
40% Percentile	7,343	10.6	7,829	11.3
50% Percentile	9,220	13.4	9,851	14.3
60% Percentile	11,417	16.5	12,215	17.7
70% Percentile	14,050	20.4	15,058	21.8
80% Percentile	17,464	25.3	18,741	27.2
90% Percentile	22,519	32.6	24,234	35.1
100% Percentile	47,189	68.4	53,288	77.2

Table 91: Expected CBR Spill Volume per Incident (Loaded Trains)–LES				
Statistical Parameter	**Shell PSR Only**		**All Crude-by-Rail Facilities**	
	Spill Volume (bbl)	**Tank Car Equivalent[267]**	**Spill Volume (bbl)**	**Tank Car Equivalent**
Mean	10,498	16.2	11,253	17.3
Median	8,686	13.4	9,280	14.3
Standard Deviation	7,303	-	7,903	-
Mean Standard Error	10.33	-	11.18	-
0% Percentile	249	0.4	261	0.4
10% Percentile	2,718	4.2	2,860	4.4
20% Percentile	3,984	6.1	4,219	6.5
30% Percentile	5,365	8.3	5,705	8.8
40% Percentile	6,918	10.6	7,375	11.3
50% Percentile	8,686	13.4	9,280	14.3
60% Percentile	10,756	16.5	11,507	17.7
70% Percentile	13,236	20.4	14,186	21.8
80% Percentile	16,452	25.3	17,655	27.2
90% Percentile	21,214	32.6	22,830	35.1
100% Percentile	44,455	68.4	50,201	77.2

[265] Assumes 690 bbl/tank car.
[266] Mean standard error is a measure of the precision with which the mean is represented based on the sample size.
[267] Assumes 650 bbl/tank car.

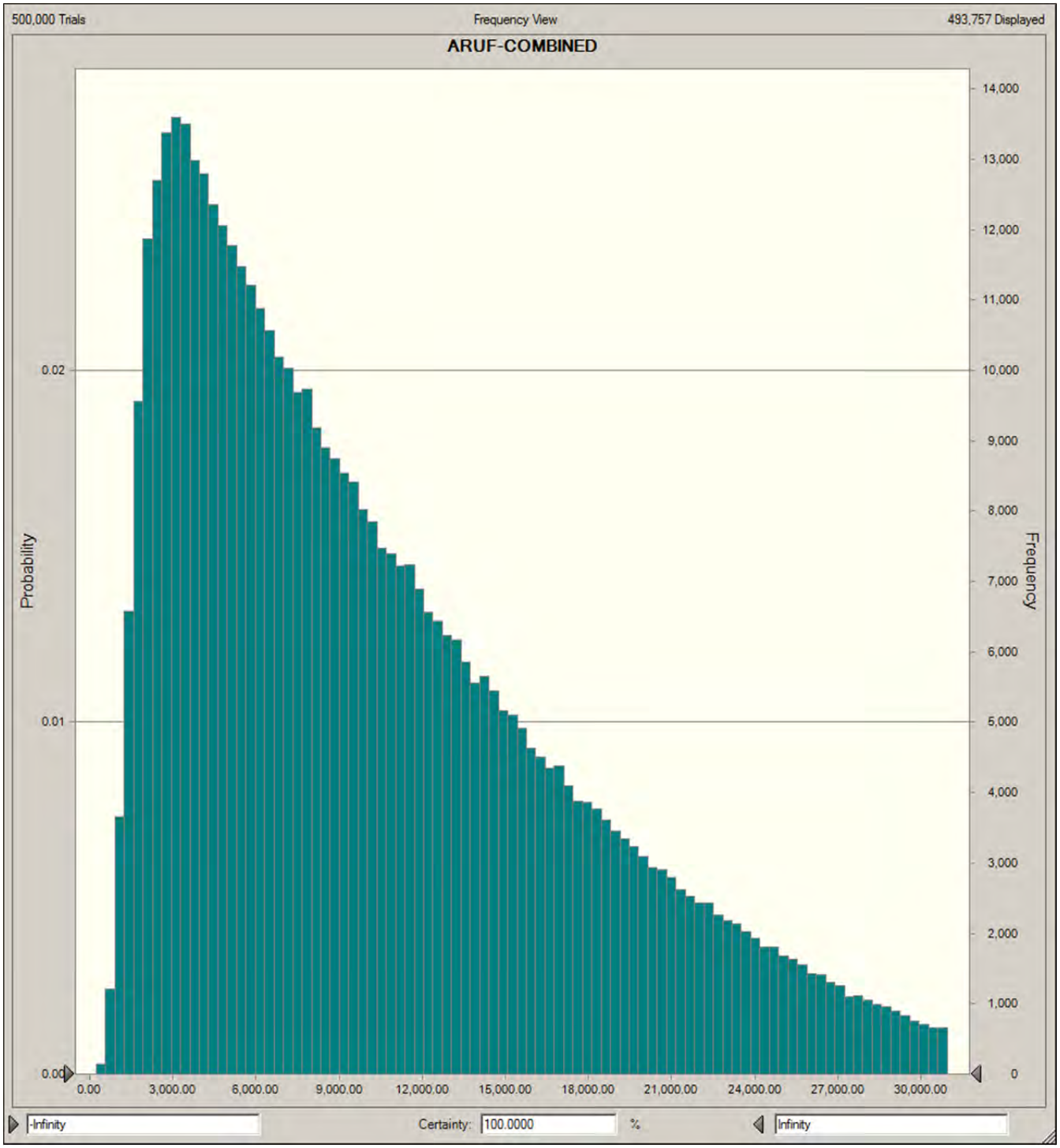


Figure 61: Distribution of Expected Crude Oil Spill Volume Distribution–Shell PSR Crude-by-Rail Transport–LES

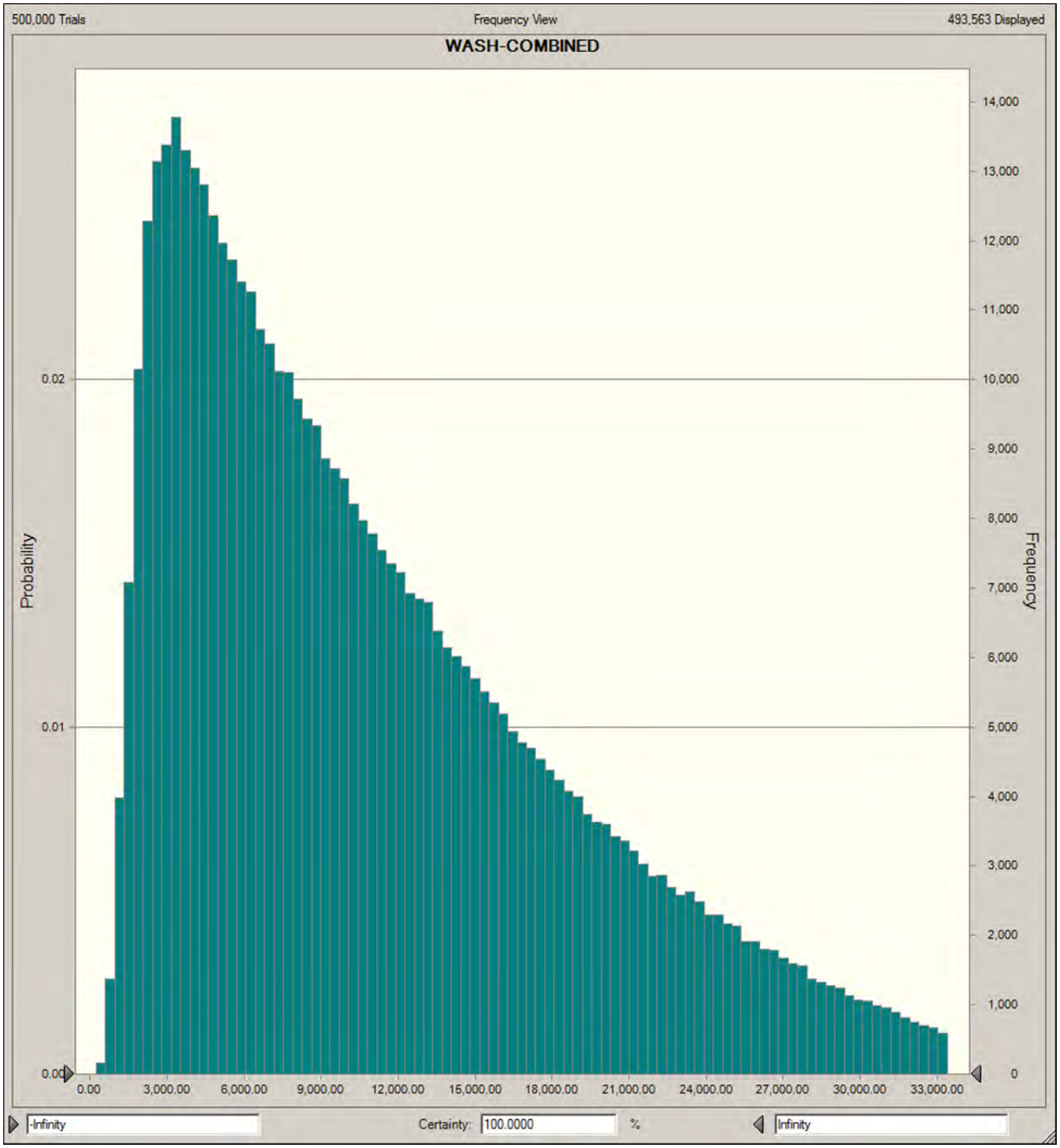


Figure 62: Distribution of Expected Crude Oil Spill Volume Distribution–Statewide Crude-by-Rail Transport - LES

Table 92 and Figure 63 show the CBR-SpillRISK-V modeling results for locomotive spills. Only 100,000 simulations were run for the locomotive spills because there were fewer variations involved compared with the crude oil tank car spills. Note that the volumes for locomotive spills would be similar for the HES and LES.

Table 92: Expected Crude-by-Rail Spill Volume per Incident (Empty Trains–Locomotive Spills)

Statistical Parameter	Spill Volume (bbl)
Mean	61
Median	54
Standard Deviation	32
Mean Standard Error[268]	0.10
0% Percentile	5
10% Percentile	27
20% Percentile	34
30% Percentile	40
40% Percentile	47
50% Percentile	54
60% Percentile	62
70% Percentile	71
80% Percentile	84
90% Percentile	103
100% Percentile	290

[268] Mean standard error is a measure of the precision with which the mean is represented based on the sample size.

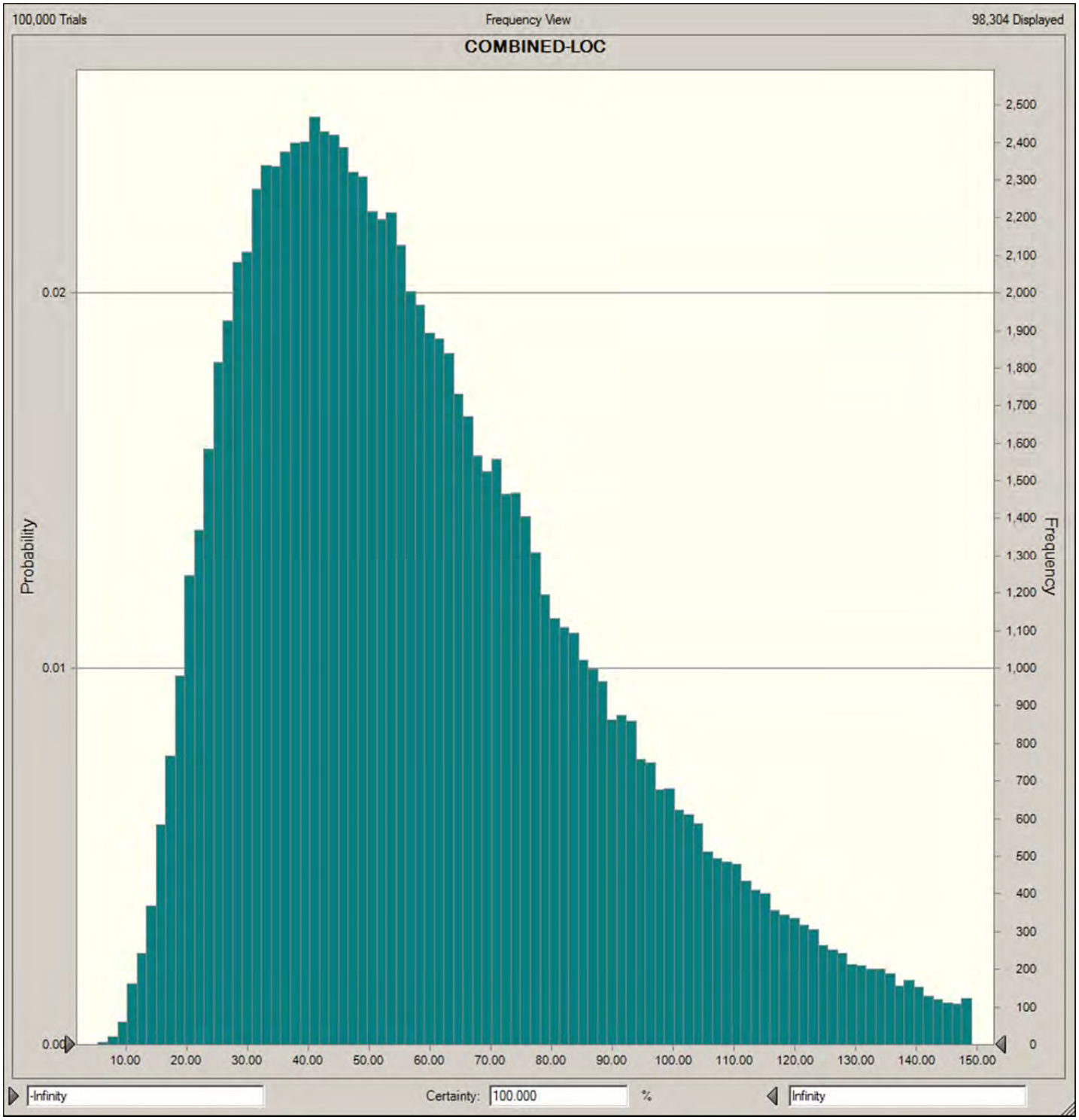


Figure 63: Distribution of Expected Diesel Spill Volumes (Empty Trains)

Comparison with Spill Volumes Selected for Effects Modeling

In separate studies for the Shell PSR EIS, the potential impacts were modeled for various spill scenarios. [There are two separate reports, one related to spill impacts and one related to fires and explosions. [269]] The modeled scenarios involved the release of two volumes of oil–5,700 bbl and 20,000 bbl–at:

- Location 1: BNSF Railway Swinomish Channel Bridge
- Location 2: BNSF Railway Skagit River Bridge
- Location 3: WSDOT Edmonds Ferry Terminal

The spill volumes for those scenarios were selected prior to the modeling of spill probabilities and volumes, as described in this report. The volumes selected in cooperation with the co-lead agencies for the Shell PSR EIS were roughly based on a previous analysis.[270]

Based on the CBR-SpillRISK-V modeling, the volume of 5,700 bbl corresponds with about the 30th to 35th percentile in Figure 64. The 20,000 bbl volume corresponds with the 90th percentile, which means that only 10 percent of spills would be expected to be larger. (The 5,700-bbl 30th percentile volume is referred to as 30PD, and the 20,000-bbl 90th percentile volume is referred to as 90PD.)

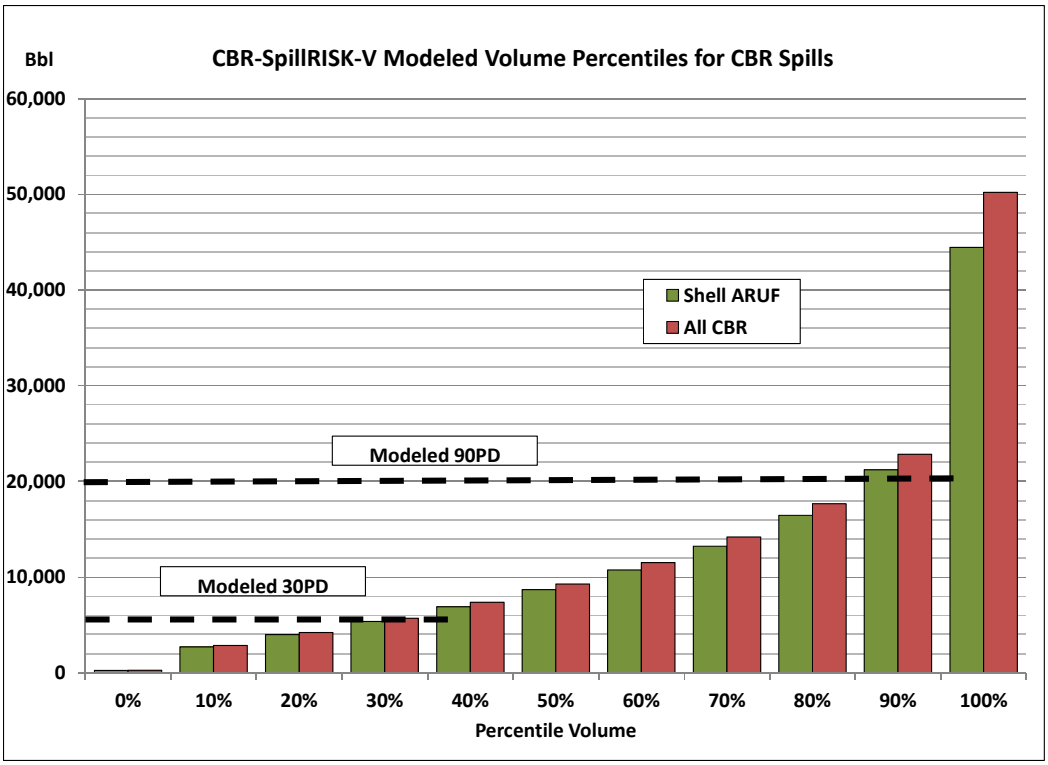


Figure 64: CBR-SpillRISK-V Volume Percentiles for Crude-by-Rail Spills Compared with 30PD/90PD

[269] Risknology 2016; RPS ASA 2016.
[270] Etkin et al. 2015b.

Comparison of Spill Volume Results with Recent CBR Incidents

The results for spill volumes derived from the Monte Carlo simulation model were compared with the highly-publicized crude-by-rail incidents that have occurred in the US (Table 93) and Canada (Table 94) during 2013 through 2016.

Table 93: Recent Accidents Involving Crude by Rail Trains (US)

Location/Date Incident Type	Crude-by-Rail Spillage (bbl)	Fire	Number of Crude-by-Rail Cars				Primary Cause
			Train Total	Derailed	Breached	Burned	
Parkers Prairie, MN[271] Mar 27, 2013	238	No	94	14	3	0	Derailment
Aliceville, AL[272] Nov 7, 2013	10,846	Yes	88	26	21	12	Derailment
Casselton, ND[273] Dec 30, 2013	11,308	Yes	106	20	18	18	Collision with derailed grain train
Philadelphia, PA[274] January 20, 2014	0	No	101	7	0	0	Derailment
Portage, WI[275] Feb 3, 2014	179	No	Unknown	0	1	0	Leak due to valve or cap failure
Vandergrift, PA[276] Feb 13, 2014	208	No	120	19	4	0	Derailment
Lynchburg, VA[277] April 30, 2014	700	Yes	105	15	3	3	Derailment
LaSalle, CO[278] May 9, 2014	189	No	100	6	1	0	Derailment
Seattle, WA[279] 24 July 2014	0	No	100	3	0	0	Derailment
Mount Carbon, WV[280] February 16, 2015	8,627	Yes	109	26	14	14	Derailment

[271] Quantity spilled from PHMSA Report Number X-2013050098.
[272] Cash undated; quantity spilled from PHMSA Report Number E-2013120116.
[273] Quantity spilled from PHMSA Report Number X-2014010238.
[274] Seven cars derailed of which six carried crude oil.
[275] Quantity spilled from PHMSA Report Number X-2014020009.
[276] 21 cars derailed, of which 19 contained crude oil; quantity spilled from PHMSA Report Number X-2014030227.
[277] Quantity spilled from PHMSA Report Number X-2014050225.
[278] Quantity spilled from PHMSA Report Number X-2014060096.
[279] http://blogs.seattletimes.com/today/2014/07/73125/
[280] Quantity spilled from PHMSA Report Number X-2015030156.

Table 93: Recent Accidents Involving Crude by Rail Trains (US)							
Location/Date Incident Type	**Crude-by-Rail Spillage (bbl)**	**Fire**	**Number of Crude-by-Rail Cars**				**Primary Cause**
			Train Total	**Derailed**	**Breached**	**Burned**	
Mosier, Oregon	1,000	Yes	100	11	2	2	Derailment

Table 94: Recent Accidents Involving Crude by Rail Trains (Canada)							
Location/Date Incident Type	**Crude-by-Rail Spillage (bbl)**	**Fire**	**Number of Crude-by-Rail Cars**				**Primary Cause**
			Train Total	**Train Total**	**Train Total**	**Train Total**	
Calgary, Alberta[281] April 2013	640	Yes	111	7	2	2	Derailment; broken wheel
Lac-Mégantic, Quebec[282] July 5, 2013	37,671 (total)	Yes	72	63	37	Unknown	Unattended runaway; brake failure
Gainford, Alberta[283] Oct 19, 2013	0	Yes	134	4	0	0	Derailment
Plaster Rock, New Brunswick[284] Jan 7, 2014	1,447	Yes	122	5	2	2	Derailment
Gogama, Ontario[285] February 14, 2015	6,289	Yes	100	29	21	21	Derailment
Gogama, Ontario[286] March 7, 2015	4,709[287]	Yes	111	39	7	7	Derailment
Mosier, Oregon	1,000	Yes	100	11	2	2	Derailment

Lac-Mégantic Incident

The 5 July 2013 incident at Lac-Mégantic, Quebec represented a "perfect storm" of failures that contributed to the accident and its consequences. This particular set of circumstances would not be expected to occur in the US due to regulations and railroad operating practices in place, most importantly:

- A train would not be left unattended in this manner;

[281] 22 cars derailed of which 7 were carrying crude oil; 113 bbl of canola oil also spilled.
[282] TSB Canada 2014b. [See also section below.]
[283] 9 tank cars of propane and four tank cars of crude oil from Canada derailed as train was entering siding at 22 mph. 3 propane cars burned, but tank cars carrying oil were pushed away and did not burn.
[284] TSB Canada 2014a. 12 tank cars derailed of which 5 carried crude oil.
[285] http://www.tsb.gc.ca/eng/enquetes-investigations/rail/2015/r15h0013/r15h0013.asp
[286] http://www.tsb.gc.ca/eng/enquetes-investigations/rail/2015/r15h0021/r15h0021.asp
[287] Estimate based on 7 cars.

- The locomotive conditions in this incident would not be considered acceptable; and
- A train with hazardous cargo would not be operated by a single person.

The use of safer tank cars (as per DOT-117 specifications) and the lower volatility of conditioned Bakken crude would also significantly reduce the probability that this series of events could recur in this manner. A synopsis of the event and an analysis of the spillage is presented here so that the volumes applied in the impacts modeling can be benchmarked against it.

For the Lac-Mégantic incident, the volume of oil can be accounted for in three phases. There were 72 DOT-111 cars loaded with a reported 7.7 million liters (48,432 bbl) of Bakken crude with each car holding about 672.66 bbl (28,252 gallons). A total of 63 tank cars derailed (holding about 42,378 bbl)– 87.5 percent of the train's tank cars. A total of about 37,739 bbl of oil were reported to have been released from the tank cars.[288] Only four cars released no oil (2,961 bbl). An additional 1,964 bbl of oil were removed from damaged cars that did not entirely release their contents. About 100,000 liters (629 bbl) ended up in Mégantic Lake and the Chaudière River by way of surface flow, underground infiltration, and sewer systems. An undetermined amount of oil saturated nearly 77 acres of land.

Of the 63 derailed cars, 37 cars (holding approximately 24,888 bbl) had a breached shell due to impact damage; of these, 21 cars had "large" breaches, 12 had "medium" breaches, and four had "small" breaches. The remaining 26 cars had no breach, although 22 of the non-breached cars had at least some denting. Only four derailed cars had no discernible damage (Figure 65 and Figure 66).

Figure 65: Lac-Mégantic Incident Tank Cars Colored by Breach Size[289]

[288] TSB Canada 2014b. *Note that with approximations and rounding in the TSB Canada report and conversions from liters to gallons to barrels, there are some rounding discrepancies.*
[289] TSB Canada 2014b. Orange = large breach, yellow = medium breach; blue = small breach.

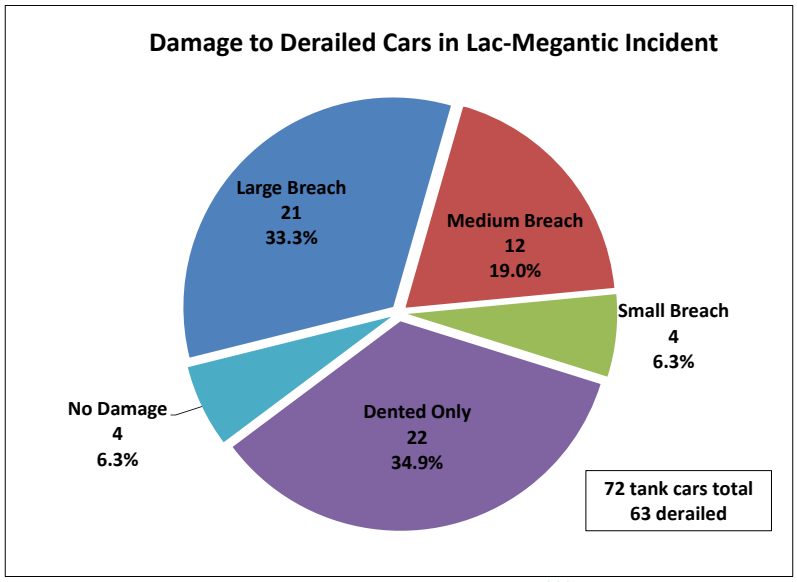


Figure 66: Damage to Derailed Cars in Lac-Mégantic Incident[290]

There appeared to be three types of releases from the derailed tank cars:

- **Phase 1A (Instantaneous Derailment-Damage-Related Releases):** Twenty-one cars *nearly instantaneously* released their entire contents (14,126 bbl) due to the size of the breaches (of a large size commensurate with car diameter);
- **Phase 1B (Subsequent Derailment-Damage-Related Releases):** An additional 12,177 bbl of oil were subsequently released from about 18 cars with lesser degrees of damage; and
- **Phase 2 (Burn-Through- and Thermal-Tear-Related Releases):** Four cars released 2,691 bbl of oil due to thermal tears that occurred as a result of the fire 20 minutes or longer after the initial releases; 13 cars later experienced localized loss of contents due to burn-through[291] (8,745 bbl).

During the response operations, 740,000 liters (4,654 bbl) of crude oil were recovered from the derailed tank cars, of which 2,691 bbl were removed from the four non-damaged cars. About 1,963 bbl that remained in damaged cars (nearly three cars-worth of oil) were also removed. The "mass balance" of the contents of the train is illustrated in Figure 67.

[290] Based on data inTSB Canada 2014b.
[291] Burn-through is a perforation of the tank shell caused by fire damage.

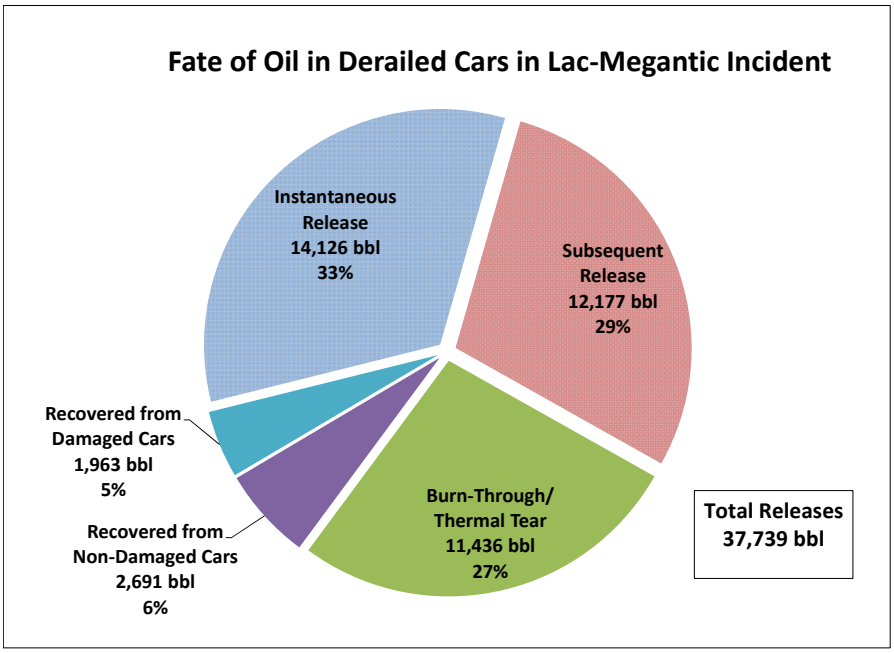


Figure 67: Fate of Oil in Derailed Cars (Mass Balance) in Lac-Mégantic Incident

While about 37,739 bbl of oil were ultimately lost from Train MMA-002, the sequence of releases should be considered with respect to the likelihood of all of the events occurring in the future. The initial and subsequent releases were likely due to damages from the derailment itself (26,303 bbl). The burn-through and thermal-tear releases (11,436 bbl) were secondarily caused by the fire. The former releases may have been reduced by better tank car designs. The latter releases would likely have been reduced by the improved thermal protection in DOT-117 cars.

The accident investigation for the Lac-Mégantic incident revealed several key factors that caused and ultimately affected the outcome, and which have a bearing on the analysis of potential future incidents that may occur with regard to the Shell PSR crude-by-rail traffic:[292]

- The train (MMA-002) had been under the control of a sole operator;
- The train was parked unattended on a main line on a descending grade with the securement of the train reliance on a locomotive that was not in proper operating condition;
- There were significant braking failures (*e.g.*, seven hand brakes that were applied to secure the train were insufficient to hold the train with the additional braking force from the locomotive's independent brakes; and the hand brakes had not been properly tested for effectiveness);
- The train was left unattended despite its abnormal condition (*i.e.*, there had been significant indications of mechanical problems with the lead locomotive);
- The lead locomotive had a non-standard repair that allowed oil to accumulate in the turbocharger and exhaust manifold, resulting in a fire; the fire precipitated the locomotive's engine being shut down, which removed the braking ability of the locomotive; no additional locomotive was started to provide braking power;

[292] For a thorough analysis refer to TSB Canada 2014b.

- DOT-111 tank cars did not withstand shell damage and had inadequate thermal protection; and
- The volatility of the oil (unconditioned Bakken crude) contributed greatly to the fire, which caused the damages, including fatalities and injuries (the oil had been improperly classified with regard to hazard).

Figure 68 shows spillage volumes of US and Canadian crude-by-rail incidents compared with the modeled 30PD and 90PD volumes.

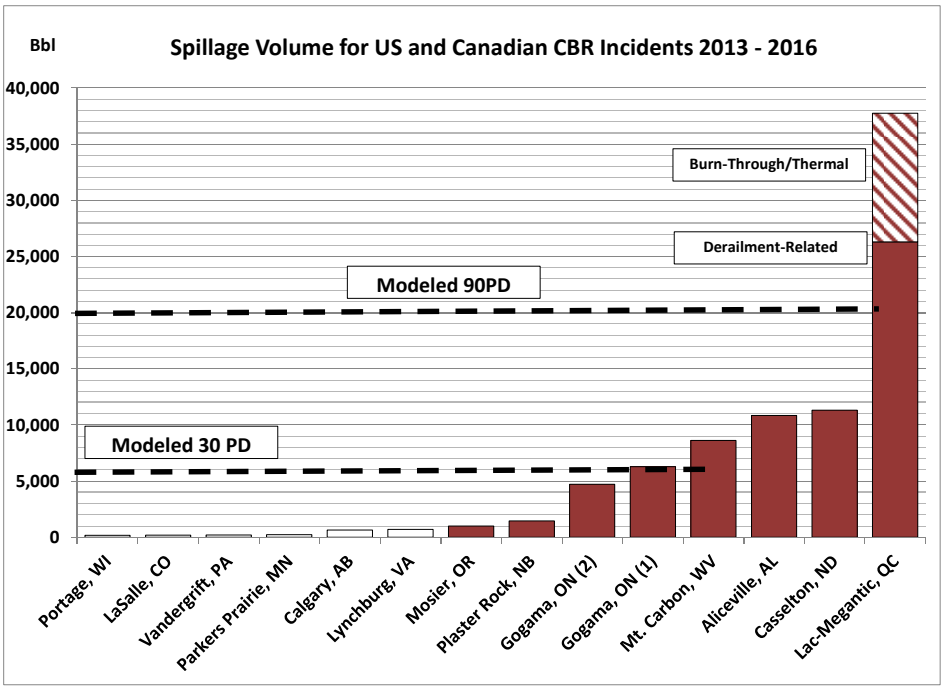


Figure 68: Spill Volumes for US and Canadian Crude-by-Rail Incidents Compared with 30PD/90PD

The 30PD is larger than 12 of the 16 recorded incidents, and the 90PD is twice as large as the largest US crude-by-rail spill incident to date. It is however, about 53 percent of the total release from the derailment and burn-through in the Lac-Mégantic incident, which represented an unusual circumstance.

Comparison with DOT/PHMSA WCD Planning Volumes

When PHMSA released its advanced copy of a Notice of Proposed Rulemaking (NPRM) on contingency planning for crude-by-rail spills, defined the "worst-case discharge" (WCD) as:

> *"The largest foreseeable discharge in adverse weather conditions," as defined at 33 U.S.C. 1321(a)(24). The largest foreseeable discharge includes discharges resulting from fire or explosion. The worst-case discharge from a train consist is the greater of: (1) 300,000 gallons of liquid petroleum oil; or (2) 15% of the total lading of liquid petroleum oil transported within the largest train consist reasonably expected to transport liquid petroleum oil in a given response zone."*

For 102-car trains transiting to Shell PSR, the WCD volume for planning would be about 9,945 bbl. For the 120-car trains transiting to other facilities in Washington State, the WCD planning volume would be 11,700 bbl.

Chapter 11: Combining Spill Probability and Volume Analyses

To predict frequency of crude-by-rail spills of varying sizes, results from the spill probability analysis (CBR-SpillRISK) needed to be combined with results from the spill volume analysis (CBR-SpillRISK-V). The former provided the probability of spillage on a per-train-mile basis, which was converted into spill frequencies by multiplying by annual train-miles (Table 70 and Table 71 in Chapter 9).

Expected Crude Spill Frequencies from Loaded Crude-by-Rail Trains

Each spill frequency value needed to be apportioned to the distribution of spill volumes. For example, based on the HES methodology, the average annual spill frequency of 0.046 for loaded crude-by-rail trains for the Shell PSR, there is an 11 percent chance that the spill would be a volume of 20,000 bbl or more. This means that annually, there is a 0.0051 probability of a 20,000 bbl or larger crude oil spill (the 90PD scenario) from a loaded crude-by-rail train headed to the Shell PSR. The expected recurrence interval or return period of such a spill volume scenario would be 200 years, based on the HES.

Based on the LES methodology, the average annual spill frequency of 0.0055 for loaded crude-by-rail trains for the Shell PSR, there is an 11 percent chance that the spill would be a volume of 20,000 bbl or more. This means that annually, there is a 0.00061 probability of a 20,000 bbl or larger crude oil spill (the 90PD scenario) from a loaded crude-by-rail train headed to the Shell PSR. The expected recurrence interval or return period of such a spill volume scenario would be 1,600 years, based on the LES.

The higher estimate (HES) probabilities of spills of different volumes for loaded crude-by-rail trains for Shell PSR, current crude-by-rail facilities, and potential future facilities are in Table 95, based on the mean results in Table 70 and Table 71. The lower estimate (LES) probabilities of spills of different volumes for loaded crude-by-rail trains for Shell PSR, current crude-by-rail facilities, and potential future crude-by-rail facilities are in Table 96, based on the mean (average) results in Table 84 and Table 85.

Note that the Higher Estimate of Spills (HES) is based on the assumption that none of the safety and risk mitigation measures are in place, as well as the use of older DOT-111 tank cars. The Lower Estimate of Spills (LES) assumes that the safety measures are in place, including the use of DOT-117 cars.

Table 95: Average Frequency of Crude-by-Rail Oil Spills by Volume

Spill Volume	Shell PSR		Current		Other Future		All Facilities	
	Prob/ Year	Return Years	Prob/ Year	Return Years	Prob/ Year	Return Years	Prob/ Year	Return Years
250 bbl	0.046	22	0.17	6	0.26	3.9	0.48	2.1
2,500 bbl	0.041	24	0.15	6.5	0.23	4.3	0.43	2.3
4,000 bbl	0.037	27	0.14	7.4	0.21	4.8	0.38	2.6
5,700 bbl (30PD)	**0.032**	**31**	**0.12**	**8.4**	**0.18**	**5.5**	**0.34**	**3**
8,000 bbl	0.025	40	0.094	11	0.14	7	0.26	3.8
10,000 bbl	0.016	62	0.060	17	0.091	11	0.17	6
15,000 bbl	0.012	87	0.043	24	0.065	15	0.12	8.3
20,000 bbl (90PD)	**0.0069**	**140**	**0.026**	**39**	**0.039**	**26**	**0.072**	**14**
40,000 bbl	0.00092	1,100	0.0034	290	0.0052	190	0.0096	100
50,000 bbl	0.00005	22,000	0.00017	5,900	0.00026	3,800	0.00048	2,100

Table 96: Lower Estimate Expected Average Frequency of Crude-by-Rail Oil Spills by Volume								
Spill Volume	**Shell PSR**		**Current**		**Other Future**		**All Facilities**	
	Prob/ Year	**Return Years**	**Prob/ Year**	**Return Years**	**Prob/ Year**	**Return Years**	**Prob/ Year**	**Return Years**
250 bbl	0.0055	180	0.025	40	0.037	27	0.069	14
2,500 bbl	0.005	200	0.023	44	0.033	30	0.062	16
4,000 bbl	0.0044	230	0.02	50	0.03	34	0.055	18
5,700 bbl (30PD)	**0.0036**	**280**	**0.016**	**62**	**0.024**	**42**	**0.045**	**22**
8,000 bbl	0.003	330	0.014	73	0.02	49	0.038	26
10,000 bbl	0.0022	450	0.01	100	0.015	68	0.028	36
15,000 bbl	0.0014	730	0.063	160	0.0093	110	0.017	58
20,000 bbl (90PD)	**0.0055**	**1,800**	**0.0025**	**400**	**0.0037**	**270**	**0.0069**	**140**
40,000 bbl	0.000055	18,000	0.00025	4,000	0.00037	2,700	0.00069	1,400
50,000 bbl	0.0000055	180,000	0.000025	40,000	0.000037	27,000	0.000069	14,000

Note that this does not predict the occurrence of these two spill volume scenarios at any of the particular locations selected for modeling–just that spills of this volume would be expected to occur somewhere along the rail corridor between the Idaho border and the Shell PSR. In fact, the probability that the spills would occur at any of those locations is a miniscule fraction of the probabilities of these spill volumes occurring anywhere along the rail corridor. [A basic geographic analysis is provided in Chapter 12.]

Expected Diesel Spill Frequencies from Crude-by-Rail Train Locomotives

The results for diesel spills from locomotives on empty trains are in Table 97 (HES) and Table 98 (LES).

Diesel spills from loaded crude-by-rail trains may also occur. In fact, it is possible for there to be accidents that result in diesel spillage from one or more locomotives in addition to crude oil spillage from crude-by-rail tank cars. The estimated spill frequencies from locomotives on loaded crude-by-rail trains traveling to the Shell PSR and other facilities are shown in Table 99 for HES and Table 100 for LES.

Table 97: Higher Estimate Average Frequency of Diesel Spills from Empty Trains by Volume								
Spill Volume	**Shell PSR**		**Current**		**Other Future**		**All Facilities**	
	Prob/ Year	**Return Years**	**Prob/ Year**	**Return Years**	**Prob/ Year**	**Return Years**	**Prob/ Year**	**Return Years**
5 bbl	0.0038	260	0.013	76	0.029	34	0.046	22
25 bbl	0.0034	290	0.012	85	0.026	38	0.041	24
40 bbl	0.0027	380	0.0091	110	0.02	49	0.032	31
50 bbl	0.0021	480	0.0072	140	0.016	63	0.025	40
60 bbl	0.0015	660	0.0052	190	0.012	86	0.018	54
70 bbl	0.0011	880	0.0039	260	0.0087	120	0.014	72
100 bbl	0.00038	2,600	0.0013	770	0.0029	340	0.0046	220
250 bbl	0.00019	5,300	0.00065	1,500	0.0015	690	0.0023	440
300 bbl	0.00006	26,000	0.00013	7,700	0.00029	3,400	0.00046	2,200

Table 98: Lower Estimate Average Frequency of Diesel Spills from Empty Trains by Volume								
Spill Volume	Shell PSR		Current		Other Future		All Facilities	
	Prob/ Year	Return Years	Prob/ Year	Return Years	Prob/ Year	Return Years	Prob/ Year	Return Years
5 bbl	0.00098	1,000	0.005	198	0.011	89	0.018	56
25 bbl	0.00088	1,100	0.0045	220	0.0099	100	0.016	62
40 bbl	0.00069	1,500	0.0035	290	0.0077	130	0.013	79
50 bbl	0.00054	1,900	0.0028	360	0.0061	170	0.0099	100
60 bbl	0.00039	2,600	0.002	500	0.0044	230	0.0072	140
70 bbl	0.00029	3,400	0.0015	670	0.0033	300	0.0054	190
100 bbl	0.000098	10,000	0.0005	2,000	0.0011	910	0.0018	560
250 bbl	0.000049	20,000	0.00025	4,000	0.00055	1,800	0.0009	1,100
300 bbl	0.000001	100,000	0.00005	20,000	0.00011	9,100	0.00018	5,600

Table 99: Higher Estimate Average Diesel Spill Frequency from Loaded Crude-by-Rail Trains								
Spill Volume	Shell PSR		Current		Other Future		All Facilities	
	Prob/ Year	Return Years	Prob/ Year	Return Years	Prob/ Year	Return Years	Prob/ Year	Return Years
5 bbl	0.0047	210	0.018	57	0.026	39	0.049	21
25 bbl	0.0042	240	0.016	62	0.023	43	0.043	23
40 bbl	0.0034	300	0.012	81	0.018	56	0.034	30
50 bbl	0.0026	380	0.0097	100	0.014	70	0.026	38
60 bbl	0.0019	540	0.007	140	0.011	93	0.019	53
70 bbl	0.0014	730	0.0053	190	0.0078	130	0.015	68
100 bbl	0.00047	2,100	0.0018	570	0.0026	390	0.0049	210
250 bbl	0.00024	4,200	0.00088	1,100	0.0013	750	0.0024	410
300 bbl	0.000075	13,000	0.00018	5,700	0.00026	3,900	0.00049	2,100

Table 100: Lower Estimate Average Diesel Spill Frequency from Loaded Crude-by-Rail Trains								
Spill Volume	Shell PSR Traffic		Current Traffic		Other Future Traffic		All Facility Traffic	
	Prob/ Year	Return Years	Prob/ Year	Return Years	Prob/ Year	Return Years	Prob/ Year	Return Years
5 bbl	0.0012	820	0.0068	150	0.0098	109	0.019	53
25 bbl	0.0011	910	0.0061	160	0.0089	119	0.017	59
40 bbl	0.00086	1,200	0.0047	210	0.0069	150	0.014	73
50 bbl	0.00067	1,500	0.0038	260	0.0055	180	0.010	96
60 bbl	0.00049	2,100	0.0027	370	0.0039	250	0.0076	130
70 bbl	0.00036	2,800	0.002	490	0.003	340	0.0057	180
100 bbl	0.00012	8,200	0.00068	1,500	0.00099	1,000	0.0019	530
250 bbl	0.000061	16,000	0.00034	3,000	0.000499	2,000	0.00095	1,100
300 bbl	0.000001	800,000	0.000068	15,000	0.000098	10,000	0.00019	5,300

Chapter 12: Sensitivity Analysis of Probability and Volume Modeling

The CBR-SpillRISK modeling processes are based on a number of assumptions for inputs, as described in Chapters 8 and 9. The various inputs to the model include distributions of values for probabilities (*e.g.*, the probability of derailment) and other parameters to take into account uncertainties and to incorporate the potential variations in inputs that might be appropriate for different scenarios (*e.g.*, differing numbers of cars). In simple terms, the model outputs are based solely on the inputs provided (Figure 69).

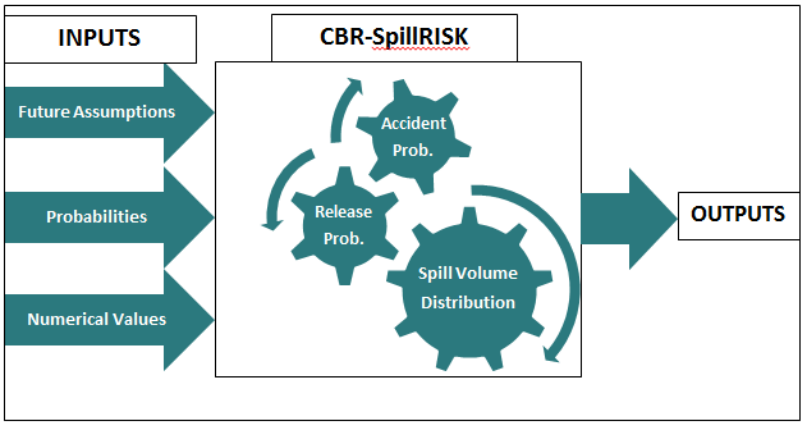


Figure 69: Inputs and Outputs of Modeling

Purpose of Sensitivity Analyses

Often in modeling, a "sensitivity analysis" is conducted to determine the degree to which different factors and inputs have affected the final results, which in this case were probabilities of spills and volumes of spills. Because the modeling process CBR-SpillRISK and its subcomponent, CBR-SpillRISK-V, incorporated distributions of values and a Monte Carlo simulation approach, the uncertainties and variations in results were actually already incorporated into the final results. If a *single* result was determined to be the only outcome, the sensitivity analysis would be a more accurate measure of the degree to which each of the inputs contributed to providing that single outcome. In other words, it would determine the key drivers of the results. In addition, the outcomes of probabilities were designed to be applied to varying numbers of crude-by-rail trains as required to derive different outcomes based on possible crude-by-rail traffic scenarios.

Nevertheless, a type of sensitivity analysis was conducted to demonstrate the degree to which the variation in different factors affected the outcomes of the CBR-SpillRISK and CBR-SpillRISK-V modeling for this study. "Tornado charts"[293] were developed for the two components of the modeling to provide a quick overview of the way in which the different inputs affected the outcomes of the modeling.

[293] The term "tornado chart" (also called "tornado diagram" or "tornado plot") is a specific type of bar chart that shows the data vertically instead of horizontally with the largest bar at the top (to represent the greatest variability) followed by the next smaller below it, proceeding down to the one showing the lowest variability. The resulting figure visually resembles a tornado funnel, thus the name. In many cases, however, especially if the input distributions are skewed (as is the case for CBR-SpillRISK and CBR-SpillRISK-V), the resulting diagrams will not have much resemblance to a tornado.

CBR-SpillRISK Spill Probability Modeling Tornado Sensitivity Analysis

The model inputs for loaded trains, as in Table 101 for HES and Table 102 for LES, were based on historical rail accident rates (probabilities per million train-miles) adjusted for crude-by-rail transport. Similarly, model inputs for empty trains (locomotive-only spill scenarios) are shown in Table 103 for HES, and Table 104 for LES.

Table 101: CBR-SpillRISK Model Rail Accident Inputs with Adjustments (Loaded Trains): HES

Accident Type	Accident Probability Per Million Train-Miles						Distribution Type
	Pre-Adjustment		Adjustment		Adjusted		
	Low	High	Train Length (cars)	Multiplier	Low	High	
Derailment	0.6620	1.1100	102 (Shell PSR)	1.374	0.9096	1.5251	Log-normal
			120 (statewide)	1.497	0.9910	1.1000	
Collision	0.0612	0.1283	102 (Shell PSR)	1.374	0.0841	0.1763	Weibull
			120 (statewide)	1.497	0.0916	0.1921	
Fire/Explosion	0.0000	0.0338	102 (Shell PSR)	1.374	0.0000	0.0464	Uniform
			120 (statewide)	1.497	0.0000	0.0506	
Hway-Rail Cross	0.0541	0.1503	102 (Shell PSR)	1.374	0.0743	0.2065	Uniform
			120 (statewide)	1.497	0.0810	0.2250	
Miscellaneous	0.0639	0.1284	102 (Shell PSR)	1.374	0.0878	0.1764	Uniform
			120 (statewide)	1.497	0.0957	0.1922	

Table 102: CBR-SpillRISK Model Rail Accident Inputs with Adjustments (Loaded Trains): LES

Accident Type	Accident Probability Per Million Train-Miles							Distribution Type
	Pre-Adjustment		Adjustment			Adjusted		
	Low	High	Train Length (cars)	Multipliers		Low	High	
				Min.	Max.			
Derailment	0.4403	0.7016	102 (Shell PSR)	0.749	0.287	0.1264	0.5255	Log-normal
			120 (statewide)	0.872	0.410	0.1805	0.6118	
Collision	0.0123	0.0946	102 (Shell PSR)	0.749	0.287	0.0035	0.0709	Weibull
			120 (statewide)	0.872	0.410	0.0050	0.0825	
Fire/Explosion	0.0000	0.0116	102 (Shell PSR)	0.749	0.287	0.0000	0.0087	Uniform
			120 (statewide)	0.872	0.410	0.0000	0.0101	
Hway-Rail Cross	0.0541	0.1338	102 (Shell PSR)	0.749	0.287	0.0155	0.1002	Uniform
			120 (statewide)	0.872	0.410	0.0222	0.1167	
Miscellaneous	0.0543	0.1284	102 (Shell PSR)	0.749	0.287	0.0156	0.0962	Uniform
			120 (statewide)	0.872	0.410	0.0223	0.1120	

Table 103: CBR-SpillRISK Model Rail Accident Inputs with Adjustments (Empty Trains): HES							
Accident Type	**Accident Probability Per Million Train-Miles**						**Distribution Type**
	Pre-Adjustment		**Adjustment**		**Adjusted**		
	Low	**High**	**Train Length (cars)**	**Multiplier**	**Low**	**High**	
Derailment	0.3116	0.5223	102 (Shell PSR)	1.374	0.4281	0.7176	Log-normal
			120 (statewide)	1.497	0.4665	0.2436	
Collision	0.0288	0.0604	102 (Shell PSR)	1.374	0.0396	0.0830	Weibull
			120 (statewide)	1.497	0.0431	0.0904	
Fire/Explosion	0.0000	0.0159	102 (Shell PSR)	1.374	0.0000	0.0218	Uniform
			120 (statewide)	1.497	0.0000	0.0238	
Hway-Rail Cross	0.0254	0.0708	102 (Shell PSR)	1.374	0.0349	0.0973	Uniform
			120 (statewide)	1.497	0.0380	0.1060	
Miscellaneous	0.0300	0.0604	102 (Shell PSR)	1.374	0.0412	0.0830	Uniform
			120 cars (statewide)	1.497	0.0449	0.0904	

Table 104: CBR-SpillRISK Model Rail Accident Inputs with Adjustments (Empty Trains): LES								
Accident Type	**Accident Probability Per Million Train-Miles**							**Distribution Type**
	Pre-Adjustment		**Adjustment**			**Adjusted**		
	Low	**High**	**Train Length (cars)**	**Multiplier**		**Low**	**High**	
				Min.	**Max.**			
Derailment	0.2072	0.3302	102 (Shell PSR)	0.749	0.287	0.0595	0.2473	Log-normal
			120 (statewide)	0.872	0.410	0.0850	0.2879	
Collision	0.0058	0.0445	102 (Shell PSR)	0.749	0.287	0.0017	0.0333	Weibull
			120 (statewide)	0.872	0.410	0.0024	0.0388	
Fire/Explosion	0.0000	0.0055	102 (Shell PSR)	0.749	0.287	0.0000	0.0041	Uniform
			120 (statewide)	0.872	0.410	0.0000	0.0048	
Hway-Rail Cross	0.0254	0.0630	102 (Shell PSR)	0.749	0.287	0.0073	0.0472	Uniform
			120 (statewide)	0.872	0.410	0.0104	0.0549	
Miscellaneous	0.0256	0.0604	102 (Shell PSR)	0.749	0.287	0.0073	0.0452	Uniform
			120 (statewide)	0.872	0.410	0.0105	0.0527	

For the calculation of crude-by-rail spill probability (disregarding volume), there are two major steps–1) calculating the probability of rail accidents and, 2) calculating the probability that those accidents result in the release of oil from tank cars and/or locomotives due to a breach, as shown in Equation 19.

Equation 19

$$P(spill)_i = P(accident)_i \cdot P(release)_i$$

The probability of a rail accident is dependent on the type of accident (*i.e.*, derailment, collision, fire/explosion, highway-rail, or miscellaneous), adjusted for crude-by-rail factors. The adjustments differ or the Higher Estimate of Spills (HES) and Lower Estimate of Spills (LES) calculations. The probability of a breach resulting in a release is dependent on the adjustments for crude-by-rail transport-specific factors related to tank car design.

The tornado charts for the accident probability distributions for loaded trains are shown in Figure 70 and **Error! Reference source not found.** The charts essentially demonstrate the skewed distributions assumed in the CBR-SpillRisk Monte Carlo simulations. The charts would be similar for both the HES and LES, though the absolute numbers for the accident rates differ.

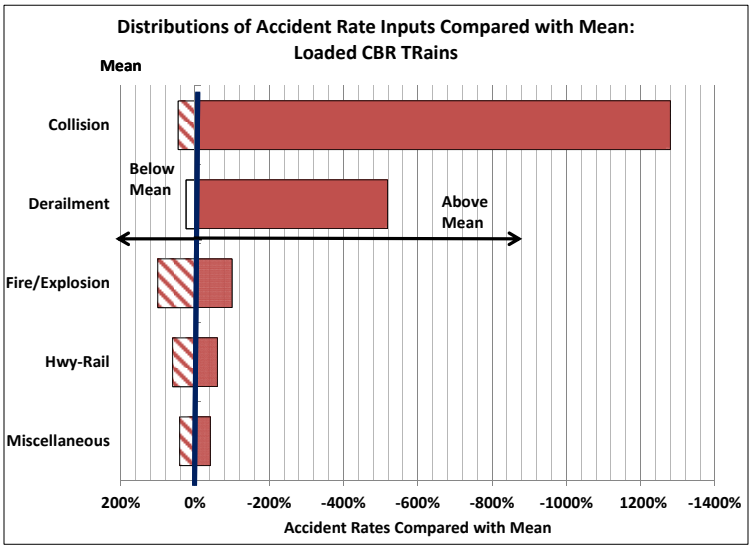


Figure 70: Tornado Chart for Accident Probability (Loaded Trains) Calculation

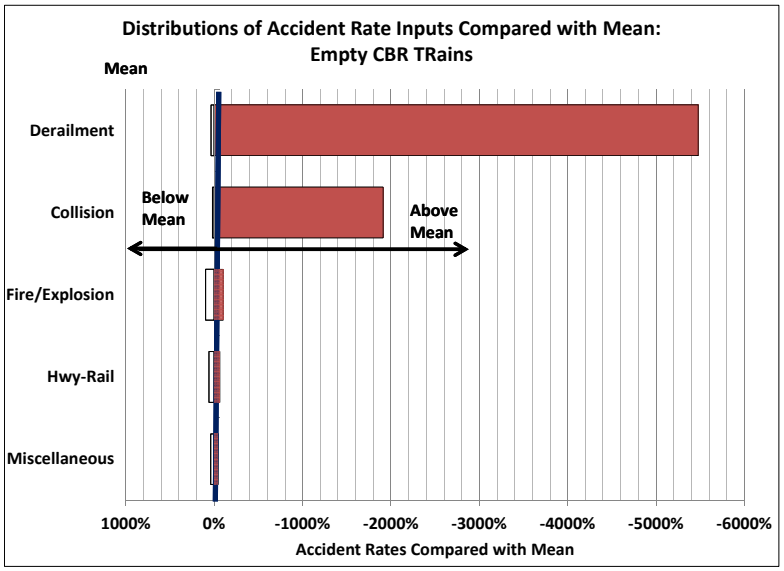


Figure 71: Tornado Chart for Crude-by-Rail Spill Probability (Empty Trains) Calculation

The adjustment multipliers shown in the tables were based on the adjustments for accident probability, (Table 105), and the spill or release probability given an accident (Table 106). Both the loaded and empty train accident rates were adjusted by the crude-by-rail-specific factors, though the approach was different for the HES and the LES. The tornado chart for the adjustments to the baseline accident probabilities to account for crude-by-rail unit trains is shown in Figure 72 for HES and Figure 73 for LES.

Table 105: Applied Adjustment Factors for Crude-by-Rail Accident Rates			
Train Length	**Adjustments to Baseline Accident Rate**		
	Higher Estimate of Spills (HES)	**Lower Estimate of Spills (LES)**	
		Minimum	**Maximum**
100-102 cars	37.4% increase	25.1% decrease	71.3% decrease
120 cars	49.7% increase	12.8% decrease	59.0% decrease

Table 106: Considered and Applied Adjustments to Tank Car Release Probability					
Release Probability Factor	**Higher Estimate of Spills (HES)**		**Lower Estimate of Spills (LES)**		
	Assumptions	**Adjustments to Baseline Tank Car Release Rate**	**Assumptions**	**Adjustments to Baseline Tank Car Release Rate**	
				Minimum	**Maximum**
Tank Car Design	DOT-111 tank car release rate applied	0%	DOT-117 tank car release rate applied[294]	43% reduction	72.2% reduction
Operating Speed	No release reduction due to reduced operating speed	0%	Release rate reduced due to lower operating speeds[295,296]	35% reduction	35% reduction
Thermal Protection	No release reduction due to reduced operating speed	0%	Thermal protection reduces releases due to fire/ explosion[297]	12% reduction	12% reduction
Total Adjustment Applied to Impact Accident Rate		0%	**Total Adjustment Applied to Impact Accident Rate**	43% reduction	72.2% reduction
Total Adjustment Applied to Fire/Explosion Accident Rate		0%	**Total Adjustment Applied to Fire/Explosion Accident Rate**	12% reduction	12% reduction

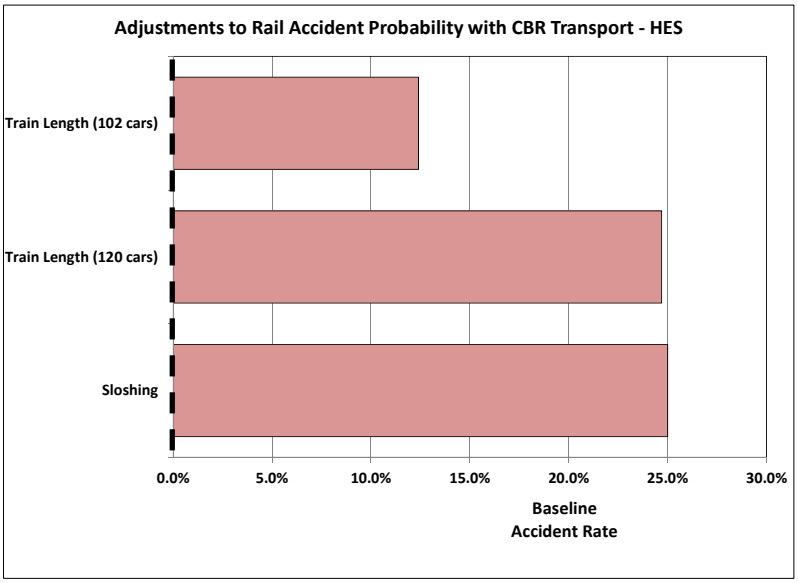


Figure 72: Tornado Chart for Crude-by-Rail Train Adjustments to Accident Rates for HES

[294] For impact-related accidents (derailments, collisions, highway-rail crossing accidents, miscellaneous).
[295] Kawprasert and Barkan 2010 (Figure 41).
[296] For impact-related accidents (derailments, collisions, highway-rail crossing accidents, miscellaneous).
[297] Reduction applied only to accidents caused by fire/explosion.

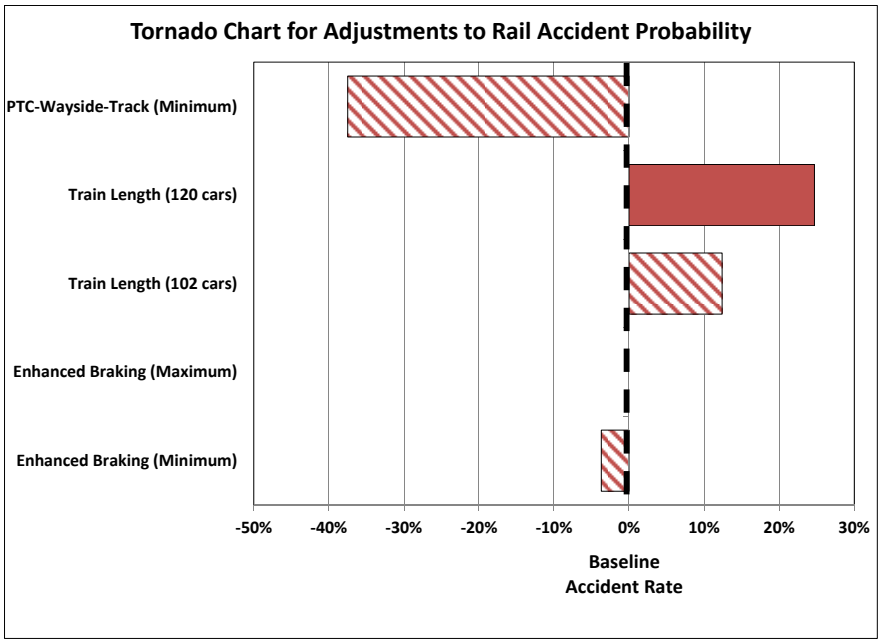


Figure 73: Tornado Chart for Crude-by-Rail Train Adjustments to Accident Rates for LES

The probability of breaches that would lead to spillage during accidents is influenced by the factors in Table 106. The tornado chart for these adjustments is shown in Figure 74. These adjustments were only applied to the LES calculations. Note that for empty trains (locomotive spills) there is no particular adjustment for crude-by-rail transport. The locomotives are the same as the ones that would be used for any other freight train regardless of cargo.

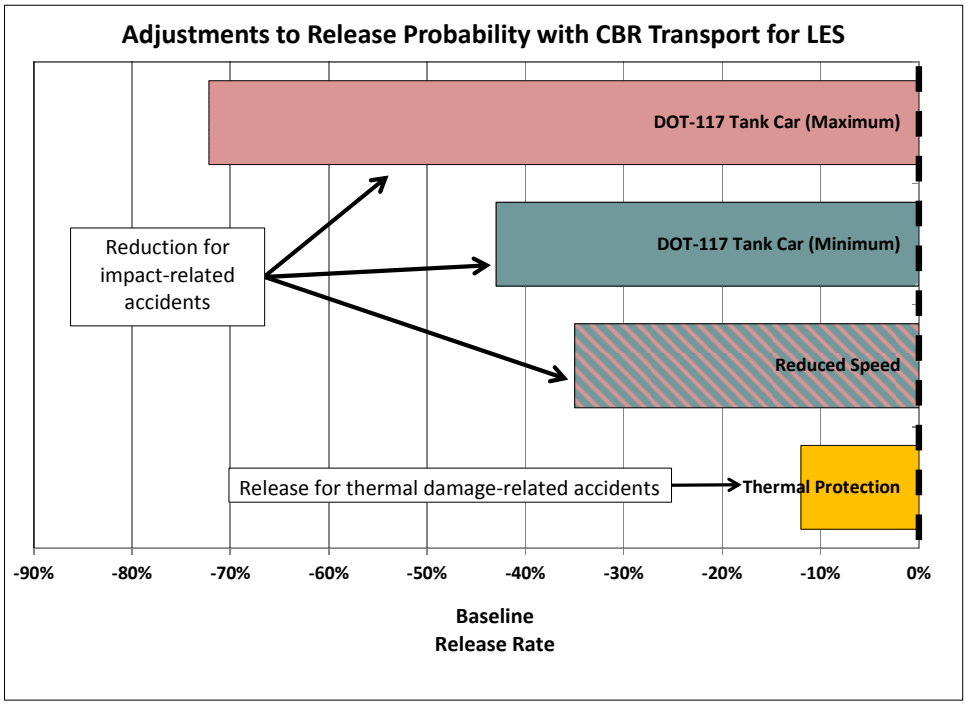


Figure 74: Tornado Chart for Adjustments to Spill Probability with Crude-by-Rail Transport - LES

Conclusions on Sensitivity Analysis

Because of the variations in potential baseline accident rates and other inputs, the CBR-SpillRISK and CBR-SpillRISK-V models were designed in a manner that incorporated distributions of inputs as part of a Monte Carlo simulation. The results in Chapters 9 through 11 were presented as low (minimum), high (maximum), mean, and median values with standard deviations and standard errors, as appropriate. In addition, the two sets of assumptions in the HES and LES calculations led to significantly different results. Depending on whether the safety measures are actually in place, including the exclusive use of DOT-117 (or higher standard) tank cars, the actual risk may be more in line with the LES results than the more conservative HES results. There are significant differences in the results between the two methods, often to orders of magnitude. This reflects that the safety measures, and the extent to which they are applied, as well as to the extent to which their tested or assumed effectiveness bears out in actual usage, will determine the rates of accidents and spills.

The main driver of spills is the accident rate. However, the most important factor in reducing spillage is the DOT-117 tank car as relates to its lowered likelihood of breaching upon impact. The thermal protection features of the DOT-117 tank car only really affect accidents related to fire and explosion, and of course the probability that an accident (*e.g.*, a derailment) might cause subsequent spillage due to secondary thermal damage.

Chapter 13: Probability of 30 PD and 90PD Spills in Specific Locations

The hypothetical spill scenarios that were modeled for potential spill and fire/explosion impacts[298] involved the release of two volumes of oil–5,700 bbl (30 PD) and 20,000 bbl (90PD)–at each of these locations (Figure 75): Location 1: BNSF Railway Swinomish Channel Swing Bridge; Location 2: BNSF Railway Skagit River Crossing Bridge; and Location 3: WSDOT Edmonds Ferry Terminal. These locations were only selected as *representative examples* of types of environments that may potentially be affected by crude-by-rail spill accidents to demonstrate and evaluate these effects. *There is no particular reason to believe that these events are more likely to occur in these specific locations than any other. Overall the probabilities of spills of this magnitude are very low. The probabilities that these types of accident would occur in the particular locations selected for modeling are even more remote.*

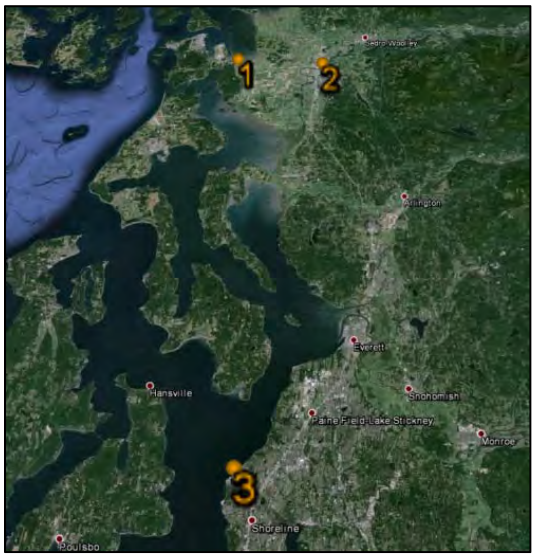


Figure 75: Representative Locations Selected for Spill Impacts Modeling (30PD and 90 PD)

It should be noted that the specific representative locations selected for modeling are already exposed to the remote potential risk of a crude-by-rail accident and spill with traffic going to the Tesoro Refinery in Anacortes (accidents at Locations 1, 2, and 3), and for the BP Cherry Point Refinery (accidents at Locations 2 and 3). The addition of the proposed crude-by-rail traffic for the Shell PSR would just somewhat increase that risk.

The route to the Shell PSR would be along 657 miles, therefore potential Shell PSR-related accidents could occur at any point along that corridor, and the probability would be dependent on the number of trains. For the larger group of crude-by-rail facilities, there would be additional track mileage and train numbers that would be involved as well. The overall probabilities of a 30PD spill or a 90PD spill would be spread over the entire loaded crude-by-rail train corridor.[299] Note that with each tank car being about 65 feet long, a whole 102-car train (with locomotives) would be about 1.4 miles long. A 120-car train would be about 2 miles long.

[298] Risknology 2016; RPS ASA 2016.

[299] Return routes with empty CBR trains would only be exposed to the potential risk of a smaller diesel spill from one or more locomotives and not the 30PD or 90PD crude spill scenarios (or any crude spills).

Issues with Determining Specific Geographic Probabilities of Accidents

A highly-detailed analysis of track conditions, geographic features, and other factors that could affect the probability and nature of rail accidents on each small portion of track (less than one-mile sections) would need to be conducted to reliably estimate the probability of accidents at each spot along the railways. As explained in Chapter 11, with the currently available data on track conditions in Washington State, it is not possible to determine the likelihood of crude-by-rail accidents at different points along the rail corridors with any meaningful degree of accuracy, especially since the only available data are seven years old and are limited in detail. *It should be recognized that there will theoretically be some mile-long track sections that are somewhat more prone or somewhat less prone to accidents and spills based on the condition of the tracks, wayside detector frequency, flood- or washout-areas, train speed, curvature, grading, numbers of at-grade crossings, and other factors.*

The *specific impacts* of spills and/or fires or explosions from loaded crude-by-rail trains are dependent on a large number of site- and time-specific factors, including, but not limited to:

- Geographic features of the site (*e.g.*, land formations, waterbodies, resource proximity)
- Climatic and wind conditions at the time of the release;
- Features that may affect behavior of fires and explosions (e.g., buildings and other structures);
- Proximity to populations and population density; and
- Potential ignition sources.

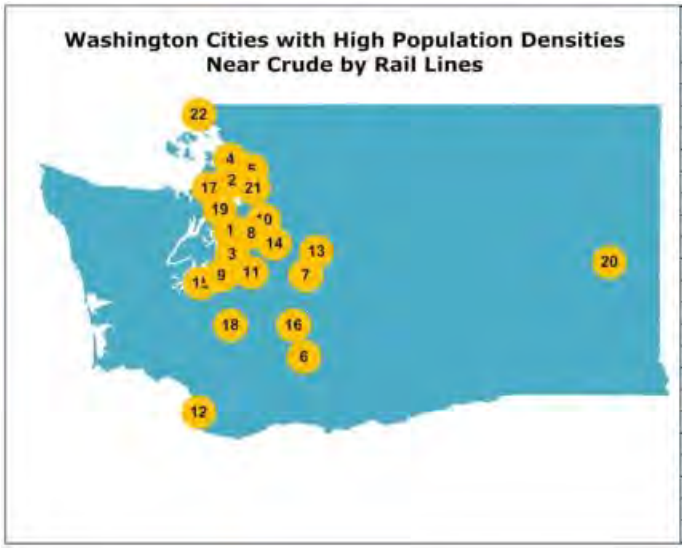
Urban Location and Timing as a Factor for Potential Impacts

The locations in Figure 75 were selected to represent the potential behavior of the spilled oil in water and in the event of ignition.[300] These types of crude oil spill events could occur at any point along the loaded crude-by-rail rail corridor with differing outcomes and putting different numbers of people at risk. For example, if the accident were to occur in an urban area with a dense population, there could be a greater effect. Historically, cities and towns were established along railroad lines and rivers for economic and practical purposes. More than three million Washington State residents live in 93 cities and towns on or near crude-by-rail train routes. The 38 heavily-populated cities and towns (over 3,000 persons per square mile) that are adjacent to crude by rail lines are shown in Figure 76. There are also at least a dozen other cities and towns with population densities of 2,500 to 3,000 per square mile at potential risk.

The potential risk to public safety and health is greatest in locations where crude-by-rail lines run through heavily populated areas, such as the City of Seattle with over 7,000 people per square mile in the vicinity of crude-by-rail lines (Figure 77).

In addition to the location, the precise time that a crude-by-rail accident and spill occurs can have a large influence on the degree of impacts, including fatalities. If the event occurs in a heavily-populated area at a time when there are a lot of people in the vicinity of the accident location, such as at a stadium or during rush-hour traffic, there may be significant casualties (injuries and/or fatalities) if there were also to be an ignition of the spilled oil.

[300] For more information, see Risknology 2016 and RPS ASA 2016.



Rank	City	Density (per square mile)
1	Seattle	7,782
2	Kirkland	4,738
3	Des Moines	4,723
4	Shoreline	4,695
5	Edmonds	4,576
6	Toppenish	4,273
7	Wenatchee	4,160
8	Renton	4,151
9	Tacoma	4,091
10	Bellevue	4,002
11	Kent	3,686
12	Vancouver	3,579
13	E. Wenatchee	3,547
14	Redmond	3,493
15	Lakewood	3,440
16	Yakima	3,375
17	Mukilteo	3,290
18	Covington	3,241
19	Everett	3,182
20	Spokane	3,066
21	Marysville	3,058
22	Bellingham	3,052

Figure 76: Densely-Populated Washington Cities near Crude by Rail Train Routes[301]

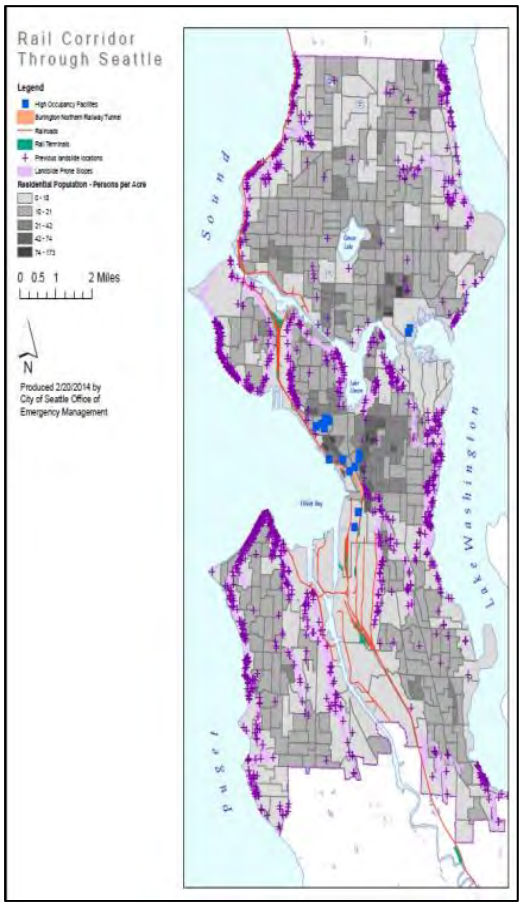


Figure 77: Rail Corridor through Seattle Showing Population Density at Risk[302]

[301] From Etkin et al. 2015a.
[302] From Etkin et al. 2015a.

Approach to Calculation of Geographical Probability of 30PD and 90PD Scenarios

To put a more meaningful perspective on the likelihood of 30 PD and 90PD volume scenarios occurring along any specific locations along the corridors with loaded crude-by-rail unit trains, another type of probability analysis was conducted to determine the *average* probability along any particular mile of *loaded* crude-by-rail track. The probability of spills per train-mile, based on the probability of rail accidents per train-mile and the probability of spillage per accident, were multiplied by the probability of a 30PD spill and a 90PD spill for hypothetical proposed project traffic and for current and potential future traffic for the other crude-by-rail facilities in the state, as in Equation 20 and Equation 21. *Note that these are only the probabilities of a spill of these particular volumes–not that there would be a fire and/or explosion with the spill.*

Equation 20

$$P_{mile}(30PD)/\,year = \left[\frac{accidents}{train-mile}\cdot\frac{spills}{accident}\right]\cdot P(30PD_{vol})\cdot\frac{trains}{year}$$

Equation 21

$$P_{mile}(90PD)/\,year = \left[\frac{accidents}{train-mile}\cdot\frac{spills}{accident}\right]\cdot P(30PD_{vol})\cdot\frac{trains}{year}$$

The result of each equation is a probability of a 30PD (or 90PD) spill per year-mile. This means that one could expect that frequency of spills along one mile of crude-by-rail track in a year (Equation 22). Over the course of multiple years, the probability that a 30PD (or 90PD) spill would occur at some point during that time period is a function of the number of years (Equation 23).

Equation 22

$$\frac{spills}{train-mile}\cdot\frac{30PDspills}{spills(total)}\cdot\frac{trains}{year}=\frac{30PDspills}{mile-year}$$

Equation 23

$$\frac{30PDspills}{mile-year}\cdot n(years)=\frac{n30PDspills}{mile}$$

Probability of 30PD Spill Scenarios per Mile along Loaded Crude-by-Rail Corridor

The calculations were carried out for the 30PD (5,700-bbl scenario) with the results shown in Table 107 for HES and Table 108 for LES. *Note that all of these results only reflect the probability that there would be a spill of this volume, not that it would ignite and cause a fire and/or explosion.*[303]

Table 107: Estimated Per-Mile Probability of 30PD (5,700-bbl) Crude-by-Rail Spill per Year–HES

Statistic	Crude-by-Rail Facilities			
	Current	Shell PSR	Other Future	All Combined
Spills/Train-Mile	0.000000235	**0.000000222**	0.000000235	0.000000235
P(30PD)	0.8	**0.8**	0.8	0.8
30PD Spills/Train-Mile	0.00000019	**0.00000018**	0.00000019	0.00000019
Crude-by-Rail Trains/Year	1,095	**314**	2,219	3,628
30PD Spill/Year-Mile	**0.00021**	**0.00006**	**0.00042**	**0.00068**

[303] For a more detailed analysis of fires and explosions, see Risknology 2016.

Return Years	**4,858**	**17,932**	**2,397**	**1,466**

Table 108: Estimated Per-Mile Probability of 30PD (5,700-bbl) Crude-by-Rail Spill per Year–LES

Statistic	Crude-by-Rail Facilities			
	Current	Shell PSR	Other Future	All Combined
Spills/Train-Mile	0.000000034	**0.000000027**	0.000000034	0.000000034
P(30PD)	0.7	**0.65**	0.7	0.7
30PD Spills/Train-Mile	0.00000002	**0.00000002**	0.00000002	0.00000002
Crude-by-Rail Trains/Year	1,095	**314**	2,219	3,628
30PD Spill/Year-Mile	**0.00003**	**0.00001**	**0.00005**	**0.00009**
Return Years	**38,372**	**181,465**	**18,935**	**11,581**

Each value shown as 30PD spill/year-mile is estimated as frequency per year or as the annual probability of spills in each particular mile of track along which loaded crude-by-rail trains transit. For a particular community, Tribal nation, county, or other jurisdiction with multiple miles of crude-by-rail -transit track, the frequency for the whole jurisdiction is the frequency per mile multiplied by the number of miles of track, as in Equation 24.

Equation 24

$$\frac{30PDspills_{jurisdiction}}{year} = \frac{30PDspills}{year - mile} \cdot miles_{jurisdiction}$$

Probability of 90PD Spill Scenarios per Mile along Loaded Crude-by-Rail Corridor

Similarly, the calculations were carried out for the 90PD (20,000-bbl scenario) with the results shown in Table 109 for HES and Table 113 for LES. These accidents would be expected to be much less frequent than the 30PD accidents.

Table 109: Estimated Per-Mile Probability of 90PD (20,000-bbl) Crude-by-Rail Spill per Year–HES

Statistic	Crude-by-Rail Facilities			
	Current	Shell PSR	Other Future	All Combined
Spills/Train-Mile	0.000000235	**0.000000222**	0.000000235	0.000000235
P(90PD)	0.15	**0.15**	0.15	0.15
90PD Spills/Train-Mile	0.00000004	**0.00000003**	0.00000004	0.00000004
Crude-by-Rail Trains/Year	1,095	**314**	2,219	3,628
90PD Spill/Year-Mile	**0.00004**	**0.00001**	**0.00008**	**0.00013**
Return Years	**25,908**	**95,637**	**12,784**	**7,819**

Table 110: Estimated Per-Mile Probability of 90PD (20,000-bbl) Crude-by-Rail Spill per Year–LES

Statistic	Crude-by-Rail Facilities			
	Current	Shell PSR	Other Future	All Combined
Spills/Train-Mile	0.000000034	**0.000000027**	0.000000034	0.000000034
P(90PD)	0.1	**0.1**	0.1	0.1
90PD Spills/Train-Mile	0.0000000034	**0.0000000027**	0.0000000034	0.0000000034
Crude-by-Rail Trains/Year	1,095	**314**	2,219	3,628

90PD Spill/Year-Mile	**0.0000037**	**0.0000008**	**0.0000075**	**0.0000123**
Return Years	**268,601**	**1,179,523**	**132,545**	**81,069**

Again, each value shown as 90PD spill/year-mile is estimated as frequency per year or as the annual probability of spills in each particular mile of track along which loaded crude-by-rail trains transit. For a particular community, tribal nation, county, or other jurisdiction with multiple miles of crude-by-rail - transit track, the frequency for the whole jurisdiction is the frequency per mile multiplied by the number of miles of track, as in Equation 25.

Equation 25

$$\frac{90PDspills_{jurisdiction}}{year} = \frac{90PDspills}{year - mile} \cdot miles_{jurisdiction}$$

Probabilities of 30PD and 90PD Crude-by-Rail Spills Over Longer Time Frames

Depending on the time frame over which crude-by-rail transport is conducted in the future and the life of the Shell PSR and other state crude-by-rail operations, the probability of an occurrence over that longer period of time can be estimated as in Equation 26 and Equation 27. Example time periods are shown in Table 111 and Table 113 for 30PD spills, in Table 113 and Table 114 for 90PD spills.

Equation 26

$$\frac{30PDspills}{time - period} / mile = \frac{30PDspills}{year - mile} \cdot \frac{years}{time - period}$$

Equation 27

$$\frac{90PDspills}{time - period} / mile = \frac{90PDspills}{year - mile} \cdot \frac{years}{time - period}$$

Table 111: Estimated Per-Mile Probability of 30PD (5,700-bbl) Crude-by-Rail Spills–HES

Crude-by-Rail Facilities	Estimated Spills per Time Period					
	1 year	**5 years**	**10 years**	**15 years**	**20 years**	**25 years**
Current	0.00021	0.00105	0.00210	0.00315	0.00420	0.00525
Shell PSR	**0.00006**	**0.00030**	**0.00060**	**0.00090**	**0.00120**	**0.00150**
Other Future	0.00042	0.00210	0.00420	0.00630	0.00840	0.01050
All Combined	0.00068	0.00340	0.00680	0.01020	0.01360	0.01700

Table 112: Estimated Per-Mile Probability of 30PD (5,700-bbl) Crude-by-Rail Spills–LES

Crude-by-Rail Facilities	Estimated Spills per Time Period					
	1 year	**5 years**	**10 years**	**15 years**	**20 years**	**25 years**
Current	0.00003	0.00015	0.00030	0.00045	0.00060	0.00075
Shell PSR	**0.00001**	**0.00005**	**0.00010**	**0.00015**	**0.00020**	**0.00025**
Other Future	0.00005	0.00025	0.00050	0.00075	0.00100	0.00125
All Combined	0.00009	0.00045	0.00090	0.00135	0.00180	0.00225

Table 113: Estimated Per-Mile Probability of 90PD (20,000-bbl) Crude-by-Rail Spills–HES

Crude-by-Rail Facilities	Estimated Spills per Time Period					
	1 year	**5 years**	**10 years**	**15 years**	**20 years**	**25 years**

Current	0.00004	0.00020	0.00040	0.00060	0.00080	0.00100
Shell PSR	**0.00001**	**0.00005**	**0.00010**	**0.00015**	**0.00020**	**0.00025**
Other Future	0.00008	0.00040	0.00080	0.00120	0.00160	0.00200
All Combined	0.00013	0.00065	0.00130	0.00195	0.00260	0.00325

Table 114: Estimated Per-Mile Probability of 90PD (20,000-bbl) Crude-by-Rail Spills–LES

Crude-by-Rail Facilities	Estimated Spills per Time Period					
	1 year	5 years	10 years	15 years	20 years	25 years
Current	0.000004	0.000019	0.000037	0.000056	0.000074	0.000093
Shell PSR	**0.000001**	**0.000004**	**0.000008**	**0.000012**	**0.000016**	**0.000020**
Other Future	0.000008	0.000038	0.000075	0.000113	0.000150	0.000188
All Combined	0.000012	0.000062	0.000123	0.000185	0.000246	0.000308

These calculations are highly speculative, as they incorporate the assumption that there would be no additional safety improvements to further reduce the chance of accidents and oil outflow, as well as the fact that train numbers would be exactly as estimated in Table 107 through Table 109. Over the long term, the economic conditions that largely govern crude oil markets for the state's refineries and international export relative to other sources of crude oil, or other energy sources, will determine future crude-by-rail transport within the state. Whether or not the other proposed crude-by-rail facilities will be permitted is also an unknown factor even in the shorter term.

Probability of Any Spill per Mile along Loaded Crude-by-Rail Corridor

The per-mile probabilities that are described in Table 111–Table 114 are for relatively large events (as modeled for impacts). There is a much greater probability that a smaller spill might occur. Even a smaller spill that occurs in a heavily-populated area may have significant impacts to human health and safety. The probability that a spill of 250 bbl or larger might occur along any individual mile was calculated with the results in Table 115–Table 118.

Table 115: Estimated Per-Mile Probability of 250-bbl Crude-by-Rail Spill per Year–HES

Statistic	Crude-by-Rail Facilities			
	Current	Shell PSR	Other Future	All Combined
Spills/Train-Mile	0.000000235	**0.000000222**	0.000000235	0.000000235
P(90PD)	1	**1**	1	1
90PD Spills/Train-Mile	0.00000024	**0.00000022**	0.00000024	0.00000024
Crude-by-Rail Trains/Year	1,095	**314**	2,219	3,628
90PD Spill/Year-Mile	**0.00026**	**0.00007**	**0.00052**	**0.00085**
Return Years	**3,886**	**14,346**	**1,918**	**1,173**

Table 116: Estimated Per-Mile Probability of 250-bbl Crude-by-Rail Spill per Year–LES

Statistic	Crude-by-Rail Facilities			
	Current	Shell PSR	Other Future	All Combined
Spills/Train-Mile	0.000000034	**0.000000027**	0.000000034	0.000000034
P(90PD)	1	**1**	1	1
90PD Spills/Train-Mile	0.00000003	**0.00000003**	0.00000003	0.00000003

Crude-by-Rail Trains/Year	1,095	**314**	2,219	3,628
90PD Spill/Year-Mile	**0.00004**	**0.00001**	**0.00008**	**0.00012**
Return Years	**26,860**	**117,952**	**13,255**	**8,107**

Table 117: Estimated Probability of 250-bbl Crude-by-Rail Spill over Time–HES

Crude-by-Rail Facilities	Estimated Spills per Time Period					
	1 year	5 years	10 years	15 years	20 years	25 years
Current	0.0003	0.0013	0.0026	0.0039	0.0052	0.0065
Shell PSR	**0.0001**	**0.0004**	**0.0007**	**0.0011**	**0.0014**	**0.0018**
Other Future	0.0005	0.0026	0.0052	0.0078	0.0104	0.0130
All Combined	0.0009	0.0043	0.0085	0.0128	0.0170	0.0213

Table 118: Estimated Per-Mile Probability of 250-bbl Crude-by-Rail Spill over Time–LES

Crude-by-Rail Facilities	Estimated Spills per Time Period					
	1 year	5 years	10 years	15 years	20 years	25 years
Current	0.00004	0.00020	0.00040	0.00060	0.00080	0.00100
Shell PSR	**0.00001**	**0.00005**	**0.00010**	**0.00015**	**0.00020**	**0.00025**
Other Future	0.00008	0.00040	0.00080	0.00120	0.00160	0.00200
All Combined	0.00012	0.00060	0.00120	0.00180	0.00240	0.00300

Meaning of Per-Mile Spill Probability Estimates

Based on the HES methodology (i.e., assuming that there are no benefits to any safety measures), there is currently (with current crude-by-rail traffic) about a one in 3,000 chance that in any one year there will be a crude-by-rail spill of at least 250 bbl along any one mile of track. If all future crude-by-rail projects are operational, the probability increases to one in 1,000. Through a 25-year time period, the probability of a spill increases to one in 50.

Assuming that there are benefits to the safety measures, based on the LES methodology, there is currently a one in 25,000 chance that there will be a spill of any size. If all crude-by-rail projects are operational, over the course of 25 years, there may be a one in 333 chance of a spill along any particular mile of track.

These probabilities do not mean that the spill will be of a 20,000-bbl magnitude. The probabilities of that are much less. Depending on whether one accepts the HES or LES assumptions, there is currently a one in 25,000 to one in 250,000 chance that a 20,000-bbl spill, such as the scenario modeled, will occur along any one mile of track. Over 25 years, that probability increases to one in 1,000 to one in 10,000 chance that there will be such a large spill. Assuming all of the facilities are operational, the additional crude-by-rail traffic will increase the probability to one in 300 to one in 3,000.

The per-mile spill probability estimates in this chapter are provided only to give a very general sense of the likelihood of different sizes of spills occurring at any particular location. The estimation assumes that there is an equal likelihood of an accident (and consequent spill) occurring on each mile of track. Clearly that is an over-simplification. There are factors in some places that may increase (or decrease) the likelihood that a spill will occur, such as actual track condition, curves, and speed.

But, even if the likelihood is roughly the same along each mile of track, the consequences of a spill will depend on the geographic features of that location, its proximity to populated areas and sensitive resources, the timing of the event, and whether or not the oil ignites. Clearly some miles of track present greater risk with regard to more significant potential consequences in the event of a spill, with or without a fire involved.

With more train traffic and with the passage of time, the probability of a spill increases. This is analogous to driving a car and the likelihood of an accident. The more driving ones does, the greater the chances of an accident. The chances that that accident will occur in any one particular location may be very small, as are the chances that an accident will occur on a specific day or in a specific year. But the more locations one passes (the more car-miles) and the more trips one takes, the greater the likelihood of an accident.

Chapter 14: Spill Probability and Volume Analysis for Spills at Facility

When the crude-by-rail trains are at the Shell PSR facility, spills related to transfer of oil from the rail cars to storage tanks, or related to accidents during movement of crude-by-rail trains within the facility could occur. [*This part of the analysis encompasses only spills from crude-by-rail trains and not from any storage tanks at the Shell PSR.*]

Expected Frequency of CBR Transfer-Related Spills

There are no available data on spills that specifically occur during transfer of oil from crude-by-rail trains within a facility. The Washington State Department of Ecology has tracked transfer operations at facilities where the transfer operations occur over water through its Advance Notification of Transfer rule,[304] but there is currently nothing analogous for rail transfer operations to facility storage tanks.

The frequency of transfer spills for vessels in Washington State is estimated to be about 0.00026 spills per transfer operation after implementation of vessel transfer spill prevention regulations.[305] If the rate of error associated with vessel transfer operations can be extrapolated to crude-by-rail transfer operations, one might expect to see one spill every 4,472 days (once in 12 years) if one assumes that each 102-car train constitutes the unit for a transfer operation. Because operations involved in vessel oil transfers are quite different from crude-by-rail transfer operations, this extrapolation may not be meaningful.

There are no reports of crude-by-rail transfer or facility spills in the US for the years 2012 through 2015 reported by National Response Center. There are also no reports of any crude-by-rail -related transfer spills (or any crude-by-rail spills) for the period July 2011 through March 2015 in Washington State[306].

During this same time period (2012 through 2015), there were two reports of spills that occurred during the transfer of ethanol from tank cars at facilities. Those two spills involved 45 gallons and 50 gallons (1.1 bbl and 1.2 bbl, respectively).[307] With about 1.2 million carloads of ethanol transported in the US during 2012 through 2015, and assuming unit trains of about 100 cars, this comes to a transfer spill rate of about 0.000083 per train.[308] This spill rate is more applicable to crude-by-rail. If there are six trains per week (about 314 trains per year), one might expect one crude-by-rail transfer-related spill every 38 years.

Expected Frequency of Other Crude-by-Rail Spills within Facility

There are no reliable data on train-miles within facilities or even facility rail visits to apply to an analysis based on per-train-mile accident rates. There are also no available data on the number of facilities within the state (or nationwide) that accept freight rail traffic for loading or unloading operations from which facility train-miles or facility visits might be extrapolated.

The only data that are available are records of 4,772 accidents, each involving at least $10,500 in damages to rail equipment or infrastructure nationwide over the years 1975 to 2015. There were 70 such accidents in Washington State.

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[304] http://www.ecy.wa.gov/programs/spills/prevention/antsystem.html
[305] Etkin 2006; Etkin *et al.* 2006.
[306] https://fortress.wa.gov/ecy/coastalatlas/storymaps/spills/spills_sm.html?CustomMap=y&BBox=-14278689,5567182,-12713259,6373746&Tab=nt6&Opacity=1&Basemap=esriLightGray
[307] Based on a review of National Response Center data.
[308] http://archive.freightrailworks.org/ethanol

As per Table 28 (Chapter 2), an average of 1.45 significant rail accidents may be expected throughout Washington State on an annual basis. This would include all kinds of facilities involved with rail transfer operations, not just crude-by-rail facilities.

Spill records for Washington State for the years 1995 through 2007, the time period *before* crude-by-rail transport began, indicate that railroad spills at facilities occurred occasionally.[309] These spills involved diesel fuel, lubricating oil, and hydraulic oil from locomotives. There were 47 accidents that occurred at facilities, or about 2.8 accidents per year. A total of 617 bbl of oil spilled. None of these accidents involved the transfer of oil from a tank car, however. There were four spill accidents involving spillage of diesel fuel from locomotives during July 2011 and March 2015 in Washington–two spills of 1,000 gallons and 1,300 gallons (23.8 bbl and 31 bbl, respectively) at Chemco, Inc., in Kickerville; and two spills of 3 gallons and 10 gallons (0.07 bbl and 0.24 bbl) at Seattle Intermodal, in Seattle. [310]

Given that there are an estimated 10 million train-miles annually in Washington (Table 7 in Chapter 3), this comes to a facility-spill rate of about 5.0×10^{-8} per train-mile. With about 628 annual train-miles estimated for proposed project traffic within the facility,[311] this means an estimated 0.000003 spills annually, or one rail-related facility spill every 31,847 years.

Expected Volume of Crude-by-Rail Facility Spills

Transfer-related spills would be expected to be small, based on the information from the ethanol spills–approximately one barrel at most. Based on the data in Table 55 (Chapter 6), it appears that if a crude-by-rail transit accident were to occur at the Shell PSR, it might involve about four cars (a total of about 2,691 bbl of crude oil cargo). There is a 0.4 percent chance that any of the cars might be damaged enough to have a release. The percent outflow would range from 5 percent to 100 percent (Figure 49 in Chapter 8). The volume of spillage of a crude-by-rail non-transfer spill at the Shell PSR might be 0.5 bbl to 10 bbl. These spills may involve crude oil or diesel fuel in small volumes.

Conclusion on Crude-by-Rail Facility Spills

There are no existing historical data that can reliably be applied to projecting the number of crude-by-rail -related spills that might occur at the Shell PSR. This is because of the infrequency of these accidents in general and the short time frame in which crude-by-rail operations have occurred throughout the US and in Washington. Applying data on ethanol transfer spill rates and other rail facility spills, the estimated spill frequency is summarized in Table 119.

Table 119: Estimated Frequency and Volume of Crude-by-RailSpills within Shell PSR

Spill Type	Frequency		Expected Volume
	Spills per Year	Return Period	
Transfers from Crude-by-RailTank Cars	0.0263	38 years	1 bbl
Rail Accidents at Facility	0.0000266	37,556 years	0.5 to 10 bbl
Total	**0.0263266**	**38 years**	**0.5 to 10 bbl**

[309] French-McCay *et al.* 2008.
[310] https://fortress.wa.gov/ecy/coastalatlas/storymaps/spills/spills_sm.html?CustomMap=y&BBox=-14278689,5567182,-12713259,6373746&Tab=nt6&Opacity=1&Basemap=esriLightGray
[311] Assuming 314 train trips annually with two miles rail transit within the facility.

Chapter 15: Spill Probability Results Summary

The analyses in this report focused solely on quantifying to the extent possible:

- The probability of a spill associated with the transport of crude oil by rail to the Shell PSR;
- The probability of a spill from locomotives from crude-by-rail trains transiting to or leaving the Shell PSR;
- The probability of a crude-by-rail -related spill at the Shell PSR; and
- The potential distribution of volumes associated with a crude-by-rail -related spill, from more typical small spill events up to 90th percentile discharges (90PDs).

Two Spill Estimation Methodologies

In order to provide a more conservative estimate[312] of rail accident and spill probabilities in addition to an estimate that incorporates the safety enhancements and risk reduction measures that have been in place or is expected to soon be in place for freight rail traffic in general and crude-by-rail traffic in particular, two separate spill probability estimates were calculated:

- Lower Estimate of Spills (LES)
- Higher Estimate of Spills (HES)

The calculated Lower Estimate of Spills (LES) provides a more "optimistic" assessment of spills based on accident and tank car release rates by incorporating the following assumptions:

- The rail accident rate calculated from historical general freight accident data needs to be adjusted to take into account the changes in rail safety that have occurred over the last decade or more;
- There are particular aspects of crude-by-rail transport that need to be taken into account with regard to accident rates and spillage rates, such as speed restrictions, enhanced braking, positive train control, wayside detectors, thermal protection, and tank car design; and
- The greater train length of crude-by-rail unit trains will increase the likelihood of accidents relative to the more typical shorter freight trains, as described in greater detail in Chapter 5.

Note that the LES incorporates two assumptions that may *increase* the likelihood of accidents over the "baseline" rate from historical rail accident data. Even with this adjustment, the overall estimate will be lower than that calculated with the HES assumptions described below. This is due to the fact that the safety enhancements would still tend to lead to a net decrease the accident and spill rates. [This is described in greater detail in Chapter 5.]

The reasoning behind assuming the two accident rate increase factors is that the purpose of the LES is to estimate an accident and spill rate that incorporates, to the extent possible and based on the available

[312] A conservative estimate is one that is cautious to avoid excess in approximating the quantity, degree, or worth of something. On the other hand a liberal estimate would be one that is cautious to avoid underestimating the quantity in question. In this case, the conservatism comes into play with respect to the assumptions of safety enhancements and reduction of accident and spill rates with the improvements that have been made or are about to be made on rail lines and equipment. In effect, a conservative estimate of the accident and spill rate would assume that there are no benefits of safety improvements. This would result in a higher estimate of spill probability.

research data, the aspects of crude-by-rail transport that would affect the overall freight rail accident and spillage rates.

The calculated Higher Estimate of Spills (HES) provides a more "conservative" assessment of accident and spill rates by incorporating the following assumptions:

- The rail accident rate calculated from historical general freight accident data is appropriate for application to crude-by-rail traffic with no adjustments for safety measures;
- There are no particular aspects of crude-by-rail transport that would make the accident or tank car release rate different than for all freight traffic;
- There may be an increase in accident rates due to "sloshing" effects; and
- The greater train length of crude-by-rail unit trains will increase the likelihood of accidents relative to the more typical shorter freight trains, as described in greater detail in Chapter 5.

The majority of the safety enhancements for freight rail (and crude-by-rail) transport have already been incorporated into the main line rail systems in Washington State. However, to remain conservative, the HES assumes that the track enhancements that were completed in Washington State in May 2016 would not be included in the estimation of accident probabilities. [This is discussed in greater detail in Chapters 5 and 7.]

Probabilities of Crude-by-Rail Spills

The probability of crude oil spills or annual spill frequency *of any volume* from loaded crude-by-rail trains traveling to the Shell PSR was estimated to be 0.046 spills per year, based on the HES approach, and 0.0055 spills per year, based on the LES approach. This translates to one spill every 22 years as the HES, and one spill every 180 years as the LES. These estimates were based on analyses of historical freight train accidents, release rates from hazmat tank cars, and adjustments made to take into account safety enhancements for crude-by-rail transport, as described above. In addition to the crude spills, there are also projected to be 0.0038 diesel spills annually from locomotives carrying empty cars, based on HES, and 0.00098 diesel spills per year, based on LES. This is the equivalent of one spill every 264 years for the HES, and one spill every 1,000 years for the LES. These estimates are based on six crude-by-rail trains per week arriving at and departing from the Shell PSR.

These hypothetical spills would occur within the context of a larger set of crude-by-rail spills for current facilities and other potential future facilities. Currently, there are an estimated 21 weekly crude-by-rail trains arriving at two operating facilities. If all the facilities, including the Shell PSR were to be approved and become operational, the weekly trainloads would reach about 70. The Shell PSR would represent 8.6 percent of the total crude-by-rail traffic.

The *net* change with the proposed project with respect to projected annual spills is summarized in Table 120 for HES and Table 121 for LES. Overall, the net increase in spills over the background of the total projected crude-by-rail -related spills for the other future crude-by-rail facilities is 15 percent (HES) or 12 percent (LES). If all of these facilities would become operational, including the Shell PSR, the proportion of crude-by-rail spills associated with the proposed project would be expected to make up 9.5 percent (HES) or 7.2 percent (LES) of the total. For crude oil spills from loaded crude-by-rail trains in particular,

the proposed project operations might increase the total spill number by eight percent. *Note that these are spills of any size, not necessarily large spills.*

Table 120: Net Increase in Crude-by-Rail Spills with the Shell PSR–HES

Spill Type	Expected Annual Spills				Shell PSR Comparison	
	Current	Shell PSR	Other Future	All Facilities	% Increase Above All Future Facilities[313]	% Total
Crude Oil	0.17	0.046	0.26	0.48	15.0%	9.6%
Diesel Loaded	0.018	0.0047	0.026	0.0485	15.3%	9.7%
Diesel Empty	0.013	0.0038	0.029	0.046	11.6%	8.3%
Total	**0.201**	**0.0545**	**0.315**	**0.5745**	**14.7%**	**9.5%**

Table 121: Net Increase in Crude-by-Rail Spills with the Shell PSR–LES

Spill Type	Expected Annual Spills				Shell PSR Comparison	
	Current	Shell PSR	Other Future	All Facilities	% Increase Above All Future Facilities	% Total
Crude Oil	0.025	0.0055	0.037	0.069	12.9%	8.0%
Diesel Loaded	0.0068	0.0012	0.0098	0.019	10.9%	6.3%
Diesel Empty	0.005	0.00098	0.011	0.018	8.2%	5.4%
Total	**0.0368**	**0.00768**	**0.0578**	**0.106**	**11.7%**	**7.2%**

Spill Volumes for Crude-by-Rail Spills

An analysis of the potential volumes of spills was also conducted. Most spills are quite small with minimal impacts. There is a low probability of larger spills. The expected numbers of crude oil spills by volume due to crude-by-rail accidents in transit are shown in Table 122 for HES and Table 123 for LES.

Diesel spills from locomotives from loaded and empty crude-by-rail trains would be much smaller because of the smaller volume of fuel in the locomotives relative to tank car volumes. Expected annual frequencies of locomotive spills are in Table 124–Table 126 for empty and loaded trains (HES and LES).

Table 122: Expected Average Frequency of Crude-by-Rail Crude Spills by Volume–HES

Spill Volume	Shell PSR		Current		Other Future		All Combined	
	Prob/ Year	Return Years	Prob/ Year	Return Years	Prob/ Year	Return Years	Prob/ Year	Return Years
250 bbl	0.046	22	0.17	6	0.26	3.9	0.48	2.1
2,500 bbl	0.041	24	0.15	6.5	0.23	4.3	0.43	2.3
4,000 bbl	0.037	27	0.14	7.4	0.21	4.8	0.38	2.6
5,700 bbl (30PD)	**0.032**	**31**	**0.12**	**8.4**	**0.18**	**5.5**	**0.34**	**3**
8,000 bbl	0.025	40	0.094	11	0.14	7	0.26	3.8
10,000 bbl	0.016	62	0.060	17	0.091	11	0.17	6
15,000 bbl	0.012	87	0.043	24	0.065	15	0.12	8.3
20,000 bbl (90PD)	**0.0069**	**140**	**0.026**	**39**	**0.039**	**26**	**0.072**	**14**
40,000 bbl	0.00092	1,100	0.0034	290	0.0052	190	0.0096	100

[313] Includes all future proposed facilities and Shell PSR (excluding current facilities).

50,000 bbl	0.00005	22,000	0.00017	5,900	0.00026	3,800	0.00048	2,100

Table 123: Expected Average Frequency of Crude-by-Rail Crude Spills by Volume–LES

Spill Volume	Shell PSR		Current		Other Future		All Combined	
	Prob/ Year	Return Years	Prob/ Year	Return Years	Prob/ Year	Return Years	Prob/ Year	Return Years
250 bbl	0.0055	180	0.025	40	0.037	27	0.069	14
2,500 bbl	0.005	200	0.023	44	0.033	30	0.062	16
4,000 bbl	0.0044	230	0.02	50	0.03	34	0.055	18
5,700 bbl (30PD)	**0.0036**	**280**	**0.016**	**62**	**0.024**	**42**	**0.045**	**22**
8,000 bbl	0.003	330	0.014	73	0.02	49	0.038	26
10,000 bbl	0.0022	450	0.01	100	0.015	68	0.028	36
15,000 bbl	0.0014	730	0.063	160	0.0093	110	0.017	58
20,000 bbl (90PD)	**0.0055**	**1,800**	**0.0025**	**400**	**0.0037**	**270**	**0.0069**	**140**
40,000 bbl	0.000055	18,000	0.00025	4,000	0.00037	2,700	0.00069	1,400
50,000 bbl	0.0000055	180,000	0.000025	40,000	0.000037	27,000	0.000069	14,000

Table 124: Expected Average Frequency of Diesel Spills from Empty Crude-by-Rail Trains–HES

Spill Volume	Shell PSR		Current		Other Future		All Combined	
	Prob/ Year	Return Years	Prob/ Year	Return Years	Prob/ Year	Return Years	Prob/ Year	Return Years
5 bbl	0.0038	260	0.013	76	0.029	34	0.046	22
25 bbl	0.0034	290	0.012	85	0.026	38	0.041	24
40 bbl	0.0027	380	0.0091	110	0.02	49	0.032	31
50 bbl	0.0021	480	0.0072	140	0.016	63	0.025	40
60 bbl	0.0015	660	0.0052	190	0.012	86	0.018	54
70 bbl	0.0011	880	0.0039	260	0.0087	120	0.014	72
100 bbl	0.00038	2,600	0.0013	770	0.0029	340	0.0046	220
250 bbl	0.00019	5,300	0.00065	1,500	0.0015	690	0.0023	440
300 bbl	0.00006	26,000	0.00013	7,700	0.00029	3,400	0.00046	2,200

Table 125: Expected Average Frequency of Diesel Spills from Empty Crude-by-Rail Trains–HES

Spill Volume	Shell PSR		Current		Other Future		All Combined	
	Prob/ Year	Return Years	Prob/ Year	Return Years	Prob/ Year	Return Years	Prob/ Year	Return Years
5 bbl	0.00098	1,000	0.005	198	0.011	89	0.018	56
25 bbl	0.00088	1,100	0.0045	220	0.0099	100	0.016	62
40 bbl	0.00069	1,500	0.0035	290	0.0077	130	0.013	79
50 bbl	0.00054	1,900	0.0028	360	0.0061	170	0.0099	100
60 bbl	0.00039	2,600	0.002	500	0.0044	230	0.0072	140
70 bbl	0.00029	3,400	0.0015	670	0.0033	300	0.0054	190
100 bbl	0.000098	10,000	0.0005	2,000	0.0011	910	0.0018	560
250 bbl	0.000049	20,000	0.00025	4,000	0.00055	1,800	0.0009	1,100

300 bbl	0.000001	100,000	0.00005	20,000	0.00011	9,100	0.00018	5,600

Table 126: Expected Average Frequency of Diesel Spills from Loaded Crude-by-Rail Trains

Spill Volume	Shell PSR		Current		Other Future		All Combined	
	Number Per Year	Return Years	Number Per Year	Return Years	Number Per Year	Return Years	Number Per Year	Return Years
5 bbl	0.0047	210	0.018	57	0.025955	39	0.049	21
25 bbl	0.0042	240	0.016	62	0.023270	43	0.043	23
40 bbl	0.0034	300	0.012	81	0.017900	56	0.034	30
50 bbl	0.0026	380	0.0097	100	0.014320	70	0.026	38
60 bbl	0.0019	540	0.007	140	0.010740	93	0.019	53
70 bbl	0.0014	730	0.0053	190	0.007787	130	0.015	68
100 bbl	0.00047	2,100	0.0018	570	0.002596	390	0.0049	210
250 bbl	0.00024	4,200	0.00088	1,100	0.001343	750	0.0024	410
300 bbl	0.000075	13,000	0.00018	5,700	0.000260	3,900	0.00049	2,100

Table 127: Expected Average Frequency of Diesel Spills from Loaded Crude-by-Rail Trains

Spill Volume	Shell PSR		Current		Other Future		All Combined	
	Number Per Year	Return Years	Number Per Year	Return Years	Number Per Year	Return Years	Number Per Year	Return Years
5 bbl	0.0012	820	0.0068	150	0.0098	109	0.019	53
25 bbl	0.0011	910	0.0061	160	0.0089	119	0.017	59
40 bbl	0.00086	1,200	0.0047	210	0.0069	150	0.014	73
50 bbl	0.00067	1,500	0.0038	260	0.0055	180	0.010	96
60 bbl	0.00049	2,100	0.0027	370	0.0039	250	0.0076	130
70 bbl	0.00036	2,800	0.002	490	0.003	340	0.0057	180
100 bbl	0.00012	8,200	0.00068	1,500	0.00099	1,000	0.0019	530
250 bbl	0.000061	16,000	0.00034	3,000	0.000499	2,000	0.00095	1,100
300 bbl	0.000001	800,000	0.000068	15,000	0.000098	10,000	0.00019	5,300

Rail-Related Facility Spills

In addition to spills that might hypothetically occur during crude-by-rail transport to and from the Shell PSR, there is the possibility that there could be spills from the crude-by-rail trains at the facility itself. These spills might occur during oil transfer operations or during movement of trains within the facility bounds.

The estimated frequency and volume of crude-by-rail spills within the facility are summarized in Table 128. These spills would also tend to be small and could involve crude oil or diesel fuel.

Table 128: Estimated Frequency and Volume of Crude-by-Rail Spills within the Shell PSR

Spill Type	Frequency		Expected Volume
	Spills per Year	Return Period	
Transfers from Crude-by-Rail Tank Cars	0.0263	38 years	1 bbl
Rail Accidents at Facility	0.0000266	37,556 years	0.5 to 10 bbl
Total	**0.0263266**	**38 years**	**0.5 to 10 bbl**

Table 129. The low estimates are summarized in Table 130.

Table 129: Projected Crude-by-Rail Oil Spill Frequencies for Shell PSR–Higher Estimate of Spills				
Spill Source	**Oil Type**	**Small Spills**	**Moderate Spills**	**Very Large Spills**
Loaded Crude-by-Rail Train in Transit (Tank Cars)	**Crude**	**250 bbl**	**5,700 bbl**	**20,000 bbl**
		0.046/year	0.032/year	0.0069/year
		1 in 22 years	1 in 31 years	1 in 140years
Loaded Crude-by-Rail Train in Transit (Locomotives)	**Diesel**	**5 bbl**	**100 bbl**	**250 bbl**
		0.0047/year	0.00047/year	0.00024/year
		1 in 210 years	1 in 21,00 years	1 in 4,200 years
Empty Crude-by-Rail Train in Transit (Locomotives)	**Diesel**	**5 bbl**	**100 bbl**	**250 bbl**
		0.0038/year	0.00038/year	0.00019/year
		1 in 260 years	1 in 26,00 years	1 in 5,300 years
Crude-by-Rail Trains at Facility Transfers (Tank Cars)	**Crude**	**1 bbl**	*Projections of larger spills were not possible due to the lack of historical accidents on large tank car transfer accidents of any kind.*	
		0.026/year		
		1 in 40 years		
Crude-by-Rail Trains at Facility Rail Accidents (Locomotives or Tank Cars)	**Diesel or Crude**	**0.5 bbl–10 bbl**		
		0.000027/year		
		1 in 38,000 years		

Table 130: Projected Crude-by-Rail Oil Spill Frequencies for Shell PSR–Lower Estimate of Spills				
Spill Source	**Oil Type**	**Small Spills**	**Moderate Spills**	**Very Large Spills**
Loaded Crude-by-Rail Train in Transit (Tank Cars)	**Crude**	**250 bbl**	**5,700 bbl**	**20,000 bbl**
		0.0055/year	0.0036/year	0.0055/year
		1 in 180 years	1 in 280 years	1 in 1,800 years
Loaded Crude-by-Rail Train in Transit (Locomotives)	**Diesel**	**5 bbl**	**100 bbl**	**250 bbl**
		0.0012/year	0.00012/year	0.00061/year
		1 in 820 years	1 in 8,200 years	1 in 16,000 years
Empty Crude-by-Rail Train in Transit (Locomotives)	**Diesel**	**5 bbl**	**100 bbl**	**250 bbl**
		0.00098/year	0.00098/year	0.000049/year
		1 in 1,000 years	1 in 10,000 years	1 in 20,000 years
Crude-by-Rail Trains at Facility Transfers (Tank Cars)	**Crude**	**1 bbl**	*Projections of larger spills were not possible due to the lack of historical accidents on large tank car transfer accidents of any kind.*	
		0.026/year		
		1 in 40 years		
Crude-by-Rail Trains at Facility Rail Accidents (Locomotives or Tank Cars)	**Diesel or Crude**	**0.5 bbl–10 bbl**		
		0.000027/year		
		1 in 38,000 years		

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Glossary of Terms and Acronyms

30PD: 30th percentile discharge (defined as 5,700 bbl)

90PD: 90th percentile discharge (defined as 20,000 bbl)

AAR: Association of American Railroads

Acoustic bearing detector (TADS-ABD): a type of wayside detector that uses acoustic signatures to evaluate the sound of internal bearings and identify those likely to fail in the near term.

Association of American Railroads (AAR): an industry trade group representing primarily the major freight railroads of North America (Canada, Mexico and the United States); Amtrak and some regional commuter railroads are also members.

At-grade crossing: a railroad crossing with a roadway where the two transport axes intersect at the same level.

Automatic Block System (ABS): a form of rail operation in which fixed block signals are controlled by a system in which signals work automatically, including clear track detection (device that detects the occupation and clearance of a track section).

Bakken crude oil: a form of light crude oil that originates from the Bakken Region or Formation in the Williston Basin located in northwestern North Dakota, northeastern Montana, southern Saskatchewan and southwestern Manitoba.

BNSF: the name for the entity formerly referred to as "Burlington Northern Santa Fe Railroad"; the acronym is the official name–BNSF is no longer spelled out as "Burlington Northern Santa Fe Railroad."

Car-mile: a unit that is the equivalent of one rail car traversing one mile.

Centralized Traffic Control (CTC): A control system in which the local interlockings are remote-controlled by a dispatcher and the trains are governed by signal indication.

Class I railroad: as per the Surface Transportation Board a railroad "having annual carrier operating revenues of $250 million or more" after adjusting for inflation using the Railroad Freight Price Index developed by the Bureau of Labor Statistics.

Class II railroad: a railroad that hauls freight and is mid-sized in terms of operating revenue (as of 2011, a railroad with revenues greater than $37.4 million but less than $433.2 million for at least three consecutive years); switching and terminal railroads are excluded from Class II status. Railroads considered by the Association of American Railroads as "Regional Railroads" are typically Class II.

Class III railroad: also called a shortline railroad, which has an annual operating revenue of less than $20 million (1991 dollars); typically local shortline railroads serving a small number of towns and industries or hauling cars for one or more larger railroads.

Class-111 tank car: the Canadian term "Class 111" non-pressure tank car is the equivalent of the DOT-111 tank car; this type of tank car is also sometimes called the CTC-111A.

Classification bowl: a section of a rail classification yard that contains tracks in which the various cars are assembled into trains bound for various destinations

Commodity Owner: the shipper, consignee or a beneficial owner.

Commodity: a marketable item; a generic term for vessel cargo.

Common Carrier Obligations: the obligation of railroads to transport all goods offered for transportation, including hazardous materials. This obligation is a common law doctrine, codified in the Interstate Commerce Act and recognized by the U.S. Supreme Court in the early 1900s. The Interstate Commerce Commission Termination Act of 1995 (ICCTA) maintains the common carrier obligations of railroads and requires railroads to "provide the transportation or service on reasonable request." This obligation ensures that railroads do not unreasonably discriminate between shippers. Thus, railroads may not refuse shipment on the basis of inconvenience or lack of profitability.

Consignee: the company receiving the shipment at the destination.

CP: Canadian Pacific Railroad

CSX: CSX Transportation Class I railroad (east coast)

CTC: Centralized Traffic Control

Density: mass or weight per unit volume; *e.g.*, one pound of lead is much more dense than one pound of feathers.

Determination of Non-Significance (DNS): documents the responsible official's decision that a proposal is not likely to have significant adverse environmental impacts.

DNS: Determination of Non-Significance

DOT: Department of Transportation

DOT-111 tank car: the general characteristics of a DOT-111 tank car under existing regulations are as follows: DOT-111 cars are roughly 60 feet long, 11 feet wide and 16 feet high; the cars weigh approximately 80,000 pounds empty and 286,000 pounds when full; the cars can hold about 30,000 gallons or 715 barrels of oil depending on oil density; the tank is made of steel plate with a thickness of

7/16 of an inch; and the tank has a life span of approximately 50 years, with a 30–40 year economic lifespan.

DOT-117 tank car: a rail tank car that meets the specifications of PHSMA and FRA with regard to having a jacket, a wall thickness of 9/16 inch, thermal protection, a bottom outlet handles, top fittings protection, ECP brakes, and other features that reduces the likelihood of release on impact.

Ecology (ECY): the environmental regulatory agency of Washington State.

ECP: Electronically Controlled Pneumatic (brake)

EFSEC: Energy Facility Site Evaluation Council

EIA: environmental impact assessment or US Energy Information Administration

EIS: environmental impact statement

Energy Facility Site Evaluation Council (EFSEC): provides a "one-stop" siting process for major energy facilities in the State of Washington. EFSEC coordinates all evaluation and licensing steps for siting certain energy facilities in Washington. EFSEC specifies the conditions of construction and operation. If approved, a Site Certification Agreement is issued in lieu of any other individual state or local agency permits. EFSEC also manages an environmental and safety oversight program of facility and site operations.

Environmental Impact Statement (EIS): under U.S. environmental law, a document required by the National Environmental Policy Act (NEPA) for certain actions "significantly affecting the quality of the human environment"; an EIS is a tool for decision making. It describes the positive and negative environmental effects of a proposed action, and it usually also lists one or more alternative actions that may be chosen instead of the action described in the EIS.

EPA: Environmental Protection Agency

Federal Railroad Administration (FRA): an agency within the US Department of Transportation that has jurisdiction over railroad safety at the federal level.

Federal Railroad Safety Act (FRSA): a Congressional act of 1970 that promotes the safety in all areas of railroad operations to reduce railroad-related accidents, and to reduce deaths and injuries to persons, and to reduce damage to property caused by accidents involving any carrier of hazardous materials (49 U.S.C §20109).

FMCSA: Federal Motor Carrier Safety Administration

FRA Class 1 Track: track classified by FRA with respect to maximum speed for track condition as 10 mph for freight, 15 mph for passenger. Much yard, branch line, short line, and industrial spur trackage falls into category.

FRA Class 2 Track: track classified by FRA with respect to maximum speed for track condition as 25 mph for freight, 30 mph for passenger; Branch lines, secondary main lines, many regional railroads, and some tourist operations frequently fall into this class.

FRA Class 3 Track: track classified by FRA with respect to maximum speed for track condition as 40 mph for freight, 60 mph for passenger. This commonly includes regional railroads and Class 1 secondary main lines.

FRA Class 4 Track: track classified by FRA with respect to maximum speed for track condition as 60 mph for freight, 80 mph for passenger. This is the dominant class for main-line track used in passenger and long-haul freight service.

FRA Class 5 Track: track classified by FRA with respect to maximum speed for track condition as 80 mph for freight, 90 mph for passenger. This is the standard for most high-speed track in the U.S.

FRA Class 6 Track: track classified by FRA with respect to maximum speed for track condition as 110 mph for freight, 110 mph for passenger. This is found in the U.S. exclusively on Amtrak's Northeast Corridor between New York and Washington, DC.

FRA: Federal Railroad Administration

FRSA: Federal Railroad Safety Act

Hazmat: hazardous material

HHFT: high-hazard flammable trains

High Level Radioactive Waste (HLRW): waste generated in core fuel of a nuclear reactor, found at nuclear reactors or by nuclear fuel reprocessing.

High/Wide/Shifted Load Detector (SLD): a device that detects significant shifts in cargo that may cause instability in a train.

Hot box and dragging equipment detector: the most commonly used types of wayside detector; a hot box detector is a heat-sensitive device used to measure the temperature of journal bearings on passing rail cars; a dragging equipment detector detects loose components and dragging under freight cars.

Hump yard: a rail yard in which the vehicles run down an artificial hill ("hump") into a classification bowl, *i.e.*, an area in which the various cars are assembled into trains bound for various destinations.

ICC: The Interstate Commerce Commission

ICCTA: The Interstate Commerce Commission Termination Act of 1995

Key train: any train with 20 carloads or intermodal portable tank loads of any combination of hazardous materials.

Ladder track: sometimes called the "lead track", is a track off which switches to yard tracks that are normally parallel to each other are contained, The switches provide access to the yard tracks from the ladder or lead track. Train/car movements arrive or depart from yard tracks by utilizing the ladder track to access the specific switch that allows movements to/from a particular yard track. The ladder or lead track is also often used as the "switching lead" when cars are pulled from a yard track and separated to other yard tracks for the purpose of combining cars with similar destinations together on one track.

Loop Track: a continuous track within a facility normally of sufficient length to allow a unit train to remain intact while loading or unloading a commodity. An example of loop tracks that allow unit train unloading while the train remains intact is the EGT export grain facility at Port of Longview. Many of the origin locations for unit grain and coal trains feature loop tracks that allow loading of a train without breaking it apart. If a loop track is not available at a loading or unloading facility, cars are spotted in smaller numbers then reassembled after the loading or unloading activity is completed to create the unit train.

LTQ: Loading Target Quantity

Main line: a track that is used for through trains or is the principal artery of the system from which branch lines, yards, sidings and spurs are connected. It generally refers to a route between towns, as opposed to a route providing suburban or metro services.

Manifest train: a freight train contains cars with various types of cargo. They may include rail tank cars that carry chemicals, refined oil products, and even crude oil. In some cases, manifest trains contain a “block” of as many as 20 crude oil tank cars.

MDNS: Mitigated Determination of Non-Significance

Mitigated Determination of Non-Significance (MDNS): a mitigated determination of non-significance is issued under WAC 197-11-350(2) or 350(3), or a DNS issued after a determination of significance is withdrawn [WAC 197-11-360(4)]

MMA: Montreal Maine & Atlantic Railroad

MP: milepost (on railroad line)

National Transportation Safety Board (NTSB): an independent federal agency that makes recommendations towards preventing future accidents based on its findings, but does not have any

regulatory authority. Unlike the FRA, the NTSB is not required to factor costs, input from stakeholders or impacts on industry when making recommendations or issuing safety advisories.

Notice of Proposed Rulemaking (NPRM): a public notice issued by law when one of the independent agencies of the United States government wishes to add, remove, or change a rule or regulation as part of the rulemaking process. It is an important part of United States administrative law, which facilitates government by typically creating a process of taking of public comment.

NPRM: Notice of Proposed Rulemaking

NRF: National Response Framework

NTSB: National Transportation Safety Board

Overheated journal bearings detector (HBD): a device that detects overheating in the trucks (or wheel axles) of a locomotive.

Packing Group (PG): the classification of cargoes with respect to flammability and other hazards

Packing Group I: the highest level of packing group (*i.e.*, the most dangerous cargo); includes toxic substances and preparations presenting a very severe risk for flammability, with an initial boiling point of less than 95°F.

Packing Group II: substances with a flash point of less than 73.4°F, and an initial boiling point of more than 95°F.

Packing Group III: substances with a flash point of between 73.4°F and 141.8°F, and an initial boiling point of more than 95°F.

PADD: Petroleum Administration for Defense Districts

Petroleum Administration Defense Districts (PADD): the U.S. is divided into five Petroleum Administration for Defense Districts, or PADDs, as created during World War II under the Petroleum Administration for War to help organize the allocation of fuels derived from petroleum products, including gasoline and diesel (or "distillate") fuel; today, these regions are still used for data collection purposes; PADD 5 includes: Alaska, Arizona, California, Hawaii, Nevada, Oregon, and Washington.

PG: Packing Group

PHMSA: Pipeline and Hazardous Material Safety Administration

Pipeline and Hazardous Material Safety Administration (PHMSA): an agency within the US Department of Transportation that is responsible for establishing and enforcing requirements for the safe transport of hazardous materials by all modes of transportation, including the design of railroad tank cars

carrying crude oil. PHMSA was created in 2004 with the purpose of providing US Department of Transportation a more focused research organization and establishing an operating administration for the inspection and enforcement of requirements for pipeline safety and hazardous materials transportation.

PNWR: Portland and Western Railroad

Positive train control (PTC): an advanced automatic train protection system that enforces movement authorities, speed restrictions (signal and civil), and protection of roadway workers.

Private grade crossing (private crossing): crossing between railroad tracks and privately owned roadways, such as on a farm or industrial area, and is intended for use by the owner or by the owner's licensees and invitees. A private crossing is not intended for public use and is not maintained by a public highway authority.

PTC: positive train control

Public grade crossings: crossings between railroads and roadways that are under the jurisdiction of, and maintained by, a public authority.

Rail capacity: the maximum traffic flow a piece of infrastructure (in this case, railroad lines) can handle under specified operating conditions.

Rail crossing: an intersection of two railroad tracks or a railroad track and a highway or road.

Railway bearing detector (RailBAM™): a type of wayside detector that detect faulty wheel bearings as trains pass by.

RCW: Revised Code of Washington

Recurrence interval: same as "return period"

Refinery throughput capacity (or refinery capacity): the maximum amount of crude oil designed to flow into the distillation units, in other words, this is the amount of crude oil that a refinery can process on a daily basis; actual throughput may be less than this and may vary from day to day.

Return period/return years: the expected period of time that would, on average, pass before a particular event might occur, which is calculated as the inverse of the annual frequency or probability; e.g., a major flood may occur approximately every 100 years or so (the "100-year-flood"). This does not mean that the event will not occur before the time period is up or that it could not occur more frequently, or less frequently.

RTRA: railroad traffic risk assessment

SEPA: State Environmental Policy Act

Siding: another term for a loop track.

Single Track: a location, either on the mainline or within a facility that features only one track on which train operations can occur at any given time. For example, an unloading facility that features a loop track operation may only have one loop track for unloading. Consequently, only one train can be in the facility at any given time, unless the loop track has sufficient length to allow a train to be on either side of the unloading location at the same time. The second train can arrive short of the unloading location as the first train is completing its unloading. If the facility only features sufficient track length for one train to be on-site at any given time, following trains waiting to access the facility when the first train departs have to be staged on other tracks off the facility site, normally either in a yard or in mainline meet/pass sidings.

Spent Nuclear Fuel (SNF): irradiated fuel or targets containing uranium, plutonium, or thorium that is permanently withdrawn from a nuclear reactor or other neutron irradiation facility following irradiation, the constituent elements of which have not been separated by reprocessing.

State Environmental Policy Act (SEPA): provides a way to identify possible environmental impacts that may result from governmental decisions. These decisions may be related to issuing permits for private projects, constructing public facilities, or adopting regulations, policies, or plans. Information provided during the SEPA review process helps agency decision-makers, applicants, and the public understand how a proposal will affect the environment; this information can be used to change a proposal to reduce likely impacts, or to condition or deny a proposal when adverse environmental impacts are identified; it also gives agencies the ability to condition or deny a proposal due to identified likely significant adverse impacts; in Washington, the Act is implemented through the SEPA Rules, Chapter 197-11 WAC.

STB: Surface Transportation Board

Surface Transportation Board (STB): an agency created by the ICC Termination Act of 1995 as the successor agency to the Interstate Commerce Commission. STB has jurisdiction over railroad rate and service issues and rail restructuring, such as mergers, sales and the construction and abandonment of rail lines. STB is an independent adjudicatory and economic regulatory agency, but administratively a part of US Department of Transportation.

Ton-mile: a unit of measure the combines the tonnage of cargo or freight and the distance traveled; a single ton-mile is a ton of cargo being transported one mile.

Track Warning Device (TWD): a device that inspects passing trains for defects or monitors for unusual trackside conditions that could adversely affect the safe and efficient movement of trains.

Track Warrant: a written form for authorization of train movements used in areas that are non-signaled.

Trackage Agreement: one of a variety of agreements that allow carriers to operate on lines owned by other companies; where trackage rights do not exist the shipment continues to destination after

transferring the material at an “Interchange Point”. At this “Interchange Point” the responsibility shifts to the new line owner.

Train-mile: a unit used in railroad accounting that is the equivalent of one mile traversed by a train.

Transporter (carrier): the entity that by federal law is required to transport from origin to destination hazardous materials that meet the USDOT requirements and as certified by the “shipper”; carriers are responsible for materials that are in transport on their system, and usually operate on their own lines but often have trackage agreements in areas they don’t own the lines.

Truck bogie optical geometry inspection (TBOGI): a type of wayside detector that is a laser-based monitoring system to measure performance of a rail car’s axle and wheel suspension (commonly known as the “truck”).

Truck performance detector (TPD): a type of wayside detector that assesses the performance of rail car suspension systems or trucks on curved track by measuring the wheel’s lateral forces at major segments of track containing four to six degrees of curvature.

TSB: Transportation Safety Board (Canada)

TWD: Track Warning Device

Unit train: a train in which all cars carry the same commodity and are shipped from the same origin to the same destination, without being split up or stored *en route* (also called “block train”).

UP: Union Pacific Railroad

US Energy Information Administration (EIA): a principal agency of the U.S. Federal Statistical System responsible for collecting, analyzing, and disseminating energy information to promote sound policymaking, efficient markets, and public understanding of energy and its interaction with the economy and the environment; EIA programs cover data on coal, petroleum, natural gas, electric, renewable and nuclear energy; EIA is part of the U.S. Department of Energy.

UTC: Utilities and Transportation Commission

Utilities and Transportation Commission (UTC): created in 1905 by the Washington State Legislature as a three-member Railroad Commission, with regulatory authority to inspect and evaluate railroad company accounts, set rates, approve time schedules, monitor safety issues and enforce violations. However, in 1970 and again in 1980, the U.S. Congress passed legislation preempting states in all areas

pertaining to economic regulation of railroads and limited the scope of state jurisdiction in regards to safety.[314]

Wayside detector: a technology that allows railroads to prevent damage and accidents before they could happen. Positioned along 140,000 miles of railroad in the nation, seven kinds of wayside detectors monitor the wheels of passing trains and alert rail car owners to potential defects enabling them to schedule appropriate maintenance in a safe, timely, and cost-effective manner.

Wheel impact load detector (WILD): a type of wayside detector that identifies rail wheels worn or damaged into an out-of-round shape before they can damage track.

Wheel profile measurement systems (WPMS): a type of wayside detector that evaluates the complete rail profile by capturing laser images and detecting worn wheel treads or flanges.

[314] The Federal Railroad Safety and Hazardous Materials Transportation Control Act of 1970, the Interstate Commerce Commission Termination Act (ICCTA) and the Staggers Rail Act of 1980.