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Technical Report

Validation of Marshalling Requirements for Dangerous Goods Cars in a Train: Phase 2

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1 Executive Summary

This report presents the findings of the Phase 2 portion of the project "Validation of Marshalling Requirements for Dangerous Goods Cars in a Train" undertaken by National Research Council Canada (NRC) in collaboration with Transport Canada (TC) Transportation of Dangerous Goods (TC-TDG) directorate. Phase 2 consisted of conducting a detailed review of the literature identified in Phase 1 as well as reviewing National Transportation Safety Board (NTSB) and Transportation Safety Board (TSB) incident[1] reports to determine (1) whether any differences in outcomes had occurred between incidents in Canada and the US before and after August 2002 due to the different buffer-car rules, (2) if there are trends arising regarding incident outcomes based on the general proximity of DG cars to each other, and (3) whether an "ideal" separation distance between DG cars and crew can be identified.

Phase 2 was divided into two tasks: Task P2.1 was a detailed review of literature identified in Phase 1 and task P2.2 was a comparison of derailments involving multiple cars.

For task P2.1 a detailed review of literature identified in Phase 1, consisting of fifty documents, was completed. This literature was selected as it pertained to the impact of the placement of DG cars on safety. The primary goal of this task was to summarize the literature, and identify key observations relating to existing regulations, and their impact on the marshalling of DG cars. In addition, literature that can be used to guide future regulation reviews were identified. This effort was guided by the following two questions:

i. What factors affect the probability of an incident?
ii. What factors affect the outcome of an incident?

Task P2.1 provides background information concerning the history of the current regulations as uncovered during the literature review, and a brief review of the train building process to provide context to the literature summarized. The summaries of the literature have been divided into categories and are presented in table form.

Task P2.2 compares derailments involving multiple cars by studying the incident data available from TC Rail Occurrence Database System (RODS) data tables and the FRA Rail Equipment Accidents data tables. The TSB rail transportation safety investigations reports and NTSB Railroad Accident Reports that were of interest were identified using software-based text searches as well as by manually reviewing the relevant reports.

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[1] The use of the term 'accident' has historically been used to describe train derailments or other incidents where dangerous goods have been released or injuries have occurred. Following the guidance of the Canadian Centre for Occupational Health and Safety[*] which states that *"The term incident can be defined as an occurrence, condition, or situation arising in the course of work that resulted in or could have resulted in injuries, illnesses, damage to health, or fatalities."* the term "incident' will be used in this report except in cases where original documents used the term "accident" in the title or quoted text. (*https://www.ccohs.ca/oshanswers/hsprograms/investig.html

The work presented in this report is broken into three main segments:

- review of past literature related to dangerous goods marshalling, and the use of buffer cars;
- the analysis of incident data for mainline incidents where dangerous goods were released; and
- the review of incident reports in the US and Canada to note differences or similarities regarding the influence of the presence of buffer cars on the outcomes of an incident.

Literature review

Literature related to dangerous goods transport, focusing on the use of buffer cars and marshalling, was completed. The Literature reviewed did not directly explain the origins of the 5 buffer car rule for Key Trains in the US and Canada prior to 2002, nor did the literature explain why the rule was changed in Canada to allow 1 buffer car for mixed goods Key Trains, and zero (0) buffer cars for unit Key Trains.

The literature found and reviewed did not discuss in any detail the risks on yard workers or the increased risks associated with switching DG cars in railyards, however these risks were acknowledged as present. As well, the literature did not identify the risk associated with a DG car placement with respect to in-train forces. The placement of a DG car was usually discussed in terms of the outcome of an incident should a DG car be damaged. Research into the risks of a DG car causing a derailment due to in-train forces because of its location in a train was not found.

The origin of the specific decision on reducing the number of buffer cars from five to one during the 2002 Clear Language updates remains unclear, but appears to be influenced by the early 1990s reports by Battelle, Bowring, and the Canadian Institute of Guided Ground Transport (CIGGT).

Incident data analysis

An analysis of available incident data for dangerous goods derailments occurring on main track was completed. The results were analyzed for the location of the first car to derail, the number of cars to derail, and the number of incidents per year.

A year to year comparison of incidents where dangerous goods were released shows little difference between the outcomes in Canada and the US. While there are noticeable incidents in Canada that standout in some years, as the results are not normalized for yearly traffic data for each country these individual incidents are not evidence that more severe incidents occur in Canada compared to the US.

Incidents within Canada and the US where DG cars derailed and released show that a higher proportion of derailments originating at the first five cars of the train result in a DG car release. This does not say that the first five car locations are higher risk, but that derailments that originate in the leading five cars of the train result in a higher likelihood of a DG car release. Further research into possible reasons for the higher severity of derailments originating in the leading five cars of a train may be required to fully understand this result.

As well, incidents where the leading cars on a train derailed first resulted in more derailed cars and more released cars per incident. These combined results highlight that the first five cars on a dangerous goods train are involved in more derailments where DG cars release, and that these incidents result in a larger number of DG cars releasing.

Although the cars in these locations may not always release, the evidence from this data analysis points to reducing the number of DG cars in the first portion of the train (such as cars 1 to 5) as a method to mitigate the risk of a DG car derailing in a front-of-train derailment, minimize the risk of a DG car releasing, as well as allowing more separation distance from the train crew and the DG cars in a derailment near the front of the train. However, the additional risk of marshalling a train to have 5 buffer cars was not within the scope of this study, and the study of this potential risk is recommended for future work.

Incident report summary

The FRA database and the TC RODS database were searched for the numerical data relevant to this project. This search identified all incidents that occurred on main track and resulted in a DG car involved in the incident or released. Database results were used to identify long form reports for significant incidents from both the TSB and NTSB. NTSB reports were available for 36 severe incidents where DG cars derailed or released. TSB reports were available for 71 incidents in Canada where DG cars derailed or released.

A review of reports where the derailment initiated at the first 1 through 5 cars was completed. The incident reports were briefly summarized to highlight the use of buffer cars, the resulting incident details and incident scene, and the outcome of the crew.

Conclusions

A review of the literature identified in Phase 1 did not uncover a definitive source for the use of 5 buffer cars in a train carrying DG cars, or why the number was reduced in Canada in 2002 from 5 buffer cars to 1. As well, the review of the literature, the incident data, and the incident reports, does not allow for a conclusion to be made regarding an ideal distance between DG cars and the locomotives or the crew, or to the general proximity of DG cars to other DG cars.

An analysis of the available incident data was completed, where incidents selected from the FRA and TC rail incident data tables that involved a DG car derailing and releasing. The analysis did not show a significant difference in the outcomes of these selected derailments between the US and Canada for post-2002 incidents.

Incidents within Canada and the US where DG cars derailed and released show a higher proportion of derailments originating at the lead portion, or first five cars of the train. As well, the data provides evidence that derailments involving dangerous goods where the derailment originated at the lead five cars resulted in more derailed cars and more released cars per incident. It should be noted that as the data used for this study was filtered for incidents only involving DG cars derailed and released, the results discussed are valid for this group of data. An analysis of the full population of derailment incidents, involving all types of goods, was out of scope for this project. It is recommended that further research and analysis of the relationship between the location of the first car to derail and the severity of derailment be completed.

Overall, it was found that there are more *similarities* in the incident outcomes for the severe derailments in Canada and the US than noticeable differences. From the incident report summaries published by the NTSB and the TSB, there are notable incidents that could potentially have been less risk to the locomotive occupants, as well as potentially result in a less severe outcome, had there been five buffer cars instead of one on unit DG train derailments. However, these incidents, identified only from the incident reports available, are estimated to be a small fraction of the incidents which occur where DG cars derailed or released and additional buffer cars could potentially have made no difference, as the leading portion of the train was not involved in the derailment. The number of these types of incidents identified from the available data summarized in the incident reports reviewed between 1990 to 2020 is relatively small (under 5) compared to the approximately 580 incidents involving DG car releases in the US and Canada in that time frame.

As well, the additional risk to workers in rail yards to complete the train marshalling required to add five buffer cars to these trains is not known, although it has been acknowledged in the literature as a potential risk. This suggests that future work could study risks of marshalling DG cars and trains to add buffers cars, and the possible additional injuries and the incidents which could occur in yards during these operations. This work would need to be collaborative with industry, as although the outcomes in the form of injuries and incidents are available for study from reported incident databases, the details of the processes involved (operations, work hours, safety protocols and procedures and other factors) are within the realm of the industry.

Although the cars in the first five positions in a train may not always release, the evidence points to reducing the number of DG cars in the first portion of the train (such as cars 1 to 5) as a method to

- mitigate the risk of a DG car derailing in a front-of-train derailment;
- lower the number of DG goods in an incident to release; and
- lower the risk to the crew following an incident by increasing the separation distance from the train crew and the DG cars which may have derailed near the front of the train.

2 Introduction

This report presents the findings of the Phase 2 portion of the project "Validation of Marshalling Requirements for Dangerous Goods Cars in a Train" undertaken by National Research Council Canada (NRC) in collaboration with Transport Canada (TC) Transportation of Dangerous Goods (TC-TDG) directorate. Phase 1 of this project involved a jurisdictional scan of regulations and a search for related literature concerning the regulations within Canada and similar jurisdictions.

The findings of Phase 1 were summarized in a written report that was delivered to TC-TDG in FY20. Phase 2 consisted of conducting a detailed review of the literature identified in Phase 1 as well as reviewing NTSB and TSB incident[2] reports to determine (1) whether any differences in outcomes had occurred between incidents in Canada and the US before and after August 2002 due to the different buffer-car rules, (2) if there are trends arising regarding incident outcomes based on the general proximity of DG cars to each other, and (3) whether an "ideal" separation distance between DG cars and crew can be identified.

2.1 Background

In Fiscal Year 2019-2020, at the request of TC-TDG, NRC undertook a review of the existing regulations surrounding how dangerous goods cars are placed within a train, and the impact of this placement on safety. Specifically, TC-TDG requested the following:

- An assessment of the effectiveness of the current dangerous goods car placement guidelines in Section 10.6 of the Transportation of Dangerous Goods Regulations (TDGR);
- A comparison of the requirements from Section 10.6 of the TDGR with:
    - Regulatory requirements from other jurisdictions for dangerous goods car placement in a train; and
    - Other rail industry practices or guidelines for the marshalling requirements for train makeup;
- An assessment of whether the presence of buffer cars results in an increased level of safety over dangerous goods trains without buffer cars;
- Confirmation of whether other dangerous goods car placement rules should be considered for inclusion in Section 10 of the TDG Regulations; and
- An assessment of whether dangerous goods cars in a train have any impact on in-train forces that should be considered when evaluating long train marshalling guidelines.

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[2] The use of the term 'accident' has historically been used to describe train derailments or other incidents where dangerous goods have been released or injuries have occurred. Following the guidance of the Canadian Centre for Occupational Health and Safety* which states that *"The term incident can be defined as an occurrence, condition, or situation arising in the course of work that resulted in or could have resulted in injuries, illnesses, damage to health, or fatalities."* the term "incident' will be used in this report except in cases where original documents used the term "accident" in the title or quoted text. (*https://www.ccohs.ca/oshanswers/hsprograms/investig.html

To reduce the project risk, it was agreed that the work to answer the above questions would be conducted in several phases, where the results of Phase 1 would guide the requirements for subsequent phases of study. Specifically, Phase 1 involved a jurisdictional scan of regulations and a search for related literature concerning the regulations within Canada and similar jurisdictions. The findings of Phase 1 were summarized in a written report that was delivered to TC-TDG in March of 2020.

The Phase 2 work aligns well with one of the strategic objectives of NRC's Rail Vehicle and Track Optimization (RVTO) research program which is to develop a fully functional risk mapping tool for all Canadian railways; a tool that can be used by regulators and operators to reduce the risk and impact of derailments. Improved knowledge and data surrounding dangerous goods transport by rail complements this effort.

2.2 Scope

The second phase of the project was divided into two tasks. Task P2.1 was a detailed review of literature identified in Phase 1 and Task P2.2 was a comparison of derailments involving multiple cars.

For task P2.1 a detailed review of literature identified in Phase 1, consisting of fifty documents, was completed. This literature was selected as it pertained to the impact of the placement of DG cars on safety. The primary goal of this task was to summarize the literature, and identify key observations relating to existing regulations, and their impact on the marshalling of DG cars. In addition, literature that can be used to guide future regulation reviews were identified. This effort was guided by the following two questions:

iii. What factors affect the probability of an incident?
iv. What factors affect the outcome of an incident?

Task P2.1 provides background information concerning the history of the current regulations as uncovered during the literature review, and a brief review of the train building process to provide context to the literature summarized. The summaries of the literature have been divided into categories and are presented in table form.

Task P2.2 compares derailments involving multiple cars by studying the incident data available from TC RODS data tables and the FRA Rail Equipment Accidents data tables. The TSB rail transportation safety investigations reports and NTSB Railroad Accident Reports that were of interest were identified using software-based text searches as well as by manually reviewing the relevant reports.

3 Task P2.1: Detailed Review of Literature Identified in Phase 1

During Phase 1 of this project, 54 documents were identified as being of potential interest with respect to the regulations surrounding how Dangerous Goods (DG)[3] cars are placed within a train, and the impact of this placement on safety. The purpose of Task P2.1 was to conduct a detailed review of these documents to identify if they had an influence on current regulations in Canada (or the US), or if they can be used to guide future changes to the current set of regulations with regards to the marshalling of train cars within a consist. During the detailed review, a few documents were removed from the list due to duplication or because they could not be obtained. The addition of new documents identified during the reviewing process brought the final number of reviewed documents to 50. A full list of the 50 documents is provided in chronological order in Appendix A. The summaries of these documents are provided in Section 2.3 of this report. The following two sections provide a brief history of marshalling regulations and a summary of the train building process to provide some context to the literature review and discussion.

3.1 A Brief History of Regulations in Canada and the USA

The regulations governing the transportation of dangerous goods by rail originated as rules setup by the railroads after the US Civil War ended in 1865 to address the issue of poorly labeled explosives and ammunitions transported by rail and subject to ignition during transport [Hazardous Materials, 1982]. There are two primary elements to these initial rules that carry forward to current regulations, proper containment, and proper identification of the DG. The initial regulations dealing with explosives and gun powder required a spacing of “at least 16 cars from the engine and 10 cars from the caboose” [Safe Placement, 2005] or in the middle of the train. These rules evolved into proper regulations and, with the onset of diesel locomotives, changed in motivation from preventing ignition or explosion, to protecting cars occupied by people from the DG cars containing explosives and other hazardous materials.

In 1922, the requirement for the “safe distance” changed to at least five cars from either the engine or caboose, or placement in the middle of the train. The FRA report [Safe Placement, 2005] states that this spacing requirement is not scientifically founded but there is also no evidence to say that it is ineffective. These spacing requirements have been carried forward to current regulations in Canada and the US. Although the official document was not located, the earliest known record of Canadian regulations was listed in the “Regulations for the transportation of dangerous commodities by rail” General order no. 1974-1-rail by the Canadian Transport Commission (CTC).

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[3] In Canada the term “Dangerous Goods” (DG) is used to describe harmful substances being transported. In the United States the term used for the same group of substances is “Hazardous Materials”. In this report the term “DG” will be used to describe all of these types of materials, whether transported in Canada or the US.

In 2002, under the TDG Clear Language Act, the Canadian regulations were modified to require only one buffer car instead of five in a mixed goods Key Train, and no buffer car requirement in a unit-train Key Train.

A Key Train is defined by Transport Canada in the "*Rules Respecting Key Trains and Key Routes*[4]" as follows:

> "Key Train" means an engine with cars:
>
> a) that includes one or more loaded tank cars of dangerous goods that are included in Class 2.3, Toxic Gases and of dangerous goods that are toxic by inhalation subject to Special Provision 23 of the *Transportation of Dangerous Goods Regulations*; or
>
> b) that includes 20 or more loaded tank cars or loaded intermodal portable tanks containing dangerous goods, as defined in the *Transportation of Dangerous Goods Act, 1992* or any combination thereof that includes 20 or more loaded tank cars and loaded intermodal portable tanks.

Prior to this change the Canadian and US regulations closely matched as can be seen in G.W. English report of 1991. The essentials of the rules are summarized in Table 1.

Table 1: Buffer Car Requirements; Canada and US pre and post 2002

Buffer Car Requirements	Pre-2002 Mixed goods Key Train	Pre-2002 Unit Key Train	Post-2002 Mixed goods Key Train	Post-2002 Unit Key Train
Canada	5	0	1	0
US	5	1	5	1

These buffer car requirement generally apply to separate the DG cars from any locomotive on the train, however exceptions to these rules have been granted to operators to remove the buffer car requirement for distributed power locomotives which are not carrying any crew.

The current Canadian regulations are stated in Transport Canada Regulation (SOR/2008-34: Section 10.6) and were last updated in 2008. They still closely follow the regulations in the United States (US) which are specified in CFR 174.84 and 174.85.

The precise reasoning behind the buffer car requirement changes of 2002 have not been fully understood, but the Transportation Safety Board of Canada report of the 2002 Canadian National (CN) incident report [R02W0063] states that "The change was based on consultants' reports on the subject of marshalling DG railway cars." In this report, they specifically identify a report published by the Canadian Institute of Guided Ground Transport[5] (CIGGT), and the conclusions

[4] https://tc.canada.ca/sites/default/files/migrated/rules_respecting_key_trains_and_key_routes.pdf

[5] CIGGT is no longer in operation.

made within this report that the five buffer cars could reduce the likelihood of injury but that that this reduction could not be quantified. The report also identified the added risk in the switching yards required in order to meet these regulations.

3.2 Buffer car implementation by the railroads.

The following are summaries of the requirements individual railroads have to implement the buffer car requirements. These are summarized only as examples of the industry practice on the implementation of the buffer cars.

Union Pacific (UP) has requirements for the buffer cars that are to be placed between the locomotive engine and shipments as required by Federal Regulations. For UP, buffer cars must meet the following requirements[6]:

1. Must be a boxcar, covered hopper, gondola or tank car. The buffer cannot be a flat car.
2. Must have a high-strength coupler (grade E coupler).
3. The length of the car must be at least 45 feet and not greater than 75 feet.
4. Must be loaded with a non-hazardous inert material that does not shift in train service.
5. Gross weight of car must be a minimum of 45 tons (90,000 lbs).
6. It is the responsibility of the shipper to provide buffer cars that are in good mechanical condition. If a car fails inspection, Union Pacific retains the right to refuse to provide train service.

Canadian Pacific (CP) buffer car requirements[7] are as follows::

1. Equipment: Covered Hopper or Box Car
2. Equipment size: Cars less than 32 feet cannot be coupled to a car longer than 65 feet and/or cars less than 41 feet cannot be coupled to a car longer than 80 feet.
3. Commodity: Ballast Rock or Stone; Sand, Pebbles, NEC; Industrial Sand
4. Minimum Weight: 90,000 lbs.

These two examples highlight that the railroads have in place practices to specify and select suitable buffer cars, as required by regulations, but that the implementation of the rules into operating practices may be slightly different for each railroad.

3.3 Review of current process for building a train consist.

In order to better understand the current regulations and how they are employed, this section provides a brief description of the train building process and the related considerations.

The build of trains can occur at any type of goods station including where the freight originates, such as a plant, mine, or port. Trains originating from these industrial source locations will often be a unit train composed entirely of one type of freight, such as iron ore or coal being transported

[6] https://www.up.com/customers/ind-prod/crude/equipment/index.htm

[7] https://www.cpr.ca/en/customer-resources-site/Documents/Tariff-5-unit-train-jan-2019.pdf

from a mine to a port or an industrial facility. In the case of DG unit trains, they may be transferring goods from one industrial source to another as a complete unit from destination to destination, such as crude oil transport from an oil processing facility to a single oil refinery or shipping port. Or they may be transferring goods from one industrial source to multiple destinations, in which case DG unit trains may originate at the source as a unit train, but may ultimately be separated into smaller blocks for delivery to different geographic locations where they may become part of a mixed goods train which contains non-DG cars and DG cars. For this report a unit train will be considered a train with one type of commodity being transported as a group in similar size and weight freight cars, where all the cars in the train are either fully loaded or empty.

Other types of dangerous goods may be transported in single car shipments, or as units of a few cars, originating for example from a chemical plant and travelling by rail for shipment to a customer or other chemical facility. The work of separating the train into common destination blocks for final delivery is conducted at a classification yard, also known as a marshalling yard.

Freight cars that arrive at the classification yard and need to be made into complete trains are divided according to their destination through a series of switches. This grouping effort is called blocking and railroads use a destination-based blocking system [Verma, 2013]. This is done to minimize the amount of handling at each yard as the train route may consist of multiple stops before reaching a final destination. Blocking reduces both cost and delay time, and improves safety by minimizing the risk to workers involved in the marshalling activities. Figure 1 below illustrates a mixed freight train divided into blocks, containing both hazmat and regular railcars.

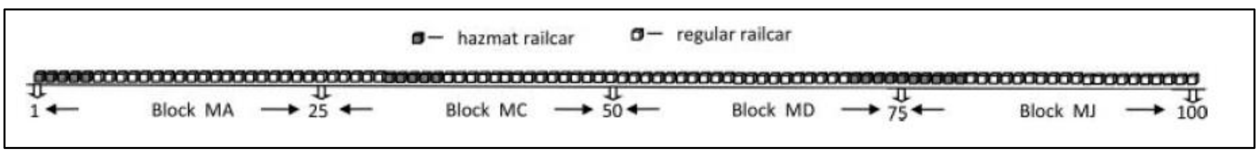

Figure 1: Mixed Freight Train Divided into Blocks [Verma, 2013].

In addition to the organization of the train with respect to destination, the railyards follow guidelines on overall length and weight, locomotive position, and the DG marshalling requirements on the separation of DG cars and the use of buffer cars as per the current set of regulations. Included in the consideration of the locations of cars in a train are the train operating and handling characteristics, or vehicle dynamics, as well as the route characteristics such as grade and curvature. It should be noted that the current regulations gives precedence to vehicle dynamics (the controlling of in-train forces) with the opening statement of *"Unless it is likely to have a serious impact on train dynamics,…"* [SOR/2008-34: Section 10.6] before listing the DG regulations. This is justified as train dynamics are important in the prevention of derailments, whereas marshalling practices for DG car placement are made to be preventative measures to reduce the severity of an incident should it occur.

The switching process is conducted either by flat switching or humping. In flat switching, the rail cars are either 'kicked' or shoved to couple to other cars. Kicking involves uncoupling from the locomotive and allowing the car to roll freely and couple with other cars. While rolling freely, the car is not under any form of control, and can move with little noise or other warning to workers nearby. During the shoving process, the car remains attached to the locomotive until it is coupled or secured to the new train. The humping process relies on gravity after the locomotive pulls the car up an artificial hump in the track and releases it to couple into a new train.

The switching process requires controlled speeds[8], slow enough to prevent incidents but fast enough to ensure coupling. The relative masses of both the car being shunted and the recipient train or car can also affect the risk of incidents as explained in two dynamic modeling studies [Hohenemser,1975 and Peters, 1980]. The work involved with switching or shunting cars in a rail yard can be dangerous. A Transportation Safety Board study revealed that 45% of Canadian railroad incidents between 1996 and 2000 occurred in classification yards [Verma, 2013].

Understanding the process and associated risks with switching is important if recommendations are to be made to the current set of regulations. The safety risks and costs of additional yard work are likely to be different for a unit train operation compared to a mixed goods train. Given the complexity of freight car and train movements, it is not clear if mixed goods trains require additional yard movements to meet a five car buffer rule compared to a unit train, or not. As well, for unit-trains, there is a cost penalty with the use of non-revenue buffer cars, as the buffer car may displace revenue generating cars from the train increasing the overall cost of shipping, while for a mixed goods train the buffer car requirement may be met with revenue generating cars which meet railway guidelines..

3.4 Summary of Reviewed Documents Listed by Category

The documents reviewed in this work can be classified into groups based on their focus. Some documents focus on the hazardous materials themselves and their interactions, quite a few documents detail tank car design and safety features and a few reports analyze the current regulations for the transportation of DG by rail. Many documents investigate probability and statistical approaches to determining the safest location of DG cars within a train consist. A few of the identified documents are incident reports which provide an analysis of how an event occurred and the repercussions of a multi-release event. There are also a number of documents that can be grouped as generic dangerous goods transportation papers, many of which do not directly discuss buffer cars or the marshalling of DG within a train.

The following sections contain summary tables of the reports and have been separated into categories based on the primary focus of the documents.

[8] The speeds at which dangerous goods cars can be switched at are controlled by regulations.

3.4.1 Category 1: DG Car Marshalling and Regulations Analysis

These three reports provide the most pertinent information regarding the regulations identified in Phase 1 of this project. These reports analyze the regulations governing the transportation of DG in Canada and the US. The Bowring report from the UK was identified as another highly influential report under this category but a full copy of this report could not be located. None of these reports appear to state any direct justification or reason for the current US or Canadian buffer car rules.

Document	Summary
Hazardous Materials Car Placement in a Train Consist, Final Report, Volume 1 and 2, Battelle, Columbus, Ohio, Technical Task No. 6, Contract No. DTFR53-86-C-00006, September 7, 1989 (document available through the Technical Information Service, Springfield, Virginia 33262	The Battelle report includes a probability analysis of dangerous goods placement, but also examines the intermingling of different chemicals, addressing the factors that affect the outcome of an incident. This approach considers the increased damage that can result if incompatible chemicals are released. The report also includes a cost/benefit analysis. The report uses incident data from 1975, and indicates that the back of the train is the safest location but that this could impact train dynamics. It also found smaller trains had less incidents than longer trains, and that speed was a major variable. It highlights the importance of separating certain chemicals to prevent mixing and recommends from 15 up to 30 car separation for certain chemicals. The authors indicate that additional switching operations would be costly and recommend an in-depth cost/benefit analysis.
Assessment of Dangerous Goods Regulations in Railway Train Marshalling, Working Paper. G.W. English et al, Canadian Institute of Guided Ground Transport, March 1991.	This report is most closely related to the current task as it provides an in-depth analysis of the then current state of DG regulations in Canada and reviews two major reports, the Bowring report from the UK and the Battelle report from the US. This provides good insight into the Bowring report which could not be obtained directly, and provides an indirect comparison and contrast of the Battelle and Bowring reports. The authors also consider the early probability analysis work conducted by Frank Saccomanno et al, and conduct their own similar analysis, identifying that the probability models are only as good as the data used. The conclusions indicate the need for a more thorough analysis of current (1991) regulations and a better, more detailed database of incident data to conduct a more effective analysis. They state that the benefits of the five car buffer regulation needs to be quantified and weighed against the added risk and cost of switching.

Document	Summary
Safe Placement of Train Cars: A Report. Report to the Senate Committee on Commerce, Science and Transportation and the House Committee on Transportation and Infrastructure. Federal Railroad Administration, Washington, DC. Corporate author code(s): 035623000 Federal Railroad Administration, Jun 2005, 32 p.	This report discusses the control and management of in-train forces with regards to minimizing the risk of derailments due to string-lining or buckling of the freight cars. The report also provides a very good history and development of the current marshalling regulations in the USA with regards to dangerous goods placement. The conclusions discuss the impact of additional switching and the increased risk involved and the impact of placement on train dynamics. The report also states the current (2005) set of regulations delivers "an appropriate level of safety".

Table 2: DG Car Marshalling and Regulations Analysis

3.4.2 Category 2: Probability models for determining the safest location of DG cars

Of particular interest for guidance of any future changes to regulations are the probability studies that attempt to define the safest locations for DG cars within a train consist. The A.D. Little report of 1983 pioneers this effort by using existing derailment and incident data within a thorough statistical probability analysis. The probability models have evolved over the years with a variety of authors expanding on previous models in attempts to provide an all-encompassing predictor of where to best place DG cars in a train to minimize the risk of derailment and release. None of these reports appear to state any direct justification or reason for the current US or Canadian buffer car rules.

Document	Summary
Event Probability and Impact Zones for Hazardous Material Accidents on Railroads Nayak, et al., A.D. Little and Associates. Report DOT/FRA/ORD-83/20, 1983.	This document created by the US Department of Transportation (DOT), was the earliest probability analysis reviewed. It is organized into sequential events; incident frequencies and rates, number of cars derailing, presence of DG cars in train, number of DG cars derailing, release probability, number of DG cars releasing, amount released, amount of DG released per incident and area affected by a release. The report provides insight into how track class impacts frequency of accidents and train speed impacts severity. The authors indicate a source of error being the sparse amount of data available to them at the time.
Transportation of Hazardous Materials 1989. Minimizing Derailments of Railcars Carrying Dangerous Commodities Through Effective Marshaling Strategies F. F. Saccomanno, S. El-Hage	Saccomanno expands on the A.D. Little work, "recalibrating" the model using Canadian (CTC) derailment data from 1980-1985. Concluding that the point of derailment is affected by the cause of derailment and train length. The number of cars derailing is a function of the cause, speed, and residual train length and depends on the point of derailment and train length. The authors conclude that marshalling can reduce the likelihood of DG cars being involved in an incident.
Establishing derailment profiles by position for corridor shipments of dangerous goods Saccomanno, F.F., El-Hage, S.M. (1991) Canadian journal of civil engineering, 18 (1), pp. 67- 75.	The 1991 report applies this model to the Sarnia-Toronto Corridor for 5 marshalling approaches, influenced by Swoveland (1987): “current regulations”, front of the train, back of the train, middle of the train, and random marshalling and concludes that marshalling of DG for that corridor can affect the expected number of DG cars derailing. The results indicate that the rear of the train is the safest location for DG cars.
Railroad derailment factors affecting hazardous materials transportation risk, Transp. Res. Rec. 1825 (2003) 64–74. C.P.L. Barkan, C.T. Dick, R.T. Anderson	In this report, Barkan addresses the issue of insufficient incident data for DG car derailments by selecting "proxy variables" of speed and number of cars derailed for all incidents to develop better statistical results to assess the risk of DG transportation by rail. The report provides a comprehensive list of incident causes and assesses their relative risk for release. This paper is the first in a series of similar works that build on this analysis by Barkan, Anderson, and others in the following decade.

Document	Summary
Dangerous goods railway car placement model Bagheri, M., Saccomanno, F., Fu, L. (2009) Proceedings - 9th International Heavy Haul Conference: "Heavy Haul and Innovation Development", pp. 863-871.	Bagheri continues on the work of Saccomanno (1989), with Saccomanno listed as co-author for all four reports by Bagheri. In the 2009 report, the equations from Saccomanno and El-Hage are updated with data from 1997-2006 and a case study of a hypothetical railway station comprised of three rail yards is presented. In the 2010 report, Bagheri makes use of a "heuristic genetics algorithm" to generate optimal results from the proposed model. The model is applied to a hypothetical corridor and the assumptions are listed, indicating the added cost of additional marshalling needs to be considered. Bagheri's work highlights the findings that track-related derailments occur towards the front of the train while rolling stock derailments are more evenly distributed and he incorporates a normalized point of derailment to account for different train lengths. In the 2011 report, Bagheri extends the analysis from DG car location to different block sequences to predict the lowest risk sequence of blocks within a train. The 2012 report is the most comprehensive of four reports and provides the most advanced version of the probability model including cost and time estimates for train assembly. The model is applied to a case study of an actual corridor from Barstow to Chicago in the US.
Effective placement of dangerous goods cars in rail yard marshaling operation Bagheri, M., Saccomanno, F.F., Fu, L. (2010) Canadian Journal of Civil Engineering, 37 (5), pp. 753-762.	
Reducing the threat of in-transit derailments involving dangerous goods through effective placement along the train consist. Bagheri, M., Saccomanno, F., Chenouri, S., Fu, L. (2011) Accident Analysis and Prevention, 43 (3), pp. 613-620.	
Modeling hazardous materials risks for different train make-up plans Bagheri, M., Saccomanno, F., Fu, L. (2012) Transportation Research Part E: Logistics and Transportation Review, 48 (5), pp. 907-918.	

Document	Summary
A tactical planning model for the railroad transportation of dangerous goods. Transportation Science, 45(2), 163–174.2. Verma, M., Verter, V., & Gendreau, M. (2011).	Verma et al, provide a detailed probability analysis that includes the yard operation impact on the overall probability model. Building on previous work by Barkan, Saccommano, Bagheri, and others, the first report from 2011 provides a good case study, and is focused on mixed freight and not unit cars. The 2012 document is a continuation that lists the three most popular measures of transportation risk as "expected consequence, incident probability, and population exposure". This document explains the work involved in train blocking in detail. The probability model considers 1) the probability that a train carrying hazmat will be in an incident, 2) the conditional probability that a hazmat car will derail, 3) the conditional probability that the car will release, and 4) the consequence as a result of release from multiple sources.
Planning models for rail transportation of hazardous materials. In R. Batta & C. Kwon (Eds.), Handbook of OR/MS models in hazardous materials transportation: Springer international series of OR/MS (Vol. 193, pp. 9–47). New York, NY: Springer Verlag. 1. Verma, M., & Verter, V. (2013).	
Optimal Strategies to Improve Railroad Train Safety and Reduce Hazardous Materials Transportation Risk Liu, Xiang, (2013)	Xiang Liu's work further builds off of A.D.Little, Saccomano and Bagheri but is tied more closely with the work of Barkan (2003). The four identified reports display the evolving probability model developed by X. Liu. In the 2018 article "Accident-Cause-Specific Risk Analysis or Rail Transport of Hazardous Materials" Liu discusses the creation of a computer tool to calculate the probability of derailment for each location on a train consist. This tool requires information or data input by the user and the data would be obtained from previous incident reports. The tool considers all possible permutations of train and can predict the lowest risk configuration.
Probability analysis of multiple-tank-car release incidents in railway hazardous materials transportation Liu, X., Saat, M.R., Barkan, C.P.L. (2014) Journal of Hazardous Materials, 276, pp. 442-451.	
Risk comparison of transporting hazardous materials in unit trains versus mixed trains Liu, X., (2017) Transportation Research Record, 2608 (1), pp. 134-142.	

Document	Summary
Accident-Cause-Specific Risk Analysis of Rail Transport of Hazardous Materials. Liu, X., Turla, T., Zhang, Z., (2018) Transportation Research Record, 2672 (10), pp. 176-187.	
Impact of train makeup on hazmat risk in a transport corridor Cheng, J., Verma, M., Verter, V. (2017) Journal of Transportation Safety and Security, 9 (2), pp. 167-194.	This report analyzed the probability of release with combined risk associated with cars in transit and in switching yards. Notable conclusions are that DG car location is a “trade-off between segment and yard risk”, and the rear of the train is lower risk. The authors recommend applying the model to multiple case studies to validate results.
Formation of a model for the rational placement of cars with dangerous goods in a freight train Lavrukhin, O., Kovalov, A., Kulova, D., Panchenko, A. (2019) Procedia Computer Science, 149, pp. 28-35.	This report from the Ukraine is similar to others works involving the use of a Genetic Algorithm (GA) to compute results, however the proposed model does not appear to be as advanced as the latest work from X. Liu or M. Verma.

Table 3: Probability models for determining the safest location of DG cars

3.4.3 Category 3: Incident Reports

These incident reports provide some insight into the impact of DG involved in an incident. They provide examples of the serious incidents in the past that were the catalyst for dangerous goods regulations implemented in the 1980s and 1990s. The change from plain journal bearings to roller bearings, the addition of head shields to tank cars, the addition of shelf-type couplers to tanks cars, the study of train dynamics, the separation of dangerous goods cars within a train, and the increased use of hot box detectors can all be linked to incident investigations and the reported findings and recommendations of incident like these.

Document	Summary
Burlington Northern Inc., Monomethylamine Nitrate Explosion, Wenatchee, Washington, August 6, 1974. National Transportation Safety Board, Washington, D.C. Bureau of Surface Transportation Safety. National Transportation Safety Board, Report number(s): NTSB-RAR-76-1, 2 Feb 1976, 72 p.	This NTSB report was flagged for review during the discovery phase of the literature search. However, the short report does not provide significant insight into potential regulation changes or rules surrounding buffer cars. The main identified issue for the incident was a chemical classification problem. The incident is typical of an increasing number of dangerous goods incidents occurring in Canada and the US during this time frame, when DG incidents were rising year to year.
Railroad Accident Report - Derailment of Illinois Central Gulf Railroad Freight Train Extra 9629 East (GS-2-28) and Release of Hazardous Materials at Livingston, Louisiana, September 28, 1982. National Transportation Safety Board, Washington, DC. Bureau of Technology. Corporate author code(s): 022327003, National Transportation Safety Board, Report number(s): NTSB/RAR-83/05, 10 Aug 1983, 88 p.	Multiple DG car release accident, with a cause related to the combination of poor marshalling of empty cars near the front of the train, an unintended emergency brake application and operator failure to bail off the locomotive brake due to alcohol incapacitation. No buffer cars were discussed. At the time, most tank cars in operation had no head shield or shelf type couplers. A large amount of dangerous goods were released.

Document	Summary
RISK ANALYSIS OF REGULATORY OPTIONS FOR THE TRANSPORT OF DANGEROUS COMMODITIES BY RAIL Swoveland, Cary, (1987) Interfaces, 17 (4), pp. 90-107. Quantalytics Inc, Vancouver, BC, Can, Quantalytics Inc, Vancouver, BC, Canada	This report was based on the commissioned analysis to review proposed changes that came out of the Mississauga derailment of 1979. This report highlights the importance of a full analysis required when suggesting changes to regulations and understanding the full impact of any changes proposed. Justice Grange proposed all cars in a train carrying DG needed roller bearings, that wayside hot box sensors become more prevalent, and that DG train speeds be limited, acknowledging that these will come at an elevated cost for the railroads. At the time, CP countered that marshalling DG cars to the front of the train and that using buffer cars with roller bearing ahead of the DG cars would be an alternative at reduced cost to the industry. The industry ultimately switched all cars to roller bearing from plain journal bearings, and marshalling requirements separating toxic, poisonous and/or flammable compressed gas cars from other flammable cars were put in place.
National Transportation Safety Board Railroad Accident Report: Derailment of Norfolk Southern Railway Company Train 68QB119 with Release of Hazardous Materials and Fire, New Brighton, Pennsylvania, on October 20, 2006. National Transportation Safety Board, Washington, DC. Corporate author code(s): 022327000, National Transportation Safety Board, Report number(s): NTSB/RAR-08/02, 13 May 2008, 56 p.	This NTSB report summarizes the “Safe Placement of Train Cars” (FRA, 2005) report, and recommends a full analysis into buffer car requirements indicating that the current regulations do not address with respect to unit train requirements.

Document	Summary
Lac-Mégantic accident: What we learned Lacoursière, J.-P., Dastous, P.-A., Lacoursière, S., (2015) Process Safety Progress, 34 (1), pp. 2-15.	This report provides a detailed analysis of events that led to the Lac-Mégantic. The train had 1 buffer car in between the block of 5 locomotives and 1 buffer car, and 72 DOT-111 tank cars. However, it does not provide insight into the effects of marshalling DG cars or the use of buffer cars, and there was no comment on the use of 1 versus 5 buffer cars. The train ultimately derailed at a speed far above the allowable track speed, separating at the 7th car behind the locomotive.

Table 4: Incident Reports

3.4.4 Category 4: Tank Car Design Changes

These reports address the modifications required to enhance the safety of tank cars transporting DG by rail but do not provide insight into train marshalling, the use of buffer cars, or on derailment frequency or frequency of release of DGs.

Document	Summary
Computer Simulation of Tank Car Head Puncture Mechanisms. Classification Yard Accidents. K. H. Hohenemser; W. B. Diboll; S. K. Yin; B. A. Szabo. Washington Univ., St.Louis, Mo. School of Engineering and Applied Science. Federal Railroad Administration, Washington, D.C. Office of Research and Development. Federal Railroad Administration, Feb 1975, 86 p.	Analysis on the added benefit and safety of shelf couplers and head shields. Provides a good description of how punctures can occur based on dynamic forces. Indicates how a light car (uncoupled) should not come into contact with heavy tank cars during switching and that speed should be kept low in yard operations.
Realistic Characterization of Severe Railroad Accidents. Case Study: Tank Cars. R. T. Anderson. Allied-General Nuclear Services, Barnwell, S.C. Corporate author code(s): 9500546 Department of Energy., Technical Information Center Oak Ridge Tennessee, Report number(s): CONF-780506-15, 1978, 17 p.	This report focusses on the transportation of radioactive material. It uses data from other DG incidents and analysis, which are transported much more frequently, to develop an analysis of safety with respect to transporting radioactive material by train. It provides insight into estimated derailment collision forces but does not discuss DG car marshalling or the use of buffer cars.

Document	Summary
Special Investigation Report - The Accident Performance of Tank Car Safeguards. National Transportation Safety Board, Washington, DC. Bureau of Technology. Corporate author code(s): 022327003, National Transportation Safety Board, Report number(s): NTSBHZM-80-1, 8 Mar 1980, 26 p.	This report is specific to tank car construction and the importance of top-and-bottom shelf couplers, head shields, and thermal protection.
Tank Car Head Puncture Mechanisms. D. A. Peters; B. A. Szabo; W. B. Diboll. Washington Univ., St. Louis, MO. School of Engineering and Applied Science. Corporate author code(s): 010065085, Federal Railroad Administration, Washington, DC. Federal Railroad Administration, Apr 1980, 107 p.	This document provides detailed analysis of tank car puncture mechanisms at switching yards. This is useful in understanding the impact of more switching on the overall hazard of TDG. Figures are not visible due to a relatively poor quality pdf. The report explains how lower energy from lower speeds can reduce or even eliminate puncture probability. At the time of this report (1980) it was concluded that main line derailment events are far too high in energy to eliminate the risk of puncture with tank car design changes.

Document	Summary
Hazardous Materials Transportation in Tank Cars: Analysis of Risks, Part 1. P. K. Raj; C. K. Turner. Technology and Management Systems, Inc., Burlington, MA. Corporate author code(s): 077179000 Federal Railroad Administration, Washington, DC., Federal Railroad Administration, Report number(s): REPT-1991-64, 15 May 1993, 244 p.	This report is the first of a pair of reports focused on the probability of release and effects of exposure for Poisonous Inhalation (PIH) chemicals looking at tank cars and population densities. The authors' approach to probability analysis makes use of MIL-STD-882B. The first report provides detailed information about car punctures in relation to the class of car and type of puncture, hole size and train speed. Unfortunately this report does not offer any new information or analysis of train car marshalling of DG or the use of buffer cars.
Hazardous Materials Transportation in Tank Cars: Analysis of Risks, Part II. P. K. Raj. Technology and Management Systems, Inc., Burlington, MA. Corporate author code(s): 077179000 Federal Railroad Administration, Washington, DC. Office of Research and Development. Federal Railroad Administration, Report number(s): REPT-1994-74, 31 Dec 1994, 160 p.	This report is the second of a pair of reports focused on the probability of release and effects of exposure for Poisonous Inhalation (PIH) chemicals looking at tank cars and population densities. The authors' approach to probability analysis makes use of MIL-STD-882B. Part 2 focuses on a comparison between DOT-111 and DOT-105 cars. Unfortunately this report does not offer any new information or analysis of train car marshalling of DG or the use of buffer cars.

Document	Summary
Hazardous materials transportation on U.S. railroads: Application of risk analysis methods to decision making in development of regulations Raj, P.K., Pritchard, E.W., (2000) Transportation Research Record, (1707), pp. 22-26.	This report focuses on tank car design and how the risk of hazardous release can be mitigated by using different types of tank cars, DOT-111 vs DOT-105. This could indicate regulation requirements specifying the type of tank car required for different DG but does not directly address marshalling of train cars or use of buffer cars. The use of MIL-STD-882-B provides an interesting and insightful way to approach risk and mitigation requirements.
Evaluation of tank car sloshing effects on rail safety, Huang, Wei; Toma, Elton; Ladubec, Christopher; Liu, Yan; Zhang, Merrina; Steiginga, Luke; Schenk, Zack. Report (National Research Council of Canada. Automotive and Surface Transportation); no. ST-R-TR-0095, 2018-02-05	This report is concerned with the dynamic forces associated with sloshing of partially filled tank cars. The report does not discuss buffer cars or tank car marshalling.

Table 5: Tank Car Design Changes

3.4.5 Category 5: Hazardous Materials and Handling

These documents are concerned with the various types of dangerous goods and the general hazards involved with handling DG.

Document	Summary
An Appraisal of the Problem of the Handling, Transportation, and Disposal of Toxic and Other Hazardous Materials (1970) Booz-Allen and Hamilton, Inc., Washington, D.C. Department of Transportation, Washington, D.C.; Council on Environmental Quality, Washington, D.C. Council on Environmental Quality, 30 Jan 1970, 180 p.	At the time of publication, this report noted that “only limited definitive statistical data are available pertaining to hazardous materials transportation and accidents. In many cases, the data reported are not organized in a form immediately useful for the development of the desired forecasts. As a result, more sophisticated forecasting methods were not possible.” At the time, railroad incidents per year were increasing. The document summarizes the known hazardous materials, their properties and hazards, and transport requirements. Marshalling is discussed with respect to impact loading on freight cars.
Control of Spillage of Hazardous Polluting Substances. G. W. Dawson; A. J. Shuckrow; W.H. Swift. Battelle Memorial Inst., Richland, Wash. Pacific Northwest Labs. Corporate author code(s): 387060 1 Nov 1970, 409 p.	A very broad document on spillage of hazardous materials with a small portion attributed to rail transportation of DG that is taken from the Booz-Allen document. No discussion of buffer cars.

Document	Summary
Hazardous Materials: A Guide for State and Local Officials. Bierlein, L.W., Washington, DC. Corporate author code(s): 075542000 Department of Transportation, Washington, DC. Office of the Secretary, Feb 1982.	This document does not provide insight into the regulations of DG car marshalling or buffer cars. It describes and explains the different agencies that govern the safety of DG in the U.S. and how the different agencies share the responsibilities.
Emergencies in the Overland Transportation of Hazardous Materials. R. Pipatti; R. Lautkaski; J. Fiet. Valtion Teknillinen Tutkimuskeskus, Espoo (Finland). Corporate author code(s): 067526000 6658300, TIC Foreign Exchange Reports, Report number(s): VTT-TUTK-380, Mar 1985, 111 p.	A report from Finland. This document focuses on the types of chemicals transported and the inherent dangers of those chemicals. The authors conclude that track condition in Finland plays a crucial role on derailment prevention. Buffer cars are not discussed.
The Hazardous Materials Ordinance and its significance for German Federal railways Zumstrull, M. (1989) EISENBAHNINGENIEUR, 40 (2), pp. 51-60.	A translated version of this report indicates that the content is focused on hazardous materials classification, labeling, and handling and does not offer any details into train make-up or buffer cars.

Document	Summary
Hazmat transport: A methodological framework for the risk analysis of marshalling yards Cozzani, V., Bonvicini, S., Spadoni, G., Zanelli, S., (2007) Journal of Hazardous Materials, 147 (1-2), pp. 412-423.	This paper focuses on risk assessment for DG rail transportation in Italy within a marshalling yard. It does not discuss marshalling or use of buffer cars, but does provide an interesting perspective of DG release during shunting and non-incident release due to tank car defects.

Table 6: Hazardous Materials and Handling

3.4.6 Category 6: Generic DG Transportation

This group provides a "catchall" for the remaining documents reviewed for Task 2.1. These reports did not provide insight into marshalling or use of buffer cars. However, they contain historical snapshot of the safety concerns in the rail industry at the time.

Document	Summary
A Comprehensive Railroad Safety Report (Including an Analysis of the State Participation Program). Federal Railroad Administration, Washington, D.C. Office of Safety. Federal Railroad Administration, Report number(s): FRA/RSS-7601, 17 Mar 1976, 359 p.	Summary of the state to state participation in the federal rail safety improvement program.

Document	Summary
An Evaluation of Railroad Safety. Office of Technology Assessment, Washington, D.C. Office of Technology Assessment US Congress, Report number(s): OTA-T-61, May 1978, 224p.	Comprehensive summary of railroad safety for a 10 year period from 1967 to 1977. Recognition of data collection as an important tool in the regulatory process. Mainline incidents are increasing in this time period. *"One type of derailment which has recently received much attention is that involving tank cars. The potential disaster resulting from a tank car derailment could significantly affect not only the railroads' physical property, but also the health and well-being of the public as well as possible damage to third-party property. As an example, during 1969-75, there were 44,432 derailments reported. Of those derailments, more than 500 involved uninsulated pressure-tank cars, of which more than 170 lost some or all of their lading. Several major accidents resulted in 20 deaths, 855 injuries, and 45 major evacuations of approximately 40,000 persons."* *"In 1974, roughly 65 percent of tank cars loaded with liquefied petroleum gas, sulfuric acid, anhydrous ammonia, and liquid caustic soda were involved in the accidental release of hazardous materials."* *"Additional analysis of the risk and exposure associated with the transportation of hazardous materials should be conducted to anticipate future problems."* *"Accident data and trends were important in initiating regulatory activity which led to the tank-car standard. Accident data should always be one tool of the regulatory process. But that alone is not satisfactory. It is critical to effective regulation, to ensure safety, that the exposure of people and property to hazardous materials be determined."* *"The bases for determining acceptable levels of safety in the future may change."* Excellent chapter on the concept of safety.

Document	Summary
Special Investigation Report - Railroad Yard Safety: Hazardous Materials and Emergency Preparedness. National Transportation Safety Board, Washington, DC. Bureau of Accident Investigation. Corporate author code(s): 022327001, National Transportation	This is a thorough investigation into the then current (1985) safety status of DG handling within railyards in the USA. This provides good information and understanding of the dangers and considerations of railyard switching involving DG.
Transportation of Hazardous Materials 1988. A. Saccomanno. Transportation Research Board, Washington, DC. Corporate author code(s): 044780000 National Academy of Science Transportation Research Board, Report number(s): TRB/TRR-1193; ISBN-0-309-04764-1, 1988, 46 p.	This report discussed safety concerns with the transport of DG such as locating emergency response along a route, but did not discuss marshalling of DG rail cars or the use of buffer cars.

Document	Summary
Transportation of Hazardous Materials 1989. F. F. Saccomanno; J. H. Shortreed; M. Van Aerde; J. Higgs; M. Abkowitz. Transportation Research Board, Washington, DC. Corporate author code(s): 044780000 National Academy of Science Transportation Research Board, Report number(s): TRB/TRR-1245; ISBN-0-309-04967-9, 1989, 74 p.	This report discussed a comparison of truck versus rail transportation of DG, concluding that although more incidents occur during truck transport, that the impact of rail incidents is higher due to the volumes transported. No discussion of marshalling or use of buffer cars.
Rail safety in the carriage of dangerous goods Abbott, Paul, (1995) Environmental Engineering, 8 (4), pp. 25-28. Railtrack HQ	A short journal article discussing the importance of safety when transporting DG within the UK, at a time when there was a conversion from rail operation to privatization. Of interest is the British Rail (BR) Total Operations Processing System (TOPS) that "verifies overall train formation including segregation (and any incompatibilities) – with discharged tanks treated as loaded."
Safety in the transport of dangerous goods Mitschi, Jean, (1995) Rail International, (5), pp. 65-67.	This article discusses the importance of safety when transporting dangerous goods within France. It does not discuss buffer cars or marshalling of DG cars within a train.
Where are we going? Baker, R. (2005) Petroleum Review, 59 (696), pp. 16-17. , Knight Support Fire, Rescue/A. S., Dar es Salaam, Tanzania.	This short article from the UK discusses the possible effects of EU harmonization of regulations for road vehicles and does not discuss DG transportation by rail.

Document	Summary
Research on evaluation method in dangerous goods transportation via railway Fang, M., Jie, X. (2010) ICCTP 2010: Integrated Transportation Systems: Green, Intelligent, Reliable - Proceedings of the 10th International Conference of Chinese Transportation Professionals, 382, pp. 218-225.	A research paper from China that used the Dow Chemical Company Fire and Explosion Risk Index to propose a transportation of dangerous goods risk index. Does not offer solutions or in-depth analysis on train marshalling or use of buffer cars.
Hazard assessment on railway dangerous goods station. Bai, F.-B., Hou, R.-H., Wang, Z. (2011) ICTIS 2011: Multimodal Approach to Sustained Transportation System Development - Information, Technology, Implementation - Proceedings of the 1st Int. Conf. on Transportation Information and Safety, pp. 2344-2352.	This report from China adds another perspective or approach to assigning risk levels to different "hazards" identified in the transportation of DG by rail. The list of hazards provided in Table 1 of this report is a comprehensive list that provides insight into many of the contributing factors to the hazards of DG transportation by rail.
Research on Marshalling Number of Vehicles in a Train for Gas-type Dangerous Goods Transport Based on Minimum Risk Gan, C., Yang, Y. (2018) Tiedao Xuebao/Journal of the China Railway Society, 40 (5), pp. 26-30.	Only the abstract for this report was obtained in English. The one page abstract did not discuss buffer cars or marshalling.

Document	Summary
Macciotta, R., S. Robitailleb, M. Hendryc, and Derek Martin C. (2018) "Hazard ranking for railway transport of dangerous goods in Canada." Case studies on transport policy 6 (6) 43-50.	This report discusses rail infrastructure and methods of calculating/estimating the risk of transporting DG through a corridor by developing a “hazard ranking tool”. The report also discusses other tools such as the Rail Corridor Risk Management System (RCRMS) in the USA, and the Safety Risk Model (SRM) in the UK.

Table 7: Generic DG Transportation

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4 Task P2.2: Comparison of derailments involving dangerous goods releases within Canada and the US.

This phase of the work analyzes the incident data relevant to dangerous goods rail incidents where a dangerous goods car released, was damaged, or was involved in a derailment. The data was obtained from the rail incident records that are maintained and made available to the public by the Transportation Safety Board (TSB) Canada, the Federal Railroad Administration (FRA), and the National Transportation Safety Board (NTSB).

The rail incident records contain data concerning many types of rail incidents, however for this study the incidents were limited to those occurring on main track, and to those that involved dangerous goods. Main track for the purpose of this study is defined as the track a train travels on that is outside of switching yards or private property, where the train is travelling at track speed between destinations. Although incidents do occur in yards and within industrial yard settings, these incidents were not considered in this analysis. By focusing on the types of incidents where the presence of buffer cars could affect the outcome of an incident, it was hypothesized that potential differences in incident outcomes may be seen between incidents that occurred within the US and Canada.

Through previous work in developing risk mapping tools, NRC has developed a rail incident database based on the publically available data tables from TC and the NTSB that can be used to search for incidents relevant to the requirements of this project. The database currently includes information for approximately 62,000 railway incidents that have occurred in Canada since 1983.

4.1 Database Building and Searching

Transportation Safety Board (TSB) maintains a record of all reported railway incidents and incidents through the Railway Occurrence Database System (RODS). The data in this system is available to the public through website access as CSV format text files[9]. TSB also publishes monthly and yearly statistical summaries on rail transportation occurrences based on the data in the RODS system[10].

The TSB RODS data comprises five CSV tables: Occurrence, Train, Rolling Stock, Injuries, Track and Rolling stock components. Each of these tables contains data relevant to each specific class of incident. For example, an incident involving the collision of two trains, will have an entry in the Occurrence table describing the data relevant to that incident, but also have entries specific to each train involved in the Train data-table. Rolling stock that is damaged will have an entry in the Rolling Stock data-table. If injuries occurred, an entry is made to the Injuries data-table. Track

[9] https://www.bst.gc.ca/eng/stats/rail/index.html

[10] https://www.bst.gc.ca/eng/stats/rail/stats.html

and/or rolling stock components involved in an incident will have an entry into the Track and Rolling stock components data-table.

NRC, as part of on-going research related to risk mapping of the Canadian rail network, downloads the RODS data monthly. The NRC database is updated each month, where the five RODS CSV files are downloaded and automatically loaded into the NRC database. Figure 2 shows the structure of all tables in the NRC-RODS database.

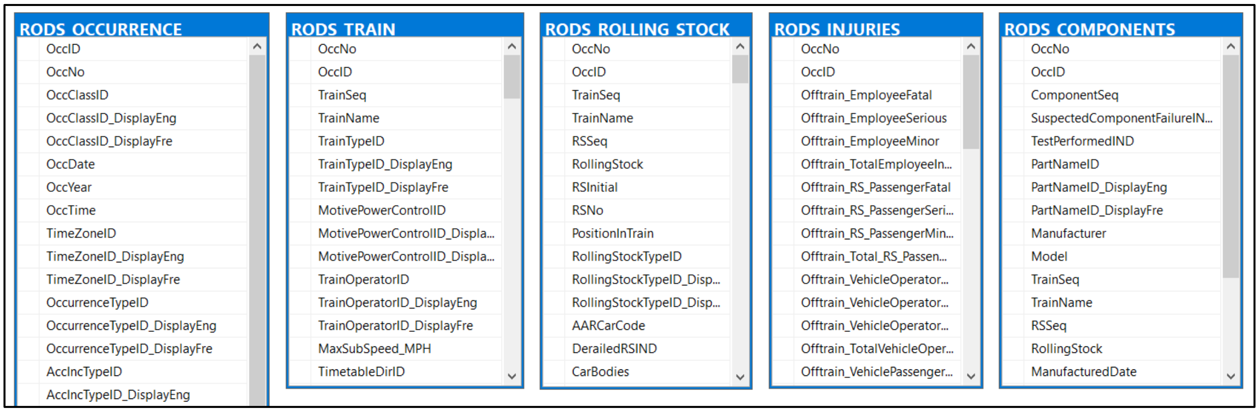

Figure 2: Table structure for NRC-RODS database

All data with excel file formats since 1987 for FRA Rail Equipment Accidents were downloaded. The excel files contain reported cases of collisions, derailments, fires, explosions, acts of God, or other events involving the operation of railroad on-track equipment and involving damages exceeding the reporting threshold for the year reported.

As well, the FRA data, available publically, was downloaded and a similar database created by NRC to allow searching for specific incident types[11]. For the FRA data, a database table named "FRAAccidentDataRailEquipment" was created with a data processing tool developed by NRC. Figure 3 shows the table structure of "FRAAccidentDataRailEquipment" in the NRC database[12].

[11] https://railroads.dot.gov/accident-and-incident-reporting/overview-reports/overview-reports

[12] The detailed data definition or inventory data for each column is available on the website of FRA Office of Safety Analysis.

FRAAccidentDataRailEquipment

Column Name	Data Type	Allow Nulls
CARS	int	☑
CARSDMG	int	☑
CARSHZD	int	☑
EVACUATE	int	☑
DIVISION	varchar(250)	☑
STATION	varchar(250)	☑
MILEPOST	varchar(250)	☑

Figure 3: Table Structure for FRAAccidentDataRailEquipment database

4.1.1 Database searches

In order to determine whether any differences in outcomes had occurred between incidents in Canada and the US before and after August 2002 due to the different buffer-car rules, NRC used several different approaches to search the NRC databases based on the TSB and FRA incident data. To better understand if buffer cars resulted in a difference in incident outcomes between countries and before and after the 2002 changes in wording, only main track train derailments where a DG car or cars were involved, derailed, damaged, or released were obtained from the database.

A second use for the NRC database of the RODS and FRA data was to identify the most severe incidents from 1990 to 2020 and identify any TSB or NTSB reports that may be associated with these incidents.

Table 8 lists all the search cases with the highest priority from item 1 to item 10. These search results identified the incidents and reports most closely related to dangerous goods car marshalling. Table 9 lists the column names and their descriptions searched from both FRA and RODS databases.

Table 8: Database Search Criteria

No.	Database Query List	Rank by the Decreasing Order
1	Find all mainline derailments with cars having DG release	Number of DG cars damaged or released
2	Find all mainline derailments with cars having DG derailed	Number of DG cars derailed
3	Find all mainline derailments with cars derailed (DG or not)	Number of cars derailed
4	Find all derailments with cars position from 1 to 5 as first car to derail	Position of car as first derailed car
5	Identify which of #4 have DG cars on the train	Number of DG cars derailed
6	Find all derailments with cars position from 6 to 10 as first car to derail	Position of car as first derailed car
7	Identify which of #6 have DG cars on the train	Number of DG cars derailed
8	Find all incidents involving injury or death to crew	Number of cars derailed
9	Identify which of #8 are mainline derailments	Number of cars derailed
10	Identify which of #8 have DG cars on the train	Number of DG cars derailed

Table 9: RODS and FRA Search Column Names and Description

TSB ROD Column Name	TSB ROD Column Name Description	FRA Column Name	FRA Column Description
OccYear	The year of the occurrence.	YEAR	year of accident / incident
Month	The month of the occurrence.	MONTH	month of incident
Day	The Day of the occurrence.	DAY	day of incident
OccNo	The TSB occurrence number	INCDTNO	railroad assigned number
TSB Report File	The TSB Report Number	NTSB Report File	Investigation Report Number
NumDGcars	The number of dangerous goods cars in the train.	cars	# of cars carrying hazmat
TotalDGCarsInvolved	Total dangerous goods cars involved	carsdmg	# of hazmat cars damaged or derailed
TotalDGReleasedCars	Total dangerous goods released cars	carshzd	# of cars that released hazmat
TotalDerailedRS	The total number of rolling stock that derailed in the occurrence.	TotalDerailedcars	loadf2+loadp2+emptyf2+ emptyp2+ caboose2 [13]
TotalTrainFatalities	The total number of people who sustained fatal injuries (on-train) during the occurrence.	rrempkld	# of RR employees killed as reported on Form F6180.54
TotalEmployeeInjuries	The total number of employees who sustained injuries.	rrempinj	# of RR employees injured as reported on Form f6180.54
TrainName	The number or name of the train involved in the occurrence.	TRNNBR	Train id number
RSInitial	The letters from the first derailed rolling stock identification number.	rrcar1	Car initials (first involved)
RSNo	The digits from the first derailed rolling stock identification number.	carnbr1	Car number (first involved)
Loc1stDerailRS	A number indicating the location (in the train) of the first derailed rolling stock.	positon1	Car position in train (first involved)
RSInitial_1	The letters from the closest occupied rolling stock identification number.	rrcar2	Car initials (causing)
RSNo_1	The digits from the closest occupied rolling stock identification number.	carnbr2	Car number (causing)
PosClosestOccupied	A number indicating the position of the released dangerous goods in comparison to the closest occupied rolling stock.	positon2	Car position in train (causing)
TrackTypeID_DisplayEng	The type of track, in English.	typtrk	Type of track: main only
Subd_Owner_Abbrev_Eng	Subdivision owner abbreviation (English)	Railroad	railroad code (Reporting RR)
SubdNameID_DisplayEng	Subdivision name (English)	subdivision	Railroad subdivision
StationID_DisplayEng	The name of the station closest to where the occurrence took place, in English.	station	Nearest city and town
SubdMileage	The mileage of the subdivision where the occurrence took place.	milepost	Milepost of the subdivision where the occurrence took place.
summary	A summary of the occurrence.	Narrative	A summary of the occurrence.

[13] **loadf2**: number of derailed loaded freight cars. **loadp2:** Number of derailed loaded passenger cars. **emptyf2**: Number of derailed empty freight cars. **emptyp2**: Number of derailed empty passenger cars. **caboose2**: number of derailed cabooses.

4.2 Railroad Incident and Safety Investigations Reports

On its website, TSB lists both active and completed rail transportation safety investigations and associated reports dating back to 1991. The PDF reports for the completed rail transportation safety investigations which are available for the public were downloaded. TSB safety investigations reports have a very consistent document structure for almost all reports: title page including TSB report number, date, location, incident type, etc., summary and the full investigation report.

The NTSB issue an incident report following each investigation which provide details about the incident, analysis of the factual data, conclusions on the probable cause of the incident, and the related safety recommendations. NTSB Railroad Accident Reports have several diverse formats and the structure of a document for each format is different. Two major types of the NTSB reports are the Railroad Accident Report (RAR) and the Railroad Accident Brief (RAB). Preliminary Reports and Safety Recommendation Reports are also available to download from the NTSB website.

For both the TSB and NTSB, there are active rail transportation safety investigations which have not been completed and the finalized investigation reports have not been released. In these cases the incidents were identified from the incident reporting database, and the available interim reports or status reports were then identified, downloaded, and reviewed.

For this project, all available TSB and NTSB reports were searched by common names or phrases for buffer car with key words: buffer [rail, box, hopper,…] car(s), no [non] placarded buffer [rail, box, hopper, …] car(s), no [non] DG buffer [rail, box, hopper,…] car(s). There are 7 out of 400 TSB incident reports and 7 out of 200 NTSB incident reports where key words "buffer car" were found.

With the exclusion of the negative prefixes such as 'no' and 'non' before the phrase "dangerous goods" and "hazardous materials", all reports for TSB and NTSB have been searched by common name or phrase in the summary or abstract section of report as follows: dangerous goods, hazardous materials, crude fuel oil, gasoline, petroleum gas, diesel fuel, hydrocarbons, toluene, phosphoric acid, sulphuric acid, ferric sulphate, hydrogen peroxide, vinyl acetate, chlorine, sodium hydroxide, caustic soda, liquid asphalt, kerosene, ammonia, anhydrous, argon, refrigerated liquid, carbon dioxide, sodium hydroxide solution, gas oil, heating oil light , motor spirit, petrol, petroleum crude oil, liquefied gas, liquefied petroleum gas, petroleum oil, propane, radioactive material, ethanol and gasoline. Table 10 shows some search samples from TSB reports. There are 100 out of 400 TSB incident reports and 50 out of 200 NTSB incident reports that were found with key words "dangerous goods" and "hazardous materials". Although search phrases such as "dangerous goods", or materials classified as dangerous goods, may be in the short incident summary, many of these incidents did not occur on main track, or involve a Key Train.

For the TSB incidents, the TSB reports match the initial incident number. However, for the NTSB reports on severe rail incidents, the NTSB report number typically does not reference the initial

FRA incident number, so identifying the NTSB reports associated with an FRA incident number was more difficult. Ultimately, the NTSB reports were found and associated with the FRA incidents using text search terms describing the incidents, and by manually screening the reports issued by the NTSB regarding dangerous goods[14].

Table 10: Example of TSB Reports with the common names for "dangerous goods"

File Name	**r00d0026.pdf**
Accident Type	**Derailment**
Railway Company	**Canadian National**
Train Information	**Freight Train No. L-525-21-10**
MilePost and Subdivision	**Mile 83.70, Massena Spur**
Location	**Brossard, Quebec**
Date	**10 March 2000**
TSB Report Number	**Report Number R00D0026**
On 10 March 2000, at about 1924 eastern standard time, Canadian National (CN) westward freight train No. L-525-21-10, destined for Saint-Isidore, Quebec, derailed five cars at Mile 83.70 on the Massena Spur of the Rouses Point Subdivision at Brossard, Quebec. The derailment occurred after the train went through a public crossing. Four cars came to rest on their side in the ditch; three of these contained **dangerous goods**, but no product was lost. Twenty people were evacuated as a precautionary measure.	
File Name	**r00e0126.pdf**
Accident Type	**Derailment**
Railway Company	**Canadian Pacific Railway**
Train Information	**Train LDRS-12**
MilePost and Subdivision	**Mile 85.94, Lloydminster Subdivision**
Location	**Lone Rock, Saskatchewan**
Date	**12 December 2000**
TSB Report Number	**Report Number R00E0126**
On 12 December 2000 at about 2225 Central standard time, Canadian Pacific Railway southward freight train LDRS-12 derailed 13 cars at Mile 85.94 on the Lloydminster Subdivision near the hamlet of Lone Rock, Saskatchewan. The 13 cars were all dangerous goods cars, seven loaded with **kerosene** and six loaded with **liquid asphalt**. Five cars lost approximately 84 000 liters of kerosene and three cars lost approximately 150 000 liters of liquid asphalt. Environmental damage occurred as a result of the spill. There were no injuries.	

[14] In the US, dangerous goods are referred to as “hazardous materials”.

4.3 Results of incident data analysis.

The following sections describe the analysis of the incident data collected from the Canadian and US incident records. All data reported for the year 2020 is as of February 2021, and it is assumed all incidents have been entered into the respective databases by that time, even though reports on the incidents are on-going and may be incomplete. Canadian data for 1990 and 1991 is reported as found for completeness, however it appears inconsistent, as incidents are on record but no incidents involving dangerous goods releases are reported. The data presented makes no distinction between incidents involving unit trains or mixed goods trains.

4.3.1 Analysis of yearly incident data

Table 11 summarizes the yearly totals for US and Canadian main-line rail incidents where dangerous goods were released. The columns represent the total DG cars in the incident trains, the total DG cars involved in the incident, and the total DG cars that released.

Table 11: Summary of DG car involvement in incidents where DG cars derailed or released.

YEAR	*Total DG Cars on incident trains (US)*	*Total DG Cars on incident trains (CAN)*	*Total DG Cars Involved (US)*	*Total DG Cars Involved (CAN)*	*Total DG Cars Released (US)*	*Total DG Cars Released (CAN)*
1990	1610	3	348	3	75	0
1991	2305	8	394	2	66	0
1992	1915	137	221	137	20	10
1993	2043	488	245	83	34	3
1994	1974	317	306	133	28	16
1995	2641	255	510	133	37	16
1996	2619	828	370	215	53	17
1997	2010	1082	336	102	23	7
1998	2630	516	373	87	42	6
1999	2880	1211	464	170	42	78
2000	3157	998	408	103	62	6
2001	3613	607	363	88	44	3
2002	3462	875	416	142	41	17
2003	3844	716	447	134	30	17
2004	3388	758	332	145	32	9
2005	3574	1465	291	148	26	6
2006	4466	762	417	109	52	3
2007	3552	387	397	101	44	4
2008	3800	722	238	78	28	2
2009	2792	185	248	56	32	22
2010	3855	58	236	58	32	2
2011	3659	212	203	101	52	1
2012	2889	93	268	44	46	2
2013	3490	420	337	135	73	64
2014	4064	968	261	168	24	15
2015	3881	1209	232	167	61	54
2016	2775	634	102	42	13	1
2017	3536	237	268	41	34	6
2018	3397	496	161	61	22	2
2019	3949	727	331	180	19	43
2020	3073	1136	141	100	12	6

Figure 4 is a plot of the total DG cars on an incident train, the first two columns in Table 11.

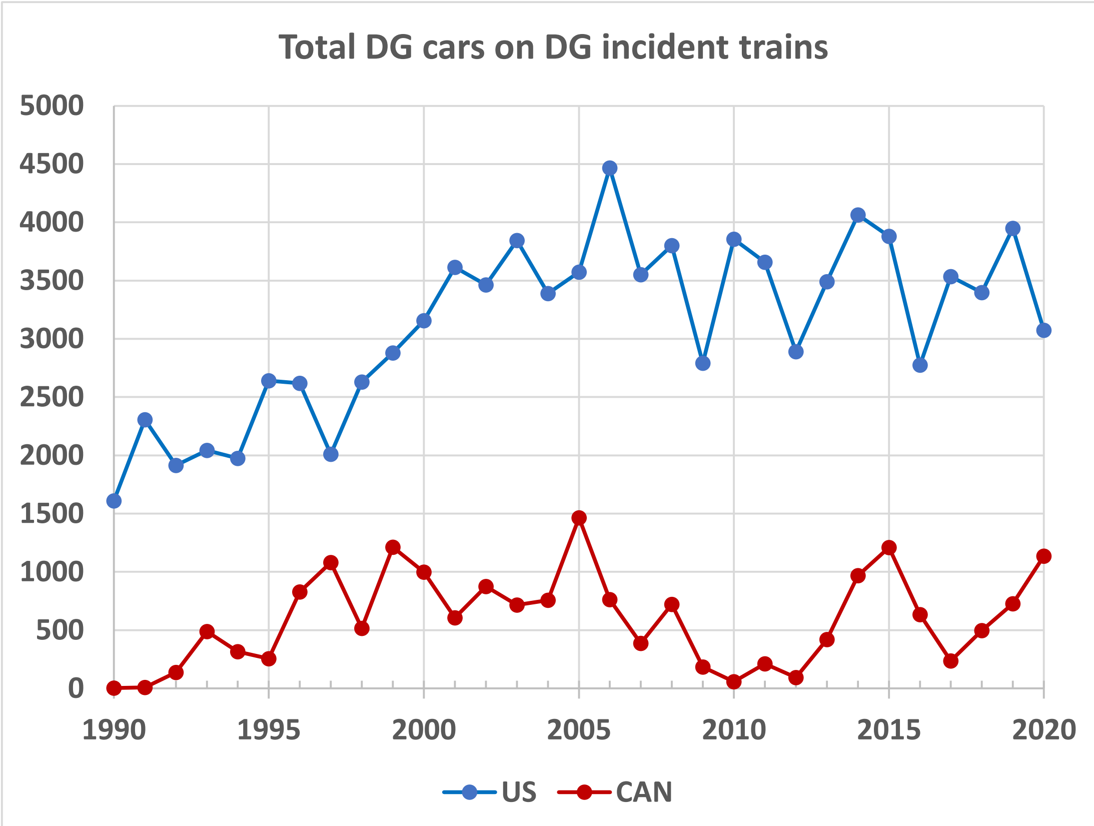

Figure 4: Number of DG cars on trains involved in a DG incident: Canada and US data for mainline incidents where DG cars released (1990 to 2020[15]).

[15] Data for 2020 is as-of Feb 2021.

Figure 5 is a plot of the total DG cars involved in an incident, the third and fourth columns in Table 11.

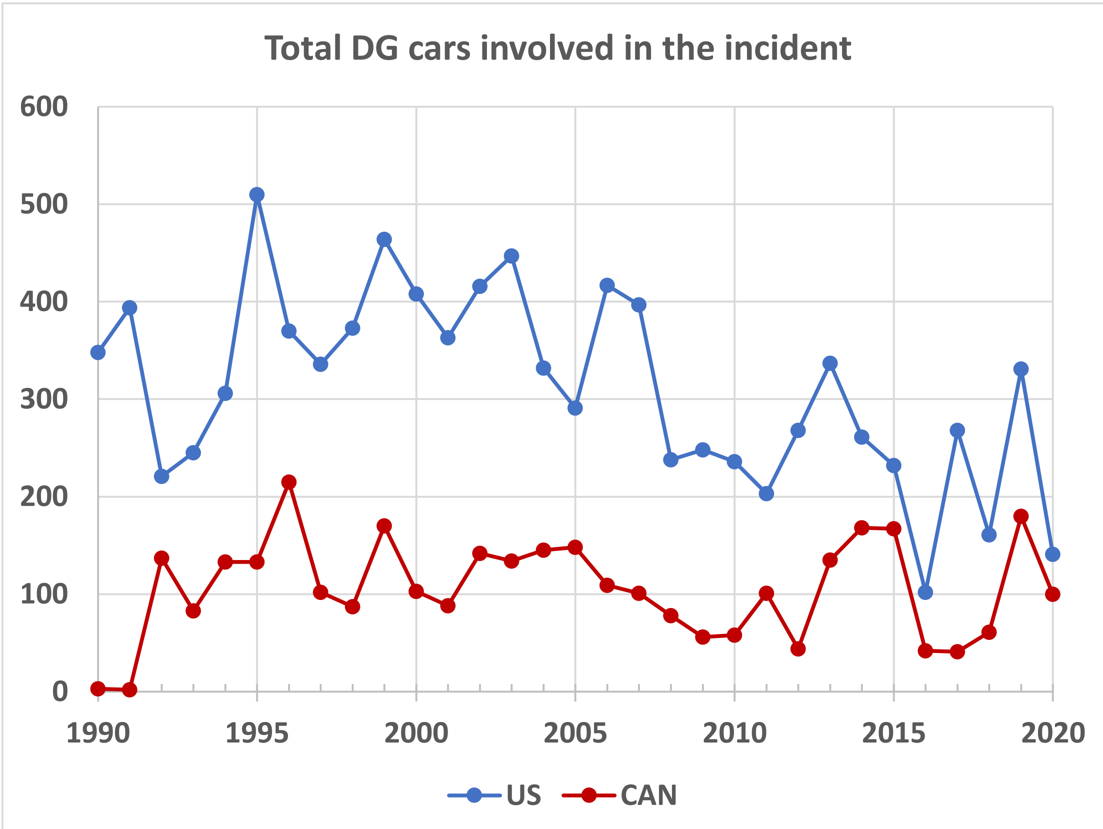

Figure 5: Total number of DG cars involved in DG incidents per year: Canada and US data for mainline incidents where DG cars released (1990 to 2020).

Figure 6 is a plot of the total DG cars released in an incident, the fifth and sixth columns in Table 11. The significant peak in Canada in 1999 represents a gasoline train derailment in St-Hyacinthe QC; the peak at 2009 represents a mixed goods Key Train derailment on the Rivers subdivision; the peak in 2013 represents the Lac-Mégantic QC incident, the 2015 peak represents the two Ruel subdivision derailments of unit oil trains which occurred 3 weeks apart; and the 2019 peak is attributed mostly to the Sutherland and Rivers subdivision unit oil train derailments.

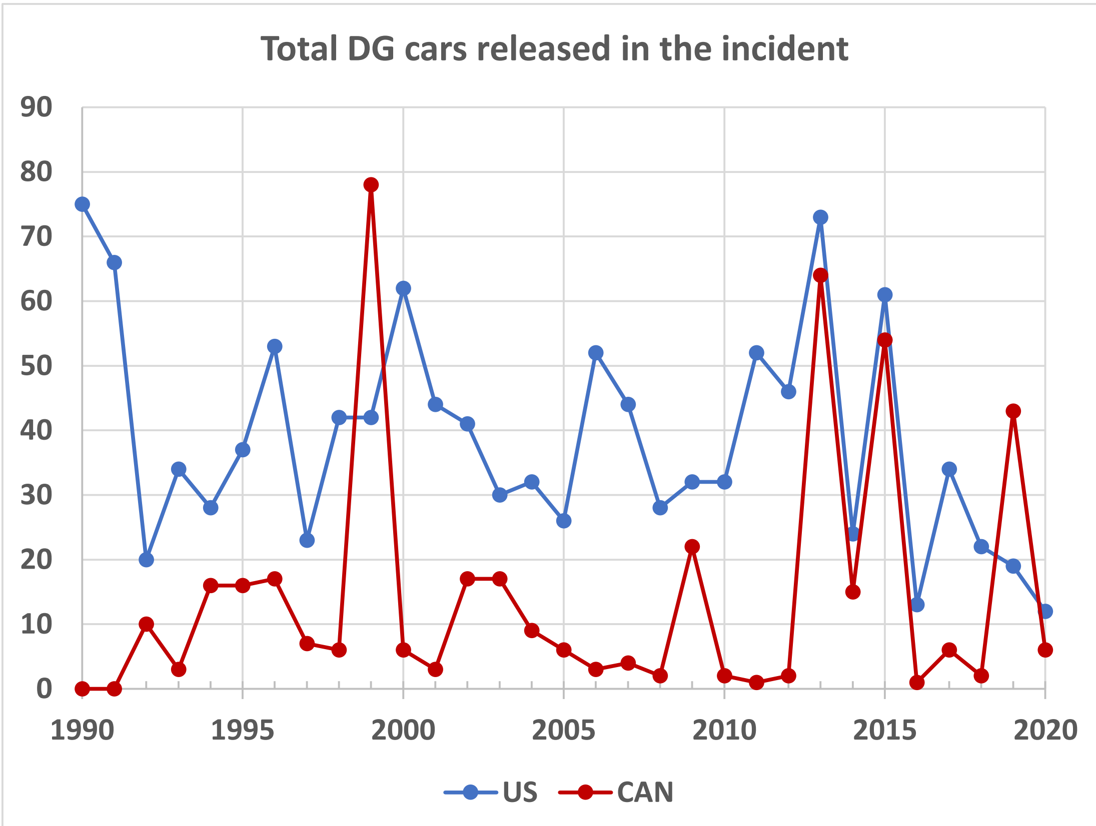

Figure 6: Total number of DG cars released in DG incidents per year: Canada[16] and US data for mainline incidents where DG cars released (1990 to 2020).

[16] Data for Canada for mainline incidents for 1990 and 1991 is incomplete.

Figure 7 is a bar chart showing the ratio of the number of DG cars released to the number of DG cars involved in an incident. This plot is a ratio of the data shown in Figure 5 and Figure 6 above. The years 1990 and 1991 are excluded in these results as data for Canada in these years are 0 for both values, resulting in invalid ratios. This ratio allows the US and Canadian data to be compared on a basis normalized per incident. The five peaks seen in the Canadian results discussed above are clearly seen.

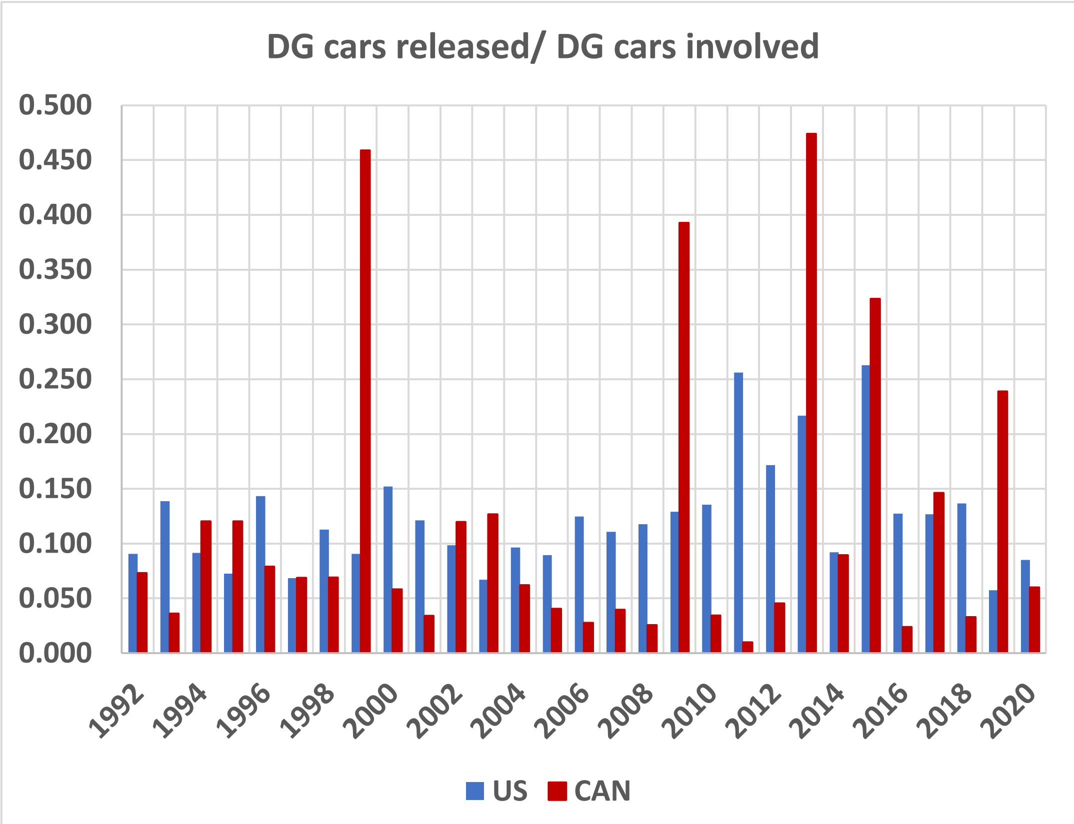

Figure 7: Ratio, per year, of number of DG cars to release to DG cars to derail: Canada and US data for mainline incidents where DG cars released (1992 to 2020).

Figure 8 shows the result of averaging the yearly results shown in Figure 7 for all the data from 1992 to 2002, 2002 to 2020, and 1992 to 2020. The bars show that on average, the ratio of DG cars released to DG cars involved between the US and Canadian data is very similar. Note that this data applies only to mainline incidents where a DG car released.

The yearly data for incidents involving DG releases does not show a difference between Canada and the US when viewed from the perspective of the number of cars releasing relative the number of cars derailing.

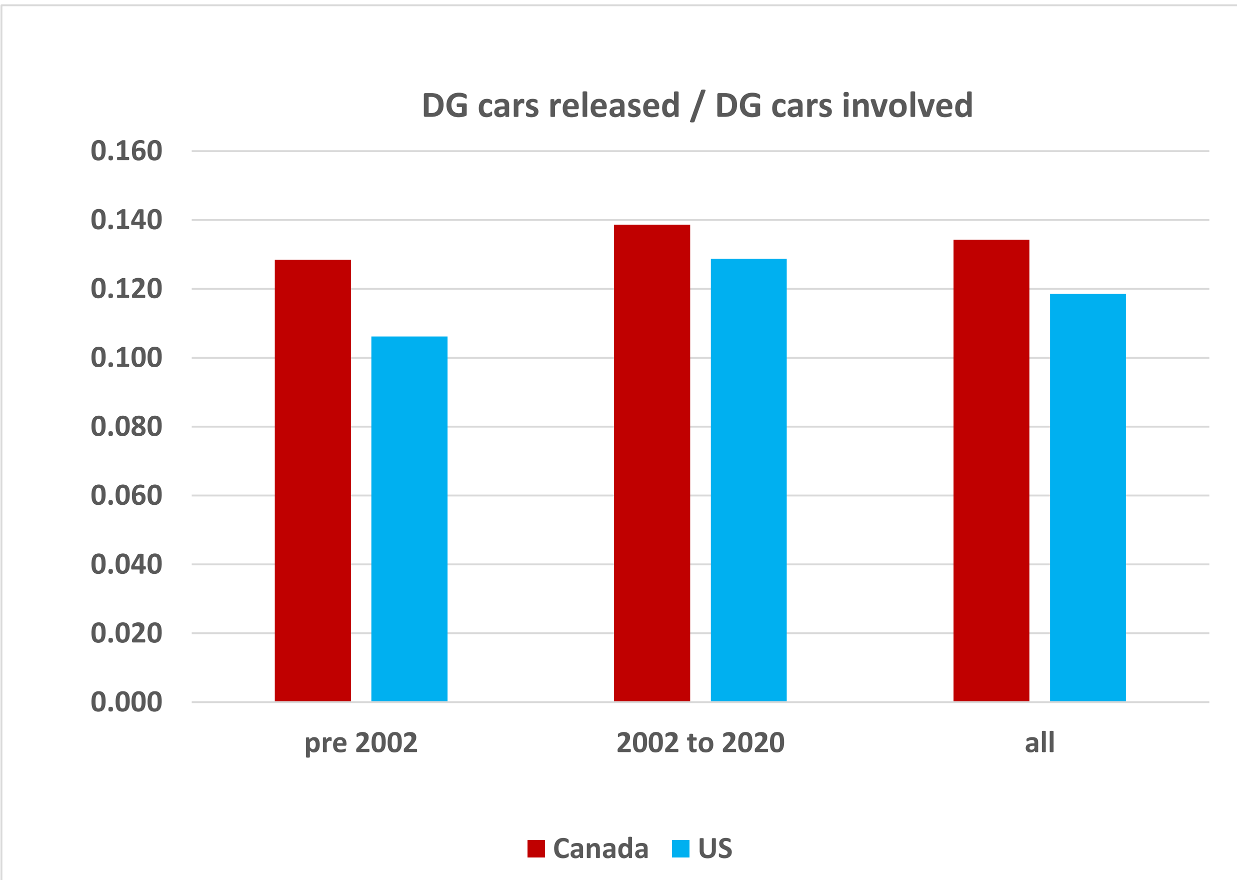

Figure 8: Ratio of DG cars to release to DG cars to derail, average of selected time frames: Canada and US data for mainline incidents where DG cars released.

4.3.2 Analysis of the number of cars to derail

For this study, using the TSB and NTSB data the data for all main line incidents where DG cars released was obtained, and the number of cars to derail in each incident was compiled. With this common data set between the US and Canadian data, an analysis into the number of cars to derail, for years 1990 to 2002 and from 2002 to 2020 was completed. The following figures summarize the results of this data search and analysis.

Figure 9 shows the relative frequency distribution of the number of cars to derail or be damaged per incident, normalized to the number of incidents which occurred in each country between 1990 and 2020. For this time-frame Canada shows a higher number of single-car damaged incidents compared to the US, however again both countries display a similar pattern of decreasing frequency of larger derailments.

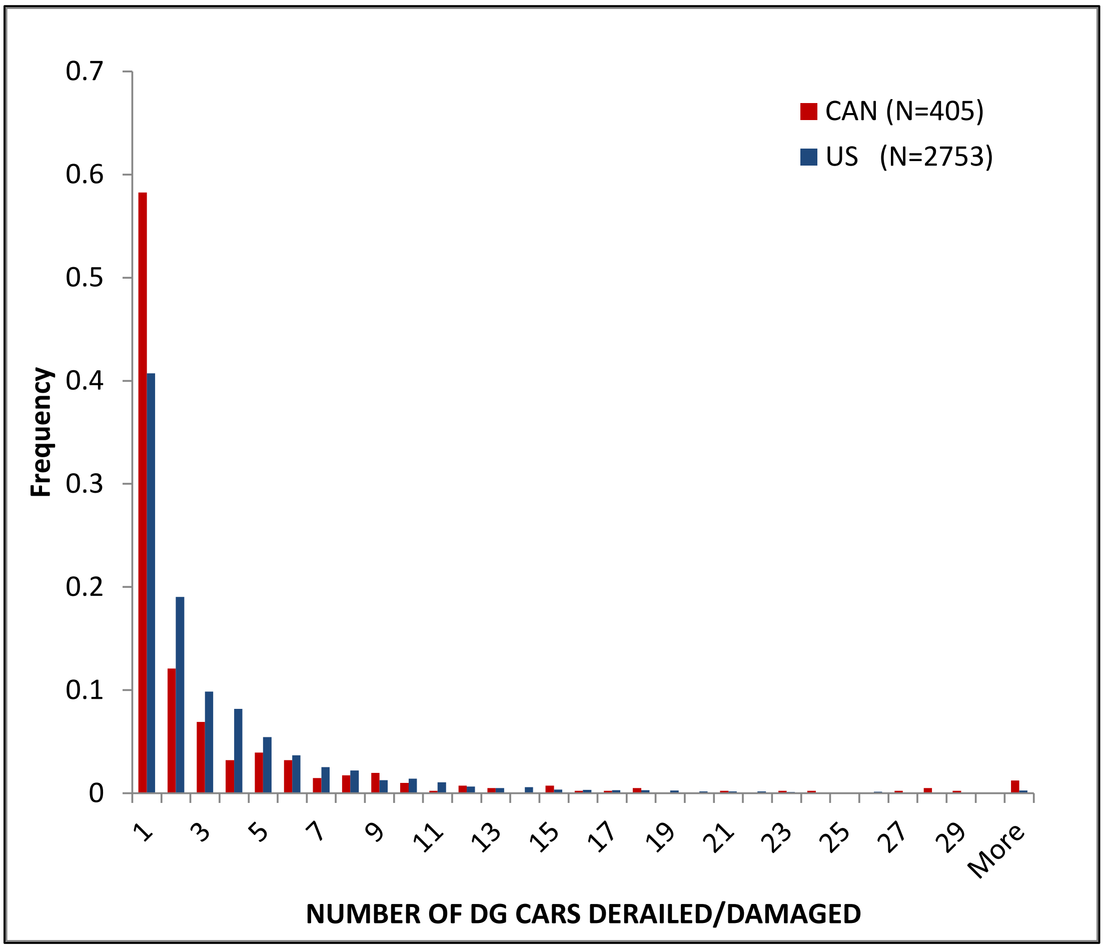

Figure 9: Relative frequency distribution of number of DG cars derailed or damaged per incident: Canada and US for mainline incidents involving DG cars (1990 to 2020).

Figure 10 shows the relative frequency distribution of the number of cars to derail or be damaged per incident, normalized to the number of incidents which occurred in each country between 2002 and 2020. For this metric Canada shows a slightly higher number of incidents where one car is damaged or derailed compared to the US, however both countries display a similar pattern of decreasing frequency of derailments where larger numbers of DG cars derail or are damaged.

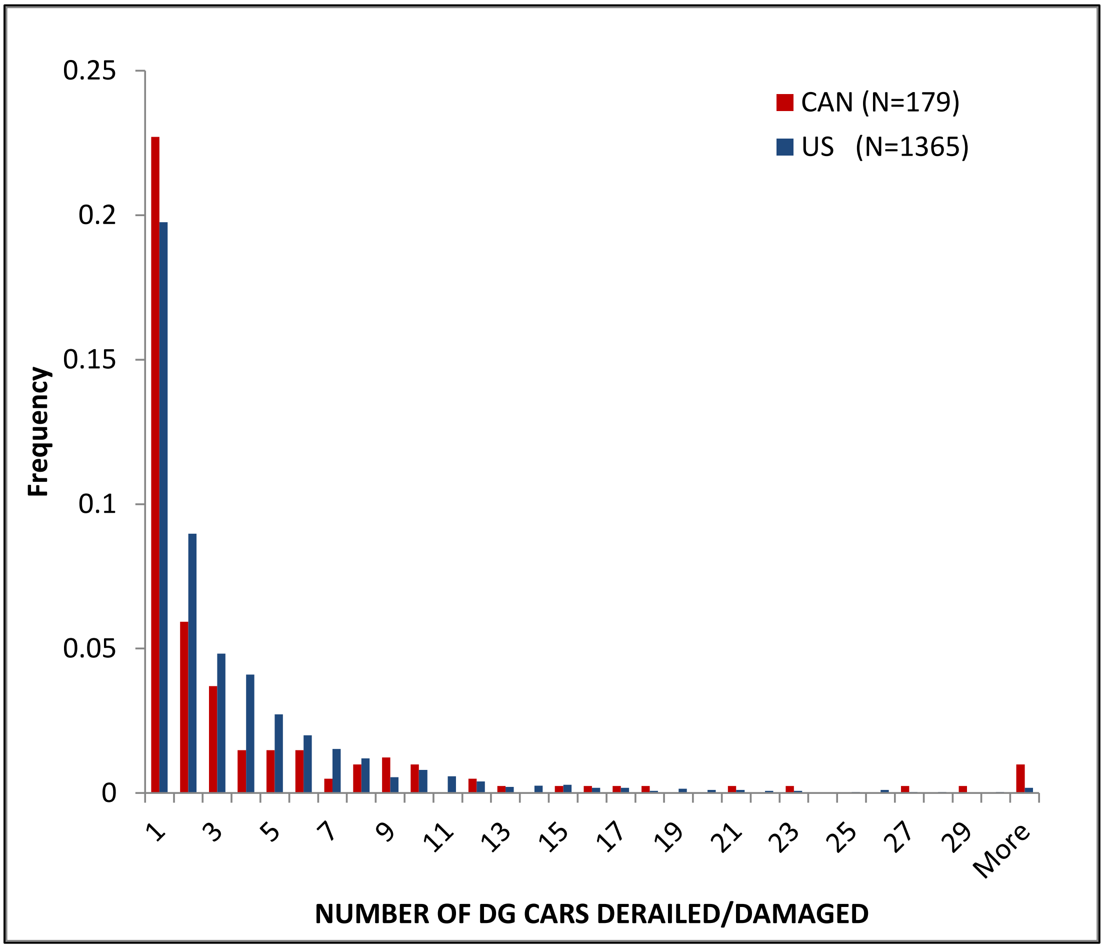

Figure 10: Relative frequency distribution of number of DG cars derailed or damaged per incident: Canada and US for mainline incidents involving DG cars (2002 to 2020).

4.3.3 Analysis of the position of the first car to derail

The TSB and NTSB data contains a record for all derailments of the position in a train where the derailment originated, known as the first car to derail. The position data exists for some records in the TC RODS data, but is inconsistently recorded and is not recorded for most incidents not involving a DG release.

The data available from the NTSB and TSB records for all incidents where DG cars released was obtained and compiled. For incidents in the TSB records where the location of the first car to derail was not present the written TSB report was identified and the location obtained from the report if it was recorded. In this manner, the location of the first car to derail was identified for all but 23 of 93 records in the TSB data[17]. With this common data set between the US and Canadian data, an analysis into the location of the first car to derail, and the number of cars to derail per incident was completed. The following figures summarize these results.

Figure 11 shows the relative frequency distribution of the position of the first car to derail, only for incidents where DG cars were involved and released for the time frame of 1990 to 2020. The incident data is compiled into histogram bins of five cars. Both Canada and the US show a much higher population of incidents with DG car release where the first car in the train to derail was car 1 to 5.

Note that the car which derailed first is not known to be a DG car – the first car or locomotive can derail and the resulting derailment may lead to a DG car release further down the train consist. However this analysis does show that there are over twice as many derailments which originate at the first five cars where a DG car releases compared to any other position in the train.

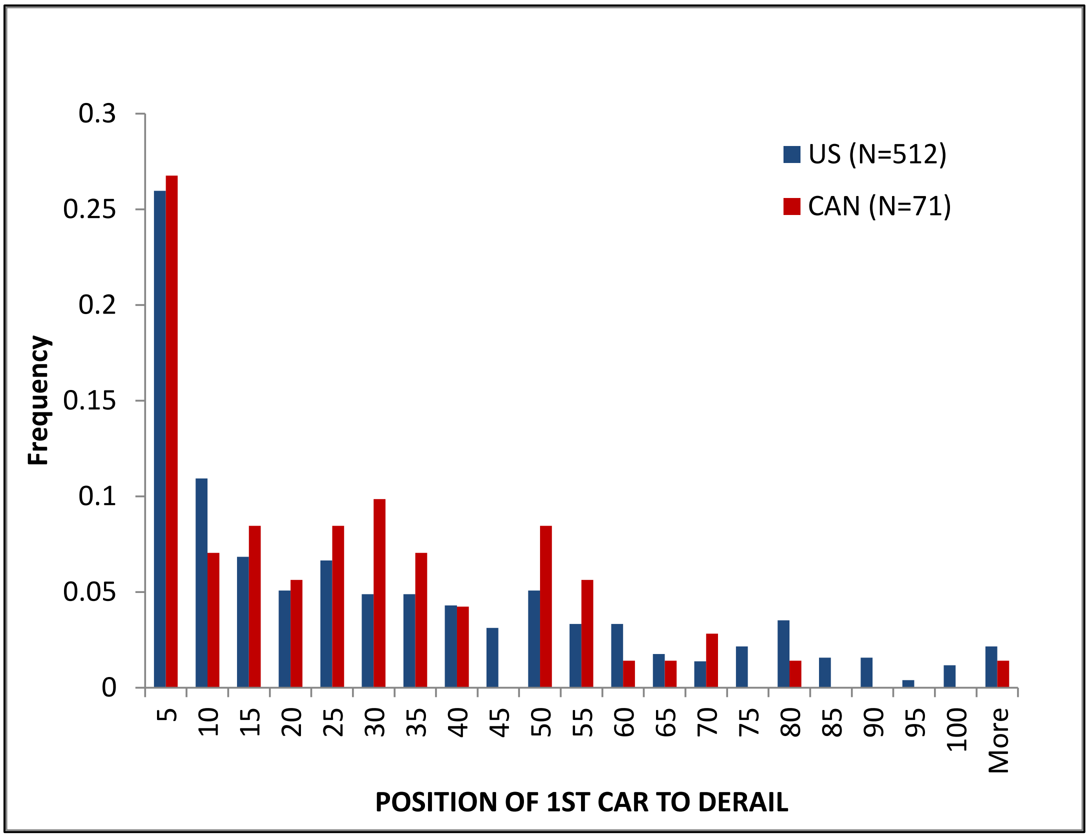

Figure 11: Relative frequency distribution of position of 1st car to derail: Canada and US mainline incidents with DG cars releasing (1990 to 2020).

[17] An analysis using the RODS rolling stock data is on-going and may provide data for the 23 records which are missing the "Loc1stDerailRS" data entry in the OCCURENCES table.

Figure 12 shows the relative frequency of the position of the first car to derail, only for incidents where DG cars were involved and released, from September 2002 to the end of 2020. Again, there are over twice as many derailments which originate at the first five cars where a DG car releases compared to any other position in the train.

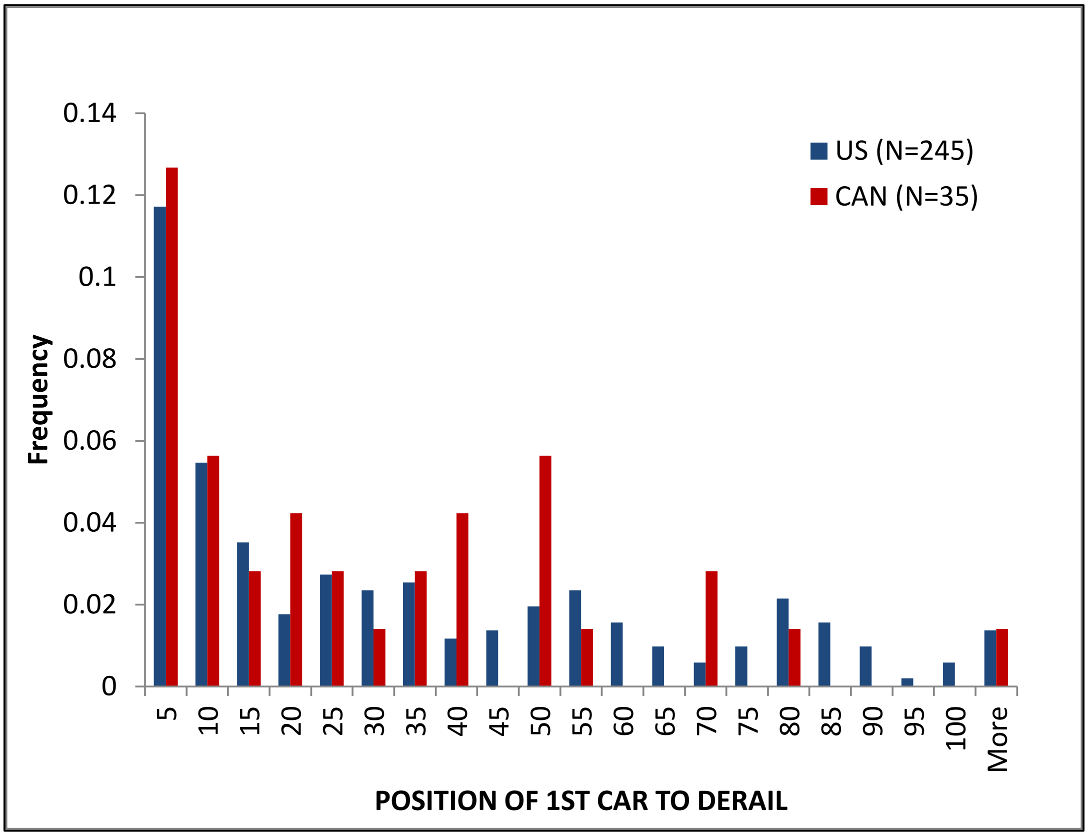

Figure 12: Relative frequency distribution of position of 1st car to derail: Canada and US mainline incidents with DG cars releasing (2002 to 2020).

The results shown in Figure 11 and Figure 12 show that for mainline incidents involving a DG car release, a release is more likely to occur if the first car to derail in the train was in the first five positions. This result does not show that the first five car positions are the most dangerous locations in the train – it does show that derailments which originated in the first five car positions result in more incidents where dangerous goods cars released, regardless of their position in the train.

Further study of the relationship between the location of the DG cars in the train, the sustained damage, and the position of the first car to derail, may bring to light greater understanding of the effect of the position of DG cars in a consist on the outcome in a derailment.

4.3.4 Number of DG cars to release per incident

The TSB and NTSB data contains a record for all derailments of the position in a train where the derailment originated, and the number of cars to release in each derailment. As was stated above the position data exists for some records in the TSB RODS data, but is inconsistently recorded and is not recorded for most incidents not involving a DG release. For the data that is available, an analysis looking at the relationship between the first car to derail and the number of derailed cars or DG cars which released was completed.

Figure 13 shows the relationship between the location of the first car to derail and the number of dangerous goods cars to release, per incident, only for mainline incidents from 1990 to 2020 in Canada and the US. The data represents a 30 year time span, with 71 representative incidents for Canada and 512 incidents for the US. The data for Canada, in large red dots, is scattered within the family of data presented for the US incidents. The Canadian data point at 59 cars represents the 2013 Lac-Mégantic incident which occurred at a train speed far above allowable track speed where the incident occurred, and far above the allowable train speed for the type of train involved.

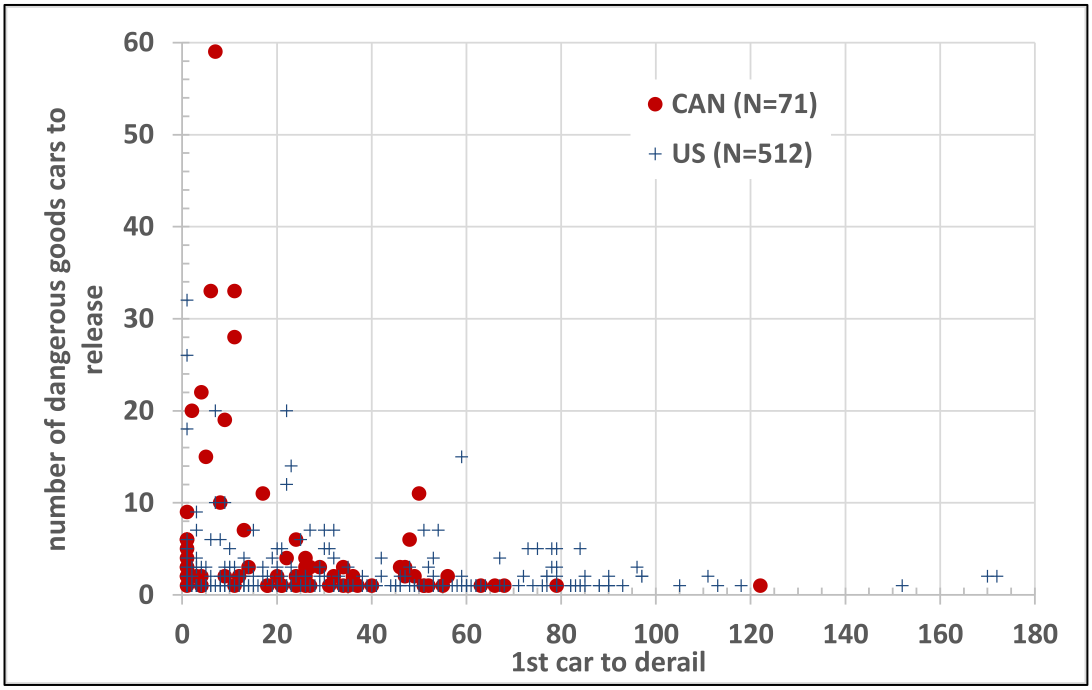

Figure 13: Number of DG cars to release per incident vs. 1st car to derail: Canada and US data for mainline incidents where DG cars released (1990 to 2020).

Figure 14 shows the relationship between the location of the first car to derail and the number of dangerous goods cars to release, per incident, only for mainline incidents from 2002 to 2020 in Canada and the US. The data represents an 18 year time span, with 35 representative incidents for Canada and 245 incidents for the US. As in Figure 13, the data for Canada, in large red dots, is again scattered within the family of data presented for the US incidents, and there is no obvious difference between the results in Canada and the US. DG-release incidents in both countries clearly show that incidents with the largest number of DG car releases originated near the front of the train.

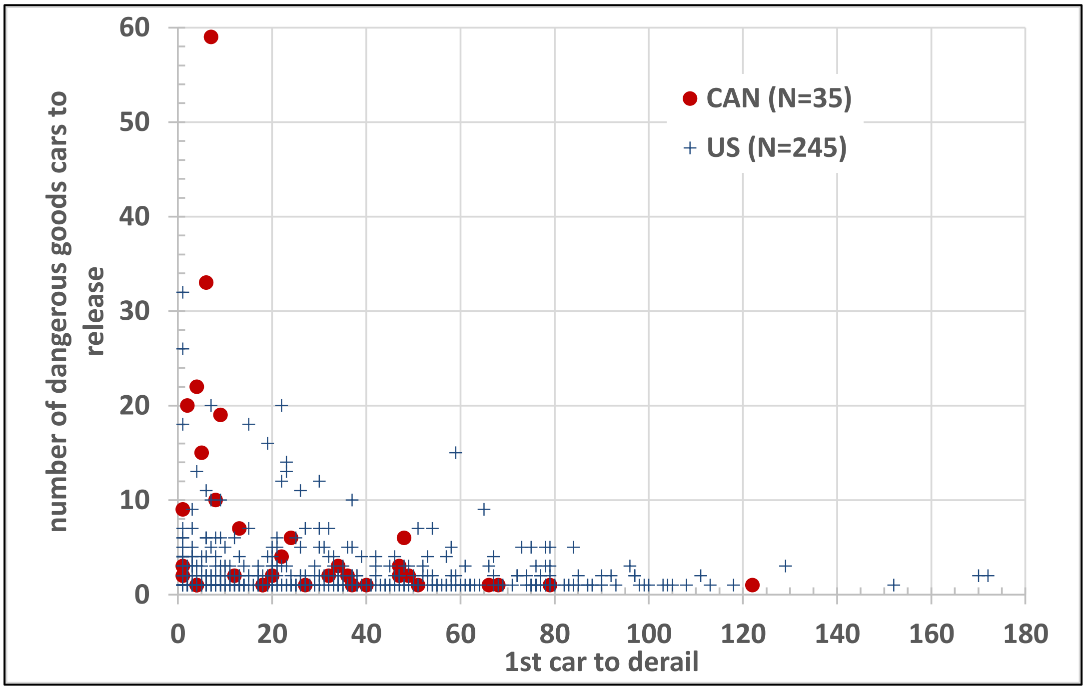

Figure 14: Number of DG cars released per incident vs 1st car to derail: Canada and US data for mainline incidents where DG cars released (2002 to 2020).

The data summarized in Figure 13 and Figure 14 highlight that incidents that originate near the front of the train result in more DG car releases per incident. As well, there is no obvious difference between the results in Canada and the US. DG-release incidents in both countries clearly show that incidents with the largest number of DG car releases originated near the front of the train. Also, note that this data is limited to main track train derailments were DG cars *released,* which is a factor in highlighting only the worst case derailments from a larger population of derailments where DG cars were on a train, but no goods were released, and from an even larger population of derailments which did not involve dangerous goods at all.

4.4 Severe DG Incident Report Analysis

The TC and FRA rail incident data was used to identify all severe dangerous goods incidents in Canada and the US using the NRC database as described in previous sections. The database was searched for mainline rail incidents where a dangerous goods car released or was involved. The TSB and NTSB incident reports associated with these incidents was then identified[18].

In general, all major derailments involving a DG release had an associated TSB detailed incident report. There were no instances found where severe incidents involving dangerous goods did not have a detailed TSB report summarizing the incident causes and outcomes. For US incidents, there were several gaps noted in the availability of detailed incident reports for severe incidents where DG cars released. However, where there was loss of life or a serious incident within a populated area, there was a detailed NTSB report.

The incident reports typically summarized the train details, but seldom recorded whether buffer cars were involved in the incident or not unless there was direct impact on the incident outcome. The reports were used to confirm or obtain the location of the first car to derail, the number of derailed cars, and in some cases to confirm the incident details with respect to the entries in the RODS database.

The following sections summarize the Canada and US incidents identified in the data search. The sections contain a table listing the identified incidents, listing the incident reports if available. A summary of the incidents identified where the first car to derail was cars 1 through 5 are further summarized in more detail in subsections. These incident summaries are presented to provide discussion on what the effects of buffers cars were, or would have been, in these incidents.

4.4.1 Review and Summary of Notable TSB Incidents Reports

Table 12 is listing of the TSB reports available for mainline incidents where DG cars released. (The report numbers shown in bold are not available online.) The table lists both active and completed rail transportation safety investigations.

[18] These reports are available for download from the TSB and NTSB websites.

Table 12: Listing of main line incidents in Canada with 1 or more DG car release.

	Occurence Year	Month	Day	Occurence No	TSB Report File	Total DG Cars Involved	Total DG Cars Released	Total Derailed Rolling Stock	Sub Owner	Sub Name
0	2013	7	6	R13D0054	R13D0054.pdf	72	59	65	MMA	SHERBROOKE
1	2015	3	7	R15H0021	R15H0021.pdf	39	33	39	CN	RUEL
2	1999	12	30	R99H0010	R99H0010.pdf	36	33	64	CN	ST-HYACINTHE
3	1999	3	8	R99C0026	R99C0026.pdf	28	28	28	CN	RAM RIVER
4	2009	12	5	R09W0252	R09W0252.pdf	22	22	36	CN	RIVERS
5	2019	12	9	R19W0320	R19W0320.pdf	33	20	34	CP	SUTHERLAND
6	2015	2	14	R15H0013	R15H0013.pdf	29	19	29	CN	RUEL
7	2019	2	16	R19W0050	R19W0050.pdf	37	15	37	CN	RIVERS
8	1999	4	13	R99Q0019	R99Q0019.pdf	11	11	10	CN	MONTMAGNY
9	1995	1	21	R95D0016	R95D0016.pdf	28	11	28	CN	LA TUQUE
10	2002	12	4	R02E0114	R02E0114.pdf	42	10	42	CP	TABER
11	2003	2	21	R03T0080	R03T0080.pdf	10	9	22	CP	BELLEVILLE
12	2014	1	7	R14M0002	R14M0002.pdf	12	7	20	CN	NAPADOGAN
13	2020	2	18	R20W0031	R20W0031.pdf	27	6	31	CN	FORT FRANCES
14	2014	7	10	R14T0160	R14T0160.pdf	13	6	26	CN	KINGSTON
15	1996	3	30	R96T0112	R96T0112.pdf	6	6	28	CN	CARAMAT
16	1994	8	5	R94T0255	R94T0255.pdf	12	6	30	CN	NEWMARKET
17	1992	12	18	R92W0300	R92W0300.pdf	24	6	32	CN	RIVERS
18	2002	5	2	R02W0063	R02W0063.pdf	5	5	23	CN	RIVERS
21	2004	8	17	R04Q0040	**R04Q0040.pdf**	18	4	18	CN	LEVIS
22	1998	5	31	R98V0100	**R98V0100.pdf**	8	4	11	CP	NELSON
23	1994	10	17	R94C0137	R94C0137.pdf	6	4	6	CP	TABER
24	2019	9	2	R19C0094	R19C0094.pdf	11	3	23	CP	ALDERSYDE
26	2003	5	21	R03T0157	R03T0157.pdf	21	3	49	CN	BALA
27	1999	4	23	R99H0007	R99H0007.pdf	3	3	8	CN	CHATHAM
28	1997	9	6	R97V0209	**R97V0209.pdf**	5	3	7	CP	NELSON
29	1996	3	11	R96M0011	R96M0011.pdf	18	3	22	CN	SUSSEX
30	1995	12	20	R95C0290	R95C0290.pdf	9	3	33	CN	EDSON
31	1994	1	30	R94T0029	R94T0029.pdf	4	3	23	CN	RUEL
32	1994	9	19	R94W0221	R94W0221.pdf	3	3	10	CN	SHERRIDON
33	2017	9	4	R17E0115	R17E0115.pdf	8	2	8	CN	LAC LA BICHE
35	2015	1	13	R15H0005	R15H0005.pdf	7	2	22	CP	NIPIGON
36	2014	10	7	R14W0256	R14W0256.pdf	6	2	26	CN	MARGO
37	2013	1	24	R13E0015	R13E0015.pdf	16	2	17	CN	BLACKFOOT
38	2013	4	3	R13T0060	**R13T0060.pdf**	8	3	22	CP	HERON BAY
39	2008	4	7	R08W0058	R08W0058.pdf	3	2	9	CP	WEYBURN
40	2006	6	4	R06Q0054	R06Q0054.pdf	7	2	14	CN	JOLIETTE
42	2003	2	13	R03T0064	R03T0064.pdf	7	2	21	CP	PARRY SOUND
43	2001	8	9	R01W0149	**R01W0149.pdf**	4	2	15	CP	INDIAN HEAD
44	2000	12	12	R00E0126	R00E0126.pdf	7	2	13	CP	LLOYDMINSTER
45	1999	9	23	R99T0256	R99T0256.pdf	18	2	26	CN	BALA
46	1997	3	10	R97W0057	**R97W0057.pdf**	6	2	10	CN	WEKUSKO
47	1996	4	1	R96W0106	R96W0106.pdf	2	2	40	CN	ALLANWATER
48	1996	8	10	R96T0231	R96T0231.pdf	3	2	36	CN	STRATHROY
49	1992	10	22	R92Q0170	R92Q0170.pdf	3	2	16	CN	ROBERVAL

(Table 12 continued)

	Occurence Year	Month	Day	Occurence No	TSB Report File	Total DG Cars Involved	Total DG Cars Released	Total Derailed Rolling Stock	Sub Owner	Sub Name
50	2019	6	28	R19T0107	R19T0107.pdf	1	1	39	CN	STRATHROY
51	2019	8	2	R19C0088	R19C0088.pdf	5	1	22	CP	MAPLE CREEK
52	2018	4	8	R18T0073	R18T0073.pdf	1	1	0	CN	DUNDAS
54	2017	1	7	R17Q0004	R17Q0004.pdf	1	1	1	CN	JOLIETTE
56	2016	3	4	R16M0009	R16M0009.pdf	2	1	0	CN	PELLETIER
57	2013	5	21	R13W0145	R13W0145.pdf	5	1	5	CP	SUTHERLAND
58	2012	1	22	R12W0013	R12W0013.pdf	22	1	22	CP	ESTEVAN
62	2010	10	18	R10D0088	**R10D0088.pdf**	6	1	18	CN	KINGSTON
64	2005	1	29	R05S0007	**R05S0007.pdf**	2	1	17	CN	STRATHROY
65	2005	5	2	R05H0011	R05H0011.pdf	1	1	0	VIA	ALEXANDRIA
66	2005	6	4	R05C0085	**R05C0085.pdf**	1	1		CP	SHANTZ
67	2005	8	5	R05V0141	**R05V0141.pdf**	1	1	9	CN	SQUAMISH
68	2004	3	4	R04E0027	R04E0027.pdf	8	1	20	CP	RED DEER
73	2001	10	6	R01M0061	**R01M0061.pdf**	7	1	15	CN	NAPADOGAN
75	2000	5	22	R00Q0023	**R00Q0023.pdf**	7	1	21	CN	ST-MAURICE
77	2000	12	9	R00M0044	**R00M0044.pdf**	3	1	7	CN	NAPADOGAN
78	1999	2	6	R99T0031	**R99T0031.pdf**	4	1	20	CN	RUEL
79	1998	4	12	R98W0073	R98W0073.pdf	1	1		CN	WATROUS
80	1998	11	11	R98W0241	**R98W0241.pdf**	2	1	22	CP	KAMINISTIQUIA
81	1997	11	24	R97D0253	R97D0253.pdf	1	1		CN	DIAMOND
83	1996	1	30	R96W0042	R96W0042.pdf	7	1	14	CP	WEYBURN
84	1996	3	4	R96C0047	R96C0047.pdf	5	1	15	CN	BALA
86	1996	8	29	R96H0021	R96H0021.pdf	3	1	36	CP	WINCHESTER
87	1995	1	14	R95C0016	R95C0016.pdf	5	1	28	CN	DRUMHELLER
90	1993	8	13	R93T0201	**R93T0201.pdf**	2	1	2	CN	BALA
91	1993	9	13	R93V0177	**R93V0177.pdf**	2	1	11	CN	YALE

The following sub-sections are brief summaries of the incident reports which describe incidents where:

- The incident resulted in a large number of derailed DG cars and the release of dangerous goods which were potentially harmful to the crew.
- The first car to derail was near the leading portion of the train.

These incident reports represent the incidents which from the available data represent situations where the crew were in danger due to the proximity of the first car to derail, as well as due to the release of DG products, or a fire involving DG products. A derailment is always a dangerous situation for a locomotive crew – these report summaries are intended to highlight the past situations where the presence of dangerous goods near the locomotive may have also created additional risk to the safety of the crew.

4.4.1.1 Firdale, Manitoba, 2 May 2002 (R02W0063)

CN freight train, Rivers subdivision, near Firdale, Manitoba, 2 May 2002. Figure 15 shows the aerial scene of the incident described in TSB report R02W0063. Figure 16 shows a diagram of the incident scene, reconstructed during the investigation. The incident details of interest are:

- Occurred on 2 May, 2002.
- Large truck failed to stop at a crossing; train collided with the rear portion of the truck.
- lead locomotive and 23 cars derailed:
    - 12 covered hoppers of plastic pellets
    - 5 tank cars carrying various DG
    - 1 tank car of ethylene glycol
    - 5 not described
- Crew not harmed
- Large fire burned for over 24 hours.

From the incident report, it can be concluded that there were at least five buffers present, consisting of covered hopper cars carrying plastic pellets.

Figure 15: Aerial view of incident described in TSB R02W0063.pdf (Image from page 4).

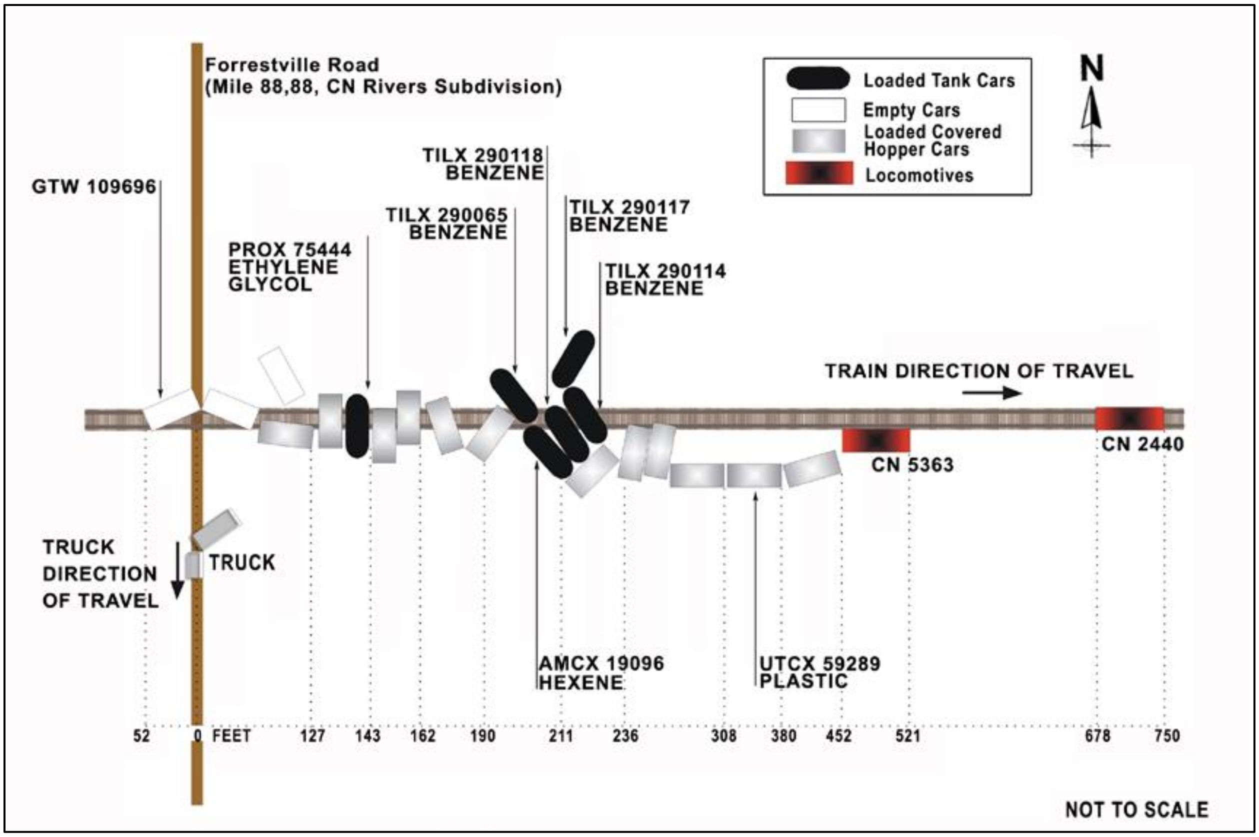

Figure 16: Diagram of incident described in TSB R02W0063.pdf (Image from page 9).

4.4.1.2 Barons, Alberta, 2 September 2019 (R19C0094)

Canadian Pacific Railway freight train on the Aldersyde subdivision near Barons, Alberta, 2 September 2019. Figure 17 shows the aerial scene of the incident described in TSB report R19C0094[19]. The train passed over a section of broken rail, the second locomotive and 21 cars derailed. Train details were as follows:

- Second locomotive derailed on broken rail, lead locomotive continued on track
- The crew escaped safely.
- Cars directly behind the second locomotive:
  - 1 **empty** flat car
  - 2 loaded tank car (not specified as a DG car in the report)
  - 3 unknown
  - 5 DOT-112 (anhydrous ammonia)
  - 6 DOT-112 (anhydrous ammonia)

Although buffer cars were present, the use of an empty flat car as the leading buffer car would not meet car marshalling guideline requirements that aim to minimize the risk of derailments due to in-train forces. However the empty flat car was not cited as the cause of the derailment in this incident.

Figure 17: Aerial view of incident described in TSB R19C0094.pdf (Figure 2 from R19C0094)

19 https://www.tsb.gc.ca/eng/rapports-reports/rail/2019/r19c0094/r19c0094.pdf

4.4.1.3 St-Lazare, Manitoba, 16 February 2019 (R19W0050)

Main-track derailment of Canadian National (CN) freight train near St-Lazare, Manitoba, 16 February 2019[20].

Train details:

- 108 tank cars loaded with petroleum crude oil (UN1267, Class 3 PG I) and 2 covered hoppers loaded with sand.
- The first 2 derailed cars (5th and 6th cars) remained upright and had no visible tank damage or leaks. 37 Class 117R tank cars derailed.

The unit oil train had 2 buffer cars with sand, and the first car to derail was in position five but was undamaged. The crew escaped uninjured.

Figure 18: View of incident described in TSB R19W0050

[20] https://www.tsb.gc.ca/eng/enquetes-investigations/rail/2019/R19W0050/R19W0050.html

4.4.1.4 Guernsey, Saskatchewan on 9 December 2019 (R19W0320)

Main-track train derailment of Canadian Pacific Railway freight train on the Sutherland Subdivision, near Guernsey, Saskatchewan on 9 December 2019[21].

Details of the incident are:

- Covered hopper car in position 2 and the following 33 tank cars derailed.
- 20 of 23 derailed tank cars breached, and a fire burned for approximately 24 hours.
- Cause not listed as the investigation in on-going.

The unit oil train appears to have used 2 buffer cars. The crew escaped safely.

Figure 19: View of incident described in TSB R19W0320

[21] https://www.tsb.gc.ca/eng/enquetes-investigations/rail/2019/R19W0320/R19W0320.html

4.4.1.5 Gogama, Ontario on 7 March 2015 (R15H0021)

Main-track train derailment of CN freight train on the Ruel subdivision, near Gogama, Ontario on 7 March 2015[22].

Details:

- 2 locomotives, 94 loaded tank cars with petroleum crude oil (UN1267).
- 6th to the 44th cars (39 cars in total) derailed due to a broken rail[23].
- No buffer cars between the 2 lead locomotives and the DG cars.
- Lead locomotive and crew came to rest more than 400 feet from the main pileup of cars, and the resulting fire.

The incident report contains a detailed description of the failure modes of the tank cars that were breached in the incident.

Figure 20: Aerial view of incident described in TSB R15H0021.

[22] https://www.tsb.gc.ca/eng/rapports-reports/rail/2015/r15h0021/R15H0021.pdf

[23] RODS data table states car 9 as first to derail – incident report states car 6.

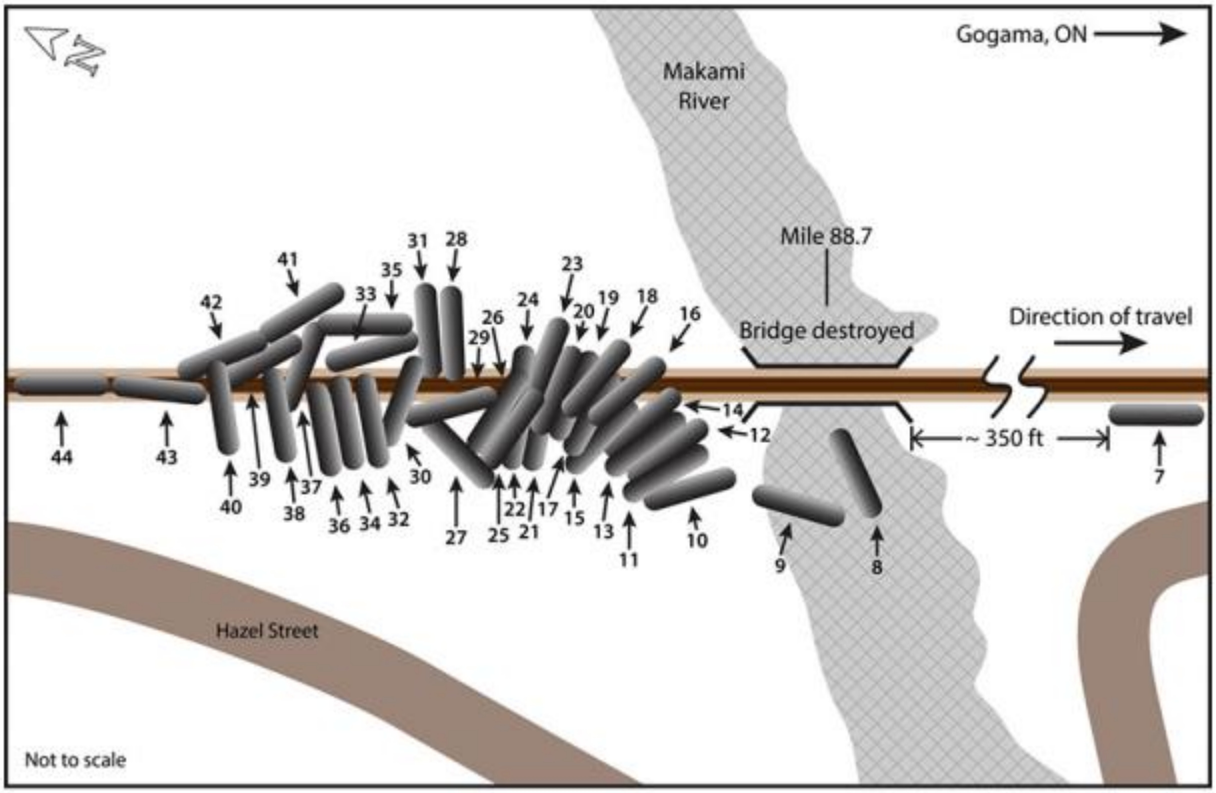

Figure 21: View of incident described in TSB R15H0021

4.4.1.6 Spy Hill, Saskatchewan, 5 December, 2009 (R09W0252)

Main-track derailment of CN freight train, Spy Hill, Saskatchewan, 5 December, 2009. Figure 22 shows an aerial view of the incident described in TSB R09W0252. Figure 23 shows a diagram of the incident site, showing the locations of the derailed cars, and the incident scene management details. It was concluded that the most likely cause of the incident was a broken rail.

Pertinent incident details:

- 2 lead locomotives
- 142 loaded cars, 26 empty cars
- Locomotives and 3 head cars separated from the train and came to a stop 3750 feet from the incident site. The crew escaped safely.
- 36 cars derailed:
    - 14 covered hopper cars containing plastic pellets
    - 22 tank cars carrying dangerous goods

It appears from the description of the train in the report that at least five buffer cars were present.

Figure 22: View of incident described in TSB R09W0252

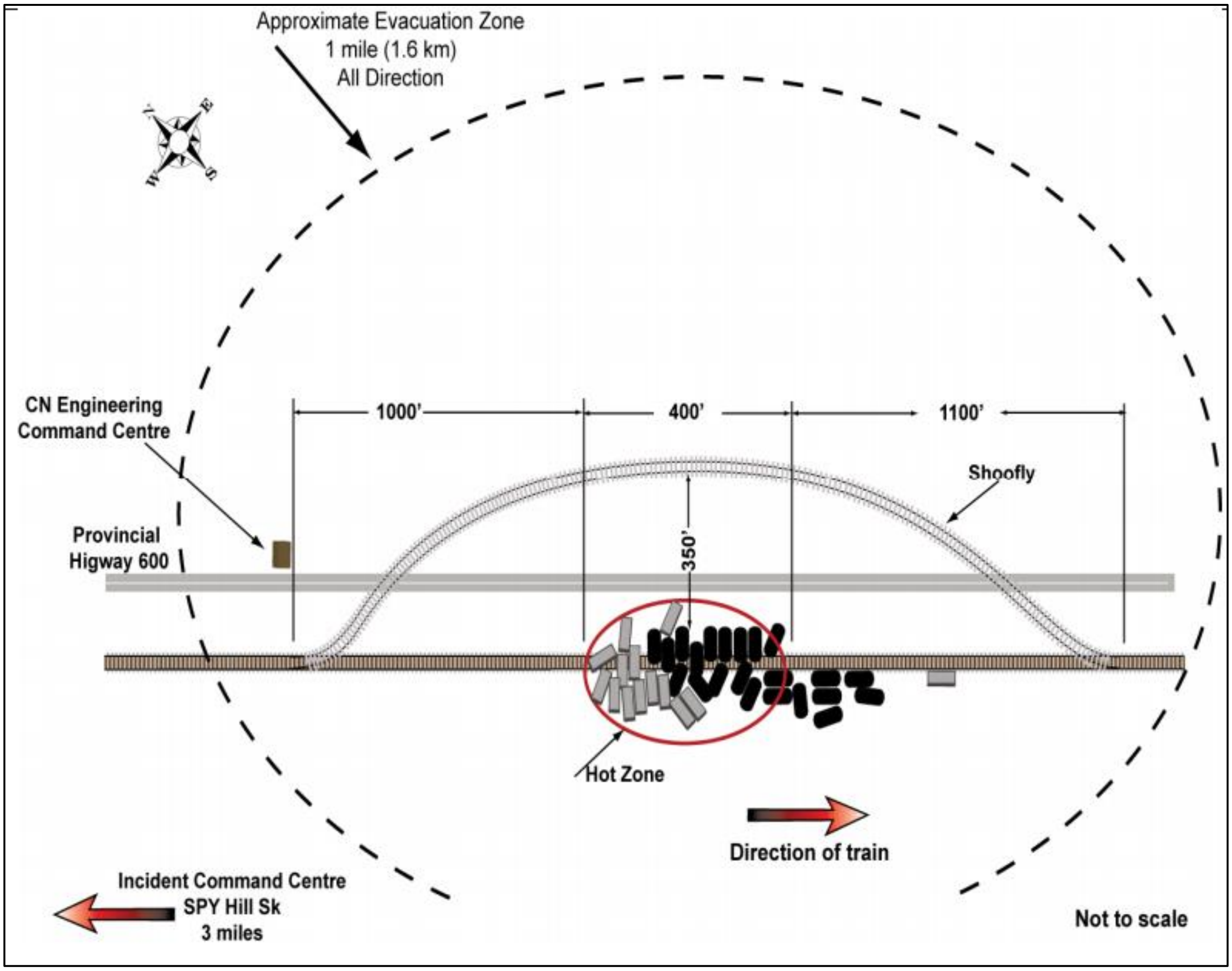

Figure 23: Diagram of incident site described in TSB R09W0252.

4.4.2 Review and Summary of Notable NTSB Reports

Table 13 is a listing of the available NTSB reports for severe DG incidents occurring in the US. When planning this project, it was expected that the number of incident reports related to dangerous goods incidents in the US would mirror that of Canada, in that all severe DG incidents would have an accompanying NTSB detailed report. Unexpectedly, the NTSB does not produce a detailed report for every severe dangerous goods release in the US. However, with the NTSB data and the available NTSB reports downloaded, searches using key terms in the incident data were used to locate the relevant available NTSB reports.

Table 13 lists the most severe incidents, ranked from the highest number of dangerous goods released. Of note is the most severe incident in the US, where over 800,000 gallons of ethanol was spilled and burned, does not have a detailed NTSB report issue. The second most severe incident has a short incident report available. The third most severe incident has a report in a different format from most other NTSB reports.

The remaining severe incidents each have a long form detailed NTSB report describing the incident cause and outcomes. These reports were read to find references to any influence of buffer cars on the outcomes of the incidents. A summary of selected reports where buffer cars were involved in the incident or would have had an influence on the outcome are summarized in the next section. This search revealed that the most relevant incident related to the use of buffer cars in increasing the safety of crew on the train was for an incident on December 30th 2013, involving a BNSF train loaded with grain and another BNSF unit oil train. This incident is summarized in report RAB-1701.

Table 13: Listing of main line incidents with DG car release where NTSB reports are available.

YEAR	MONTH	DAY	INCDTNO	Report File	carshzd	Total Derailed cars	RAILROAD	subdivision
2011	2	6	041313	MEMA Ethanol Accidents Case Studies 2016.pdf	32	33	NS	LAKE
2013	11	7	AGR444413	HQ-2013-1050 Final.pdf	26	27	AGR	SYSTEM
2015	2	16	000141581	2015_10_09_Mount_Carbon_Findings_Report_FINAL.pdf	20	27	CSX	NEW RIVER
2006	10	20	026865	RAR0802.pdf	20	23	NS	PITTSBURGH
2013	12	30	TC1213121	RAB1701.pdf	18	21	BNSF	K O
2000	5	27	0500LV027	RAR0203.pdf	18	32	UP	LIVONIA
2009	6	19	636850	RAR1201.pdf	15	19	CC	CHICAGO
2017	3	10	0317TC008	RAR1802.pdf	14	20	UP	ESTHERVILLE SUB
2012	8	5	MT0812101	FRA Report RIN 2130-AC47	12	18	BNSF	HETTINGER
2002	1	18	170488	RAR0401.pdf	11	31	SOO	ST PAUL
2011	10	7	2011072	RAB1302.pdf	9	26	IAIS	ONE
2015	2	4	1000170207	HQ-2015-1007 Final Report.pdf	7	15	CP	MARQUETTE
2007	1	16	000028241	RAB1203.pdf	7	26	CSX	LOUISVILLE
2003	2	9	0000174324	RAR0501.pdf	7	22	IC	GULF
2007	3	12	000029622	RAB0805.pdf	6	29	CSX	ALBANY
1996	2	21	T0356	RAB9808.pdf	6	39	DRGW	DENVER
2015	5	6	TC0515101	RAB1712.pdf	5	6	BNSF	K O
2012	1	6	000099335	RAB1303.pdf	5	6	CSX	GARRETT
2007	10	10	000037664	RAB0902.pdf	5	31	CSX	GREAT LAKE
1996	2	1	110296100	RAR9605.pdf	4	45	ATSF	SOUTHERN CALIFORNIA
2019	4	24	0419TO038	RRD19FR007-preliminary-report.pdf	3	27	UP	MIDLOTHIAN SUB
2015	9	19	TC0915110	RAB1707.pdf	3	7	BNSF	ABERDEEN
2013	5	20	237127	MEMA Ethanol Accidents Case Studies 2016.pdf	3	5	CP	MASON CITY
2012	7	11	100477	RAB1408.pdf	3	17	NS	LAKE
1998	9	2	AO0998100	RAR0001.pdf	3	4	BNSF	AMARILLO
1996	4	11	116	RAB98087.pdf	3	19	MRL	SYSTEM
2020	2	13	000188437	RRD20FR002-preliminary-report.pdf	2	5	CSX	KINGSPORT
2002	9	15	010139	RAB0305.pdf	2	25	NS	CENTRAL
1998	6	20	069828004	RAR9901.pdf	2	20	CSX	CCBU
1991	9	17	T099100384	RAR9202S.pdf	2	5	NW	LAKE
2020	7	29	0720LA037	RRD20LR005-preliminary-report.pdf	1	12	UP	PHOENIX SUB
2014	4	30	000129247	RAB1601.pdf	1	17	CSX	JAMES RIVER
2012	11	30	102363	RAR1401.pdf	1	7	CRSH	SOUTH JERSEY
2005	10	15	1005LK032	RAB0604.pdf	1	13	UP	NORTH LITTLE ROCK
2004	6	28	0604SA011	RAR0603.pdf	1	20	UP	SAN ANTONIO

The following sub-sections are brief summaries of the incident reports which describe incidents where:

- The incident resulted in a large number of derailed DG cars and the release of dangerous goods which were potentially harmful to the crew.
- The first car to derail was near the leading portion of the train.

These incident reports represent the incidents which from the available data represent situations where the crew were in danger due to the proximity of the first car to derail, as well as due to the release of DG products, or a fire involving DG products. A derailment is always a dangerous situation for a locomotive crew – these report summaries are intended to highlight the past situations where the presence of dangerous goods near the locomotive may have also created additional risk to the safety of the crew.

4.4.2.1 Review of Casselton unit-oil train derailment (NTSB RAB-1701)

NTSB RAB-1701 is a Railroad Accident Brief describing the BNSF railway derailment and subsequent train collision near Casselton, North Dakota, on December 30th, 2013.

The oil train was powered by two head-end locomotives, a rear distributed power locomotive, and had one buffer car on either end of the 104 tank cars loaded with crude oil, i.e. between the oil tank cars and the nearest locomotives. The oil train, on double track, derailed when it collided with a BNSF grain train that had derailed due to a broken axle, fouling the track in the path of the oil train. The engineer of the oil train made an emergency brake application, however the train collided with the derailed grain cars at approximately 42 mph, causing the oil train's two locomotives, the single buffer car, and the first 20 loaded tank cars to derail to the south of the track.

The front door of the lead locomotive of the oil train was damaged which prevented the crew from exiting to the front of the train, away from the derailed oil cars. The crew used the *rear door of the lead locomotive* (moving towards the derailed wreck and oil pools) to escape the locomotive, ultimately reaching the nearest highway-rail grade crossing where they met emergency responders. The lead locomotive was ultimately destroyed by fire, with the data recorder 'black boxes' destroyed.

Twenty hazardous materials tank cars derailed in this incident, all of them were general service US Department of Transportation (DOT) specification 111 (DOT-111) tank cars. These tank cars were in positions 2 through 21 in the train. Eighteen of these tank cars were breached and released product, where the damages included 13 tank cars with torn or punctured heads and shells, 3 with thermal tears, 10 with damaged valves and fittings, and 3 that released product from bottom outlet valves. Some tank cars had more than one breach of the types listed here.

The report states the following regarding the safety of the crew in exiting the train:

> *"Following the collision, the crew of the oil train narrowly escaped the area before the locomotives were destroyed by the eruption of a post-accident fire and energetic fireballs. During an interview with NTSB investigators the oil train conductor stated the following:*

> *[I] was exiting the cab … and started to get away from all the fire. … The heat was intense. … I was in knee-deep snow. I couldn't get away as quickly as I would like to. … It was about a minute later the locomotive that we were traveling in was engulfed in flames. I suppose we were about 200 yards [away]. I believe that that's when one of the tankers exploded.*

NTSB investigators asked the conductor how long it took for the locomotive to be engulfed in flames, and he said the following:

> *[It] seems like a minute to me, a couple minutes. … I turned around to make sure my engineer was behind me, and that's when I noticed that the locomotive was being engulfed in flames."*

It was ultimately determined that the derailed tank cars in positions 2 through 5 were breached, had released their contents, caught fire and exhibited severe thermal damage. The NTSB concluded that had additional buffer cars instead of flammable hazardous material tank cars been placed in positions 2 through 5 of the train, the danger to the train crew would have been significantly reduced and would have allowed for more time for a safe egress from the locomotive. The NTSB also concluded that a one-car buffer between the locomotives and the dangerous goods (hazardous materials) exposes the train crew to unnecessary risk in incidents where cars are derailed closer to the head end of the train.

Figure 24 shows an aerial view of the Casselton derailment scene, where it can be seen that the single buffer car provides some separation of the damaged oil tank cars from the locomotives. As was concluded by the NTSB, had buffer cars been placed in positions 2 through 5, 4 fewer tank cars would have been breached, and the risk to the crew would have been minimized significantly.

Had the incident occurred with no buffer car, and had the car in position 1 been breached, the risk to the crew in escaping the lead locomotive in this situation would potentially be greatly increased.

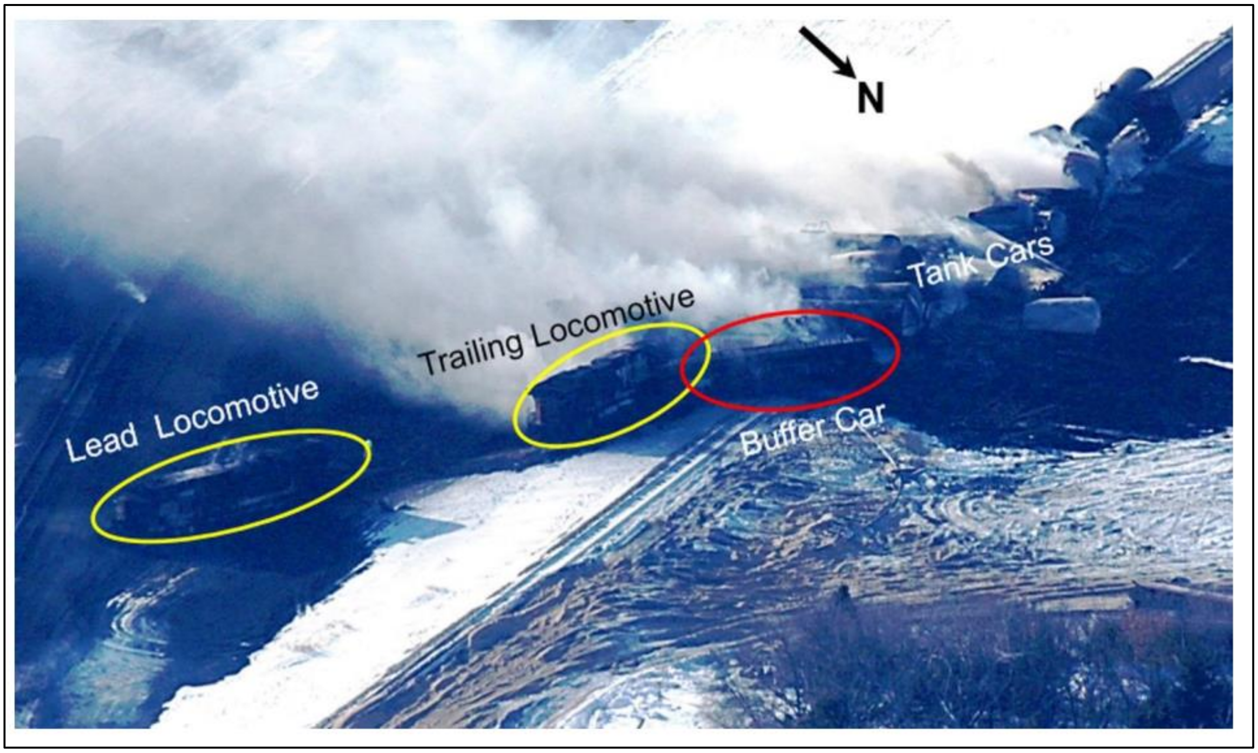

Figure 24: Aerial view of Casselton derailment scene, showing the location of the lead locomotive (occupied) and the buffer car in relation to the derailed oil cars. (Figure 11 from RAB-1701, PHMSA photo)

The NTSB summarized the situation as follows:

> *The FRA, PHMSA, and the railroads have recognized that buffer cars should be required on unit trains transporting hazardous materials to comply with the intent of 49 CFR 174.85. Since a hazardous materials unit train is composed of cars loaded with the same hazardous commodity, additional non-placarded cars must be added to the train to provide a buffer between occupied railcars and locomotives and the hazardous materials. The FRA, PHMSA, and the railroads have interpreted the regulation to allow use of a single buffer car between the locomotives and the first placarded car, and those trains may travel across the country with only one buffer car required. Conversely, a train of mixed freight cars with one hazardous materials car must have a five-car buffer between that car and the occupied locomotives unless the train is too short and does not have enough cars to allow for a five-car buffer.*

Following the investigation of a derailment near New Brighton PA in 2006, the NTSB issued Safety Recommendations R-08-12 to the FRA and R-08-13 to PHMSA. These are:

> ***R-08-12****: Assist the Pipeline and Hazardous Materials Safety Administration in its evaluation of the risks posed to train crews by unit trains transporting hazardous materials, determination of the optimum separation requirements between occupied locomotives and*

hazardous materials cars, and any resulting revision of 49 Code of Federal Regulations 174.85.

***R-08-13**: With the assistance of the Federal Railroad Administration, evaluate the risks posed to train crews by unit trains transporting hazardous materials, determine the optimum separation requirements between occupied locomotives and hazardous materials cars, and revise 49 Code of Federal Regulations 174.85 accordingly.*

The following new recommendations were made as part of RAB1701:

To the Pipeline and Hazardous Materials Safety Administration:

Evaluate the risks posed to train crews by hazardous materials transported by rail, determine the adequate separation distance between hazardous materials cars and locomotives and occupied equipment that ensures the protection of train crews during both normal operations and accident conditions, and collaborate with the Federal Railroad Administration to revise 49 Code of Federal Regulations 174.85 to reflect those findings. (R-17-01)

Pending completion of the risk evaluation and action in accordance with its findings prescribed in Safety Recommendation R-17-01, withdraw regulatory interpretation 06-0278 that pertains to 49 Code of Federal Regulations 174.85 for positioning placarded rail cars in a train and require that all trains have a minimum of five nonplacarded cars between any locomotive or occupied equipment and the nearest placarded car transporting hazardous materials, regardless of train length and consist. (R-17-02)

To the Federal Railroad Administration:

Evaluate the risks posed to train crews by hazardous materials transported by rail, determine the adequate separation distance between hazardous materials cars and locomotives and occupied equipment that ensures the protection of train crews during both normal operations and accident conditions, and collaborate with the Pipeline and Hazardous Materials Safety Administration to revise 49 Code of Federal Regulations 174.85 to reflect those findings. (R-17-03)

4.4.2.2 Aliceville, AL, November 7, 2013 (HQ-2013-1050 Final.pdf)

The train consisted of two lead locomotives, a buffer car of sand, 88 DOT 111 tank cars loaded with crude oil (UN1267), a second buffer car, and a single trailing end locomotive. The lead buffer car was the first car to derail, due to broken rail. 26 tank cars derailed. Figure 25 shows a drawing of the incident scene, showing the proximity of the crew relative to the main pileup of cars.

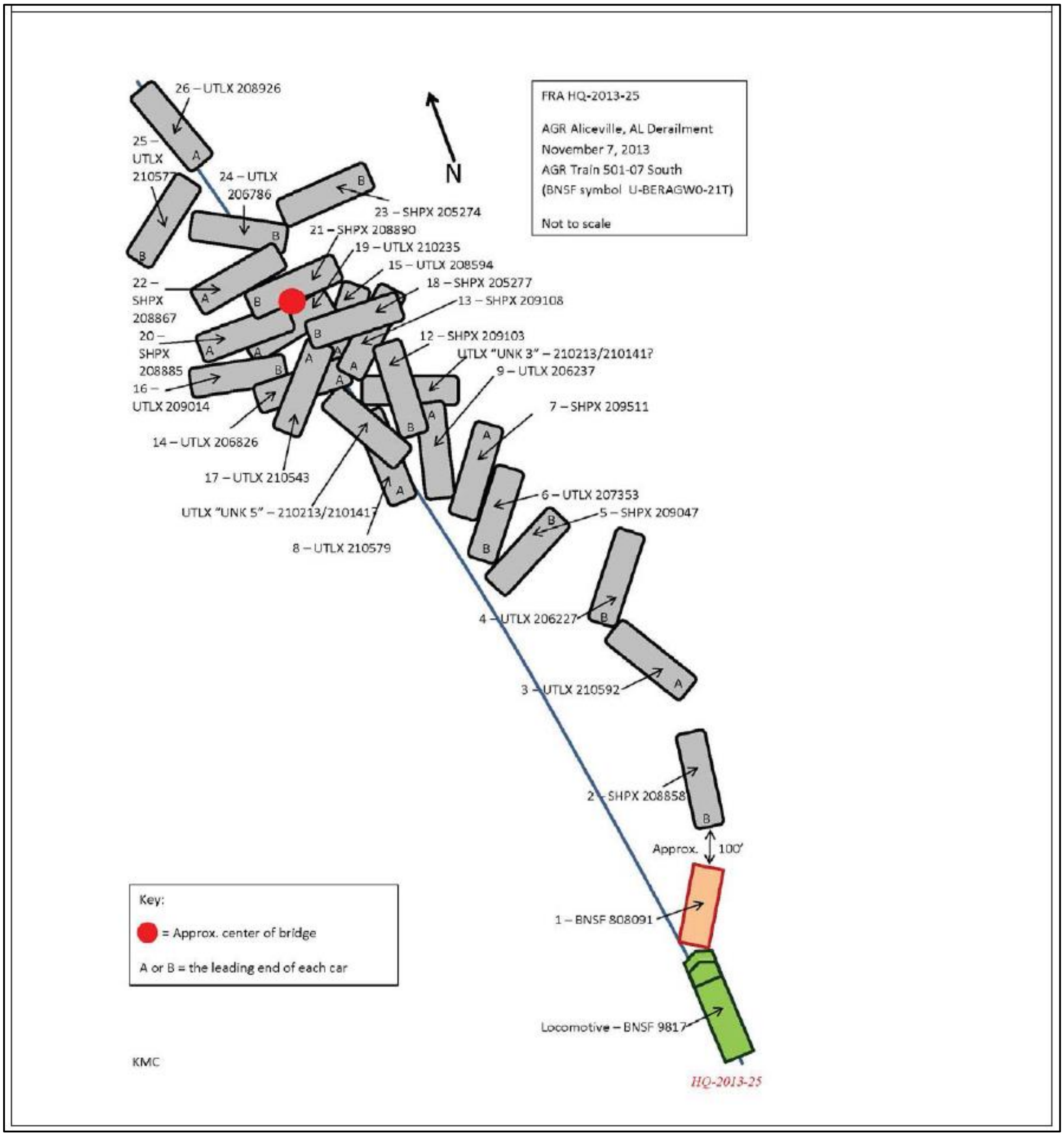

Figure 25: Sketch of Aliceville, AL, incident showing the location of the lead locomotive (occupied) and the buffer car in relation (from HQ-2013-1050 Final.pdf))

4.4.2.3 Draffin, Kentucky, February 13, 2020 (RRD20FR002)

“The derailment involved all three locomotives, one buffer car, and four loaded tank cars. Two of the derailed tank cars were breached and released 38,400 gallons of denatured ethanol. The ethanol and diesel fuel from the locomotives ignited and caught fire, which engulfed the locomotives and the second and third tank cars.”

“The train crew escaped from the burning lead locomotive by jumping into the river, where they were rescued by emergency responders.”

This incident clearly displays the result of a single buffer followed by four tank cars. Had 5 buffer cars been used, the incident may have resulted in no loss of DG, or fire.

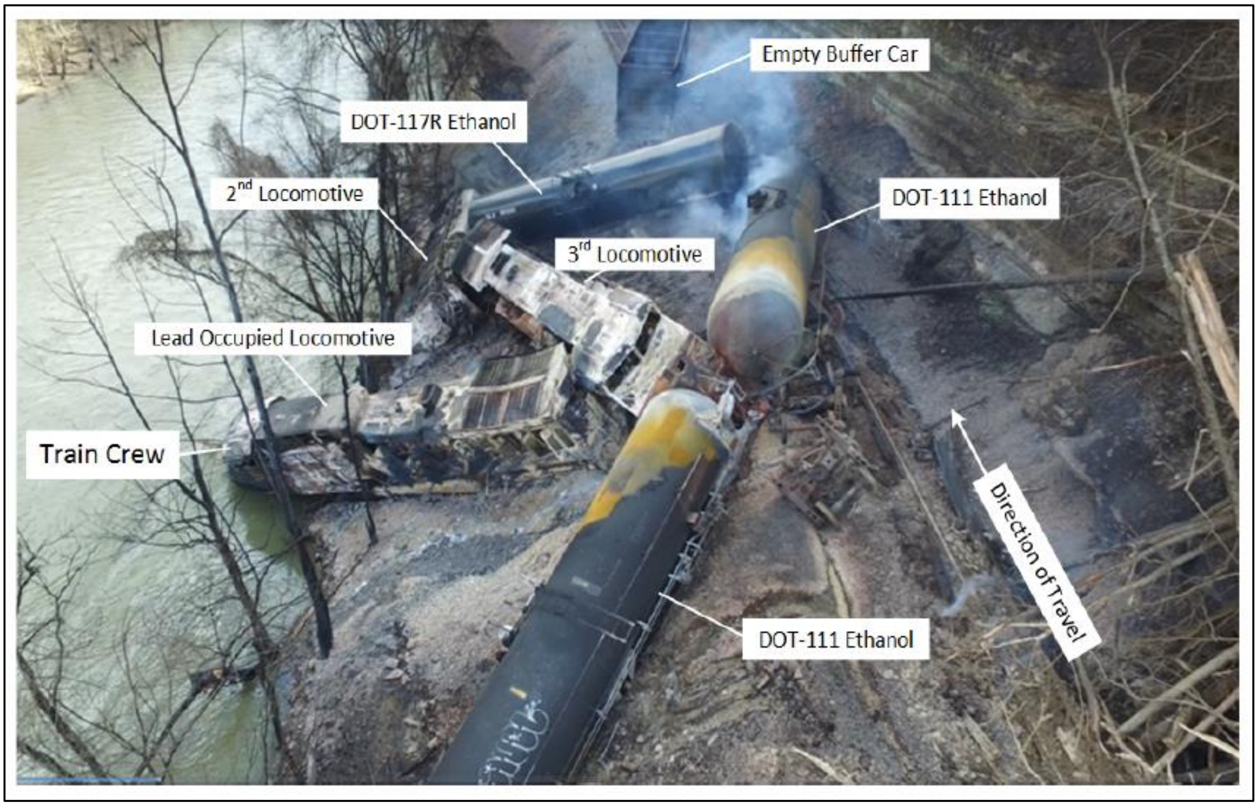

Figure 26: Incident scene of Draffin, Kentucky (from RRD20FR002.pdf)

4.4.2.4 Tiskilwa, Illinois, October 7, 2011 (RAB1302.pdf)

26 cars derailed in Tiskilwa, Illinois. Ten of the derailed cars contained ethanol. Ethanol released from the damaged tank cars ignited and burned.

> *“The first 26 cars behind the locomotives had derailed. The first 15 derailed cars were covered hopper cars carrying corn mash followed by a hopper car carrying sand and 10 tank cars carrying ethanol. Nine of the derailed ethanol cars were damaged and lost product, which burned. (See figure 2.) The intense fire caused three of the tank cars to fail and erupt in massive fireballs.”*

The contrast of the outcome of this incident – with 15 non-DG cars leading the ethanol cars, the train crew were well away from harm when the fires began.

Figure 27: Incident scene of Tiskilwa, Illinois. (from RAB1302.pdf)

4.4.2.5 Sherrill, IA February 4, 2015 (HQ-2015-1007.pdf)

From the report 2015 HQ-2015-1007.pdf:

"Synopsis

Canadian Pacific Railway Company (CP) freight Train Symbol 632-015, traveling southbound at 24 mph on a single main track, in non-signaled track warrant control (TWC) territory, experienced a major derailment on February 04, 2015, at 11:30 a.m. The accident occurred near Sherrill, Iowa, at Milepost 61.7, on the CP Marquette Subdivision. It resulted in 2 locomotives and 15 cars derailed, release of hazardous materials from 7 derailed cars, and a fire. There were no injuries to the train crew and no evacuation.

At the time of the accident it was daylight and clear after a major snow storm and 16° F.

The FRA's investigation determined the probable cause was a Transverse/Compound Fissure broken rail (T220)."

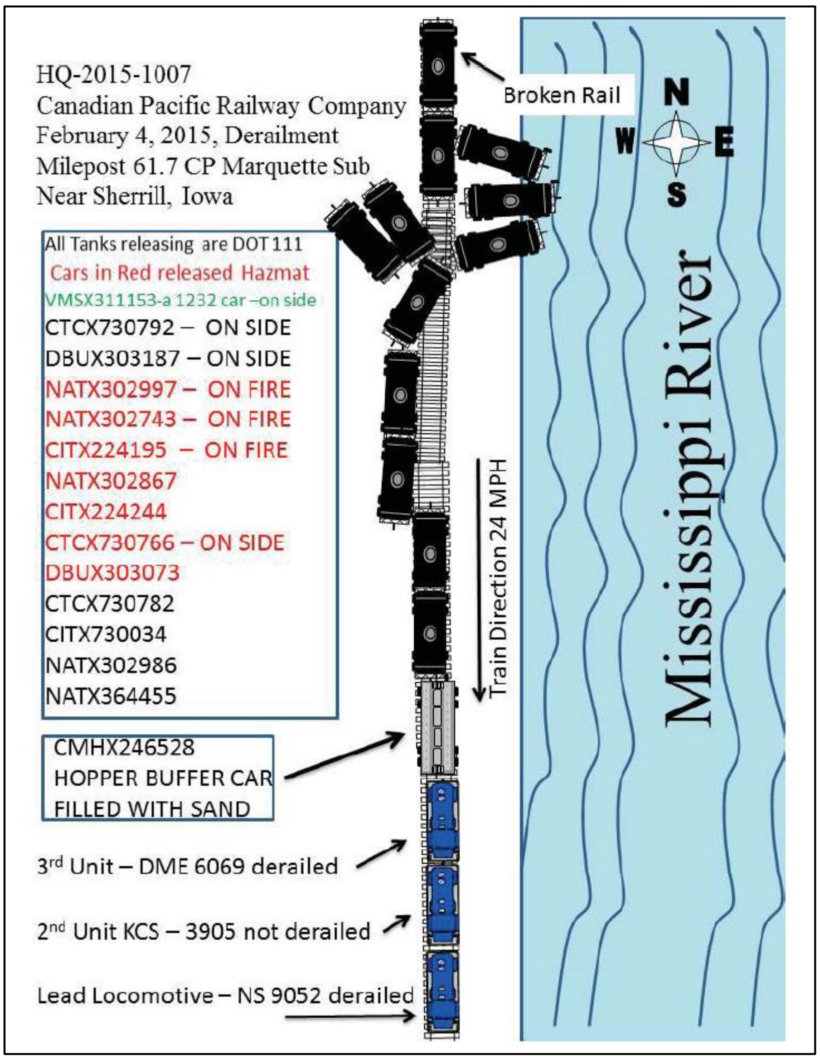

Figure 28: Incident scene of Sherrill, IA February 4, 2015 (from HQ-2015-1007.pdf)

4.4.2.6 Lesterville, South Dakota, September 2015 (RAB1707.pdf)

From the accident report RAB1707:

“Seven cars (tank car 2 through tank car 8 from the head end of the train) derailed. Two of the derailed cars breached and released 49,743 gallons of denatured fuel ethanol (ethanol) that caught fire. A third car leaked ethanol from its bottom outlet valve.”

Another example where the use of five buffer cars would have resulted in reduced incident severity.

Figure 29: Incident scene of Lesterville, South Dakota, September 2015 (RAB1707)

4.4.2.7 Mount Carbon, West Virginia, October 2015 (HQ-2015-1009 FINDINGS REPORT)

From the report:

"The train consisted of two engines, 107 fully loaded tank cars carrying crude, and two covered hopper buffer cars.

A total of twenty-seven tank cars derailed in the incident. Two tank cars were punctured, released crude oil, ignited, and caught fire. The fire spread quickly, resulting in a pool fire that eventually led to thermal tears in thirteen additional derailed tank cars. Ultimately, twenty-four of the twenty-seven derailed tank cars sustained significant damage in the incident and resulting fire."

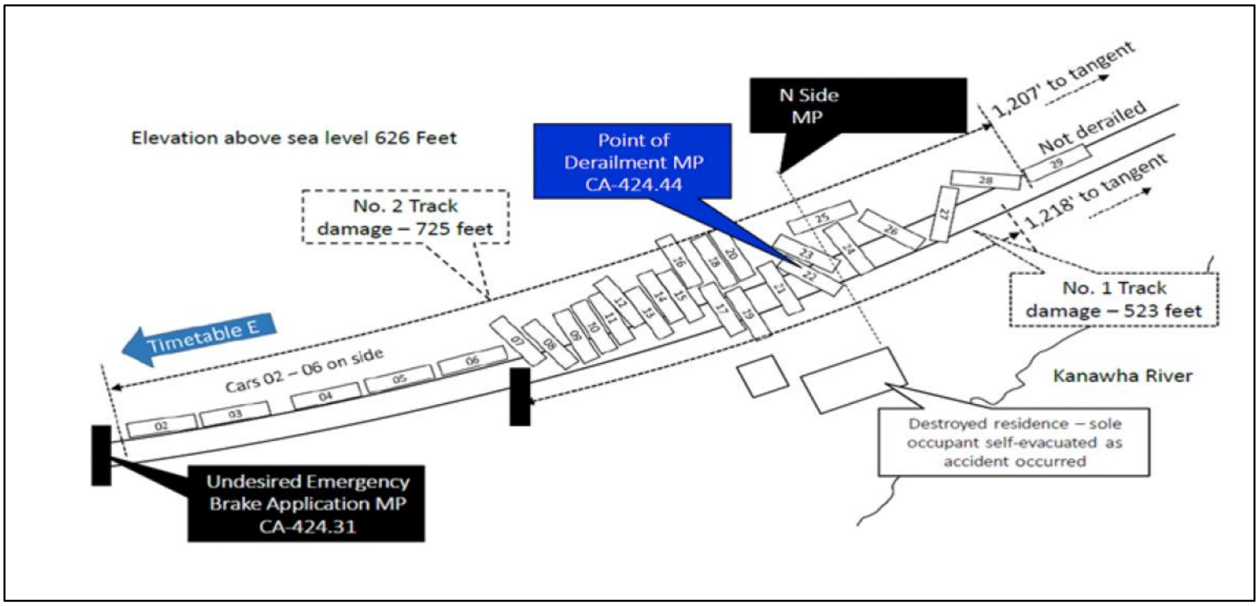

Figure 30: Incident scene of Mount Carbon, West Virginia, (from HQ-2015-1009 FINDINGS REPORT[24])

24 https://railroads.dot.gov/sites/fra.dot.gov/files/fra_net/15369/2015_10_09_Mount_Carbon_Findings_Report_FINAL.pdf

5 Discussion

The work presented in this report is broken into three main segments:

- review of past literature related to dangerous goods marshalling, and the use of buffer cars;
- the analysis of incident data for mainline incidents where dangerous goods were released, and;
- the review of incident reports in the US and Canada to note difference or similarities regarding the influence of the presence of buffer cars on the outcomes of an incident.

5.1 Literature review

Literature related to dangerous goods transport, focusing on the use of buffer cars and marshalling, was completed. The literature reviewed did not directly explain the origins of the five buffer car rule for Key Trains in the US and Canada prior to 2002, nor did the literature explain why the rule was changed in Canada to allow one buffer car for mixed goods Key Trains, and continue with zero buffer cars for unit Key Trains. Since 2002 the US has maintained a five buffer car rule for mixed goods Key Trains and a one buffer car rule for unit Key Trains.

The literature found and reviewed did not discuss in any detail the risks on yard workers or the increased risks associated with switching DG cars in railyards, however these risks were acknowledged as present, but the literature found did not quantify it. As well, the literature did not identify the risk associated with a DG car placement with respect to in-train forces. The placement of a DG car was usually discussed in terms of the outcome of an incident should a DG car be damaged. Research into the risks of a DG car causing a derailment due to in-train forces because of its location in a train was not found.

After a detailed review of the documents identified in Phase 1 of this project, several historical events that led to the current set of regulations have been identified, and these events guided future changes to the regulations with the intent to improve safety. However, the specific decision on reducing the number of buffer cars from five to one during the 2002 Clear Language updates remains unclear, but appears to be influenced by the early 1990s reports by Battelle, Bowring, and the Canadian Institute of Guided Ground Transport (CIGGT).

A review of the historical information found that the separation requirements of the regulations are a best guess provision to buffer employees in the locomotives from dangerous goods, and to separate incompatible dangerous goods from each other to minimize the potential for chemical reactions between ruptured tanks that could result in fires, explosions and other reactions that are potentially harmful to the train crew and to the public.

Many reports in the literature study consisted of probability modeling based on incident data to predict the safest location for DG cars in a train. These models have progressed considerably since the A.D. Little report from 1983 to the more recent reports by Manish, Verma, and Xiang Liu. These models are promising as a method to bring quantitative evidence to decisions regarding marshalling and train handling rules. However these models do make assumptions about cars, such as all cars are equivalent or that the reorganization of the DG cars to differing locations in the train will not impact vehicle dynamics. As identified by the authors of the CIGGT report (1992), models based on incorrect or incomplete data may be invalid, and should be used within the limits of their assumptions. This requirement also reinforces the need to collect wide ranging and accurate incident data that can be used with future statistical models. As shown in the current study, lack of data or incorrect entries from incidents as recently as 10 years ago has an impact on the confidence in making conclusions.

5.2 Incident data analysis

An analysis of available incident data for dangerous goods derailments occurring on main track was completed. The results were analyzed for the location of the first car to derail, the number of cars to derail, and the number of incidents per year.

A year to year comparison of incidents where dangerous goods were released shows little difference between the outcomes in Canada and the US. While there are noticeable incidents in Canada that standout in some years, as the results are not normalized for yearly traffic data for each country these individual incidents are not evidence that more severe incidents occur in Canada compared to the US.

Incidents within Canada and the US where DG cars derailed and released show that a higher proportion of derailments originating at the first five cars of the train result in a DG car release. This does not say that the first five car locations are higher risk, but that derailments that originate in the leading five cars of the train result in a higher likelihood of a DG car release. A hypothesis put forward to explain this is that derailments involving a broken rail where a leading locomotive is derailed without warning, followed by a large pileup that begins *before* the train goes into emergency braking may produce worse outcomes compared to say a derailment where a car derails and the train is forced into an emergency brake situation *prior* to the pileup starting. Further research into this hypothesis, and other possible reasons for the higher severity of derailments originating in the leading five cars of a train may be required to fully understand this.

As well, incidents where the leading cars on a train derailed first resulted in more derailed cars and more released cars per incident. These combined results highlight that the first five cars on a dangerous goods train are involved in more derailments where DG cars release, and that these incidents result in a larger number of DG cars releasing.

Although the cars in these locations may not always release, the evidence from this data analysis points to reducing the number of DG cars in the first portion of the train (such as cars 1 to 5) as a method to mitigate the risk of a DG car derailing in a front-of-train derailment, minimize the risk of a DG car releasing, as well as allowing more separation distance from the train crew and the DG cars in a derailment near the front of the train. However, the additional risk of marshalling a train to have five buffer cars was not within the scope of this study, and the study of this potential risk is recommended for future work.

5.3 Incident report summary

It was expected that the consolidated incident datasets would be investigated to determine whether any differences in outcomes had occurred between incidents in Canada and the US before and after August 2002 due to the different buffer car rules. As well, it was planned that the general proximity of DG cars to each other, or their location in the train could be assessed, to the extent possible given the details provided in the incident reports, to determine if any trends arise regarding incident outcomes.

The FRA database and the TC RODS database were searched for the numerical data relevant to this project. This search identified all incidents and incidents that occurred on main track and resulted in a DG car involved in the incident or released. Database results were used to identify long form reports for significant incidents from both the TSB and NTSB. NTSB reports were available for 36 severe incidents where DG cars derailed or released. TSB reports were available or 71 incidents in Canada where DG cars derailed or released.

A review of reports where the derailment initiated at the first 1 through 5 cars was completed. The incident reports were briefly summarized to highlight the use of buffer cars, the resulting incident details and incident scene, and the outcome of the crew.

From the incident reports summarized in this report, there are incidents identified which occurred in both the US and Canada where had five buffer cars been used instead of one, the incident severity could potentially have been reduced by having fewer DG cars derail or release. As well, there are incidents in the US where 1 buffer car was present, which if it had occurred in Canada where no buffer car is required for the same train configuration, could have potentially increased the risk of injury or loss of life to the crew if it had resulted in a DG car release. However, the number of these types of incidents identified from the available data summarized in the incident reports reviewed between 1990 to 2020 is relatively small (under 5) compared to the approximately 580 incidents involving DG car releases in the US and Canada in that time frame.

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6 Conclusions

A review of the literature identified in Phase 1 did not uncover a definitive source for the use of five buffer cars in a train carrying DG cars, or why the number was reduced in Canada in 2002 from five buffer cars to one for mixed goods key trains. As well, the review of the literature, the incident data, and the incident reports, does not allow for a conclusion to be made regarding an ideal distance between DG cars and the locomotives or the crew, or to the general proximity of DG cars to other DG cars.

An analysis of the available incident data was completed, where incidents selected from the FRA and TC rail incident data tables that involved a DG car derailing and releasing. The analysis did not show a significant difference in the outcomes of these selected derailments between the US and Canada for post-2002 incidents.

Incidents within Canada and the US where DG cars derailed and released show a higher proportion of derailments originating at the lead portion, or first five cars of the train. As well, the data provides evidence that derailments involving dangerous goods where the derailment originated at the lead five cars resulted in more derailed cars and more released cars per incident. It should be noted that as the data used for this study was filtered for incidents only involving DG cars derailed and released, the results discussed are valid for this group of data. An analysis of the full population of derailment incidents, involving all types of goods, was out of scope for this project. It is recommended that further research and analysis of the relationship between the location of the first car to derail and the severity of derailment be completed.

From the incident reports summarized in this report, there are incidents which occurred in both the US and Canada where had five buffer cars been used instead of one, the incident severity could potentially have been reduced by having fewer DG cars derail or release. As well, there are incidents in the US where 1 buffer was present, which if it had occurred in Canada where no buffer car was required, could have resulted in injuries or loss of life to the crew.

Overall, it was found that there are more *similarities* in the incident outcomes for the severe derailments in Canada and the US than noticeable differences. From the incident report summaries published by the NTSB and the TSB, there are notable incidents that could potentially have been less risk to the locomotive occupants, as well as potentially result in a less severe outcome, had there been five buffer cars instead of one on unit DG train derailments. However, these incidents, identified only from the incident reports available, are estimated to be a small fraction of the incidents which occur where DG cars derailed or released and additional buffer cars could potentially have made no difference, as the leading portion of the train was not involved in the derailment. The number of these types of incidents identified from the available data summarized in the incident reports reviewed between 1990 to 2020 is relatively small (under 5) compared to the approximately 580 incidents involving DG car releases in the US and Canada in that time frame.

As well, the additional risk to workers in rail yards to complete the train marshalling required to add five buffer cars to these trains is not known, although it has been acknowledged in the literature as a potential risk. This suggests that future work could study risks of marshalling DG cars and trains to add buffers cars, and the possible additional injuries and the incidents which could occur in yards during these operations. This work would need to be collaborative with industry, as although the outcomes in the form of injuries and incidents are available for study from reported incident databases, the details of the processes involved (operations, work hours, safety protocols and procedures and other factors) are within the realm of the industry.

Although the cars in the first five positions in a train may not always release, the evidence points to reducing the number of DG cars in the first portion of the train (such as cars 1 to 5) as a method to

- mitigate the risk of a DG car derailing in a front-of-train derailment,
- lower the number of DG goods in an incident to release,
- lower the risk to the crew following an incident by increasing the separation distance from the train crew and the DG cars which may have derailed near the front of the train.

Project Team

Gordon Poole	Project manager
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Patrick Kehoe	Literature review
Chengbi Dai	TC and NTSB database searches

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Acronyms and Abbreviations

BNSF	BNSF Railway (railway)
BR	British Rail
CAN	Canada
CIGGT	Canadian Institute of Guided Ground Transport
CN	Canadian National Railway (railway)
CP	Canadian Pacific Railway Company (railway)
CSV	comma-separated values
DG	Dangerous goods
DOT	Department of Transportation (US)
FRA	Federal Rail Administration (US)
MMA	Montreal, Maine and Atlantic (railway)
NRC	National Research Council Canada
NTSB	National Transportation Safety Board (US)
PDF	portable document format
PIH	poison inhalation hazard
RAB	Railroad Accident Brief
RAR	Railroad Accident Report
RCRMS	Rail Corridor Risk Management System (US)
RODS	Rail Occurrence Data System
RVTO	Rail Vehicle and Track Optimization (program, NRC)
SRM	Safety Risk Model (UK)
TC	Transport Canada
TC-TDG	Transportation of Dangerous Goods (TC Directorate, Canada)
TDGR	Transportation of Dangerous Goods Regulations
TIH	toxic inhalation hazard
TOPS	Total Operations Processing System (UK)
TSB	Transportation Safety Board (Canada)
UK	United Kingdom
US	United States

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Appendix A

An Appraisal of the Problem of the Handling, Transportation, and Disposal of Toxic and Other Hazardous Materials (1970) Booz-Allen and Hamilton, Inc., Washington, D.C. Department of Transportation, Washington, D.C.; Council on Environmental Quality, Washington, D.C. Council on Environmental Quality, 30 Jan 1970, 180 p.

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