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Used Fuel Transportation System – Transportation Collision Data Analysis Report

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Used Fuel Transportation System

Transportation Collision Data Analysis Report

Nuclear Waste Management Organization (NWMO)

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Table of Contents

Figures

Tables

List of Acronyms and Abbreviations

AEBS	Advanced Emergency Braking System
AECL	Atomic Energy of Canada Ltd.
APM	Adaptive Phased Management
CITS	Cooperative Intelligent Traffic Systems
CN	Canadian National Railway
CNL	Canadian Nuclear Laboratories
CNSC	Canadian Nuclear Safety Commission
CP	Canadian Pacific Railway
DGAIS	Dangerous Goods Collision Information System
DGR	Deep Geological Repository
DSC-TP	Dry Storage Container Transportation Package
EITS	Event Information and Tracking System
EU	European Union
FEA	Finite Element Analysis
GRS	Gesellschaft fuer Anlagen-und Reaktorsicherheit
HAC	Hypothetical Accident Conditions
HGV	Heavy Goods Vehicle
HLW	High-Level Radioactive Waste
HSM	Highway Safety Manual
IAEA	International Atomic Energy Agency
KM	Kilometre
LLNL	Lawrence Livermore National Laboratory
MTO	Ministry of Transportation Ontario
MTQ	Québec Ministry of Transportation
MVA	Motor Vehicle Accident
NCT	Normal Conditions of Transport
NWMO	Nuclear Waste Management Organization
OPG	Ontario Power Generation
PATRAM	Packaging and Transportation of Radioactive Materials
PPE	Personal Protective Equipment
PDO	Property Damage Only
PIN	Product Identification Number
PTNSR	Packaging and Transport of Nuclear Substances Regulations
RODS	Rail Occurrence Database System
SAAQ	Québec Automobile Insurance Company
SMV	Single Motor Vehicle
SNF	Spent Nuclear Fuel
TC	Transport Canada
TDG	Transportation of Dangerous Goods
TSB	Transportation Safety Board (of Canada)
U.S.	United States
USNRC	United States Nuclear Regulatory Commission

Terms and Definitions

Artificial Dawn/Dusk	In terms of lighting conditions for vehicular collisions, artificial dawn/dusk refers to the lighting conditions normally occurring between half an hour before and half an hour after sunrise/sunset, with artificial illumination functioning at the collision site.
Collision	An unexpected and unintentional event that results in damage or injury. For this report, the event involves a large truck or train, resulting in subsequent "collision" and "non-collision" events.
Collision with a fixed object	Encompasses collisions with fixed objects, such as bridges structures, trees, guide rails, rocks, ditches, etc.
Collision with a non-fixed object	Encompasses collisions with moving objects, such as another vehicle, trains, animals, pedestrians, cyclists, etc.
Collision Rate	The ratio between the number of collisions that happened in a given time period (e.g., year) and a baseline statistic over that same period (e.g., kilometres travelled). The collision rate estimates the collision occurrence per unit of measurement (e.g., collisions per kilometre). In roadway safety studies, traffic volume, measured as million vehicle kilometres, can be used to calculate the collision rate.
Conditional Probability	Conditional probability is defined as the likelihood of an event or outcome occurring based on the occurrence of a previous event or outcome. Conditional probability is calculated by multiplying the probability of the preceding event by the updated probability of the succeeding or conditional event.
Event Tree	An event tree is an inductive analytical diagram that analyzes an event using Boolean logic to examine a chronological series of subsequent events or consequences.
Heavy Goods Vehicle	A transport truck/trailer in the European Union, with a gross combined weight of 3,500 kg, including cargo, also known as a large goods vehicle (LGV).
Motor Vehicle Accident	A motor vehicle accident is an accident that involves a collision with another motor vehicle(s) (as defined in Canadian Nuclear Safety Commission (CNSC) data).
Non-collision Event	Encompasses those incidents in the Ontario's collision database that cannot be labelled as collisions with fixed or non-fixed objects, such as fire/explosion, load spill, skidding/sliding, ran off road, rollover, and jack knifing.
Probability	A probability is a number that reflects the chance or likelihood that a particular event will occur. Probabilities can be expressed as proportions that range from 0 to 1. They can also be expressed as percentages ranging from 0% to 100%.
Property Damage Only (PDO) Collision	Regarding collision severity, a "property damage-only collision" is a collision without injury or fatality.
Single Motor Vehicle (SMV) Collision	In terms of collision impact type, collisions that only involve one operating vehicle in which the operating vehicle collides with one or more fixed objects or unattended vehicles (i.e., vehicles that are not under the care and control of a driver, such as parked, stopped, disabled, abandoned, and runaway vehicles).

Screening Criteria	Data elements (e.g., contributing factors) in the overall dataset are examined to determine the element's effect on the interpretation of results from statistical models.
Train Accident (Collision)	Train accident is an event in which the involved train collides with other objects (e.g., other trails, vehicles, fixed objects, lifeforms), derails, catches fire or explodes (as defined in Transportation Safety Board Data).
Train Derailment	Any instance where one or more wheels of rolling stock have come off the normal running surface of the rail, including occurrences where there are no injuries and no damage to track or equipment.
Train Incident	Train incident is an event with a risk of collision, but no collision occurred (as defined in Transportation Safety Board Data).
Truck Tractor	A motor vehicle is designed to draw a trailer and is not constructed to carry a load other than what is drawn behind the vehicle.
Type B Package	Type B packages are used to transport materials with high levels of radioactivity, such as spent nuclear fuel, high-level radioactive waste, or high-radiation sources. These packages are typically large and heavy; designed and tested to provide adequate containment and shielding when subjected to normal conditions of transport and under hypothetical accident conditions set forth in regulations (i.e., pass stringent impact, drop and puncture tests, an engulfing fire test, and immersion in water). In Canada, these packages are certified by CNSC.
Used Nuclear Fuel	Used fuel assemblies removed from a reactor after several years of use. The fuel is a solid material in the form of ceramic pellets contained within tubes made of corrosion-resistant zircaloy.

1 Executive Summary

Why was this study completed?

Transporting used nuclear fuel raises many concerns and queries by members of the public and interested parties as they relate to collisions and potential impacts.

The Nuclear Waste Management Organization (NWMO) is responsible for the long-term management of Canada's used nuclear fuel. NWMO's plan calls for used nuclear fuel to be safely contained and isolated in a deep geological repository (DGR), consistent with international practice. Currently, two candidate communities are being considered to host the DGR. One is in the Wabigoon Lake Ojibway Nation-Ignace area in Northwestern Ontario, and the second is in the Saugeen Ojibway Nation-South Bruce area in Southern Ontario. A final decision regarding the site for the DGR is expected by the end of 2024.

The transportation of used nuclear fuel from interim storage facilities located in Ontario, Quebec, and New Brunswick to the centralized DGR location will be required.[1] However, while there is a strong international track record regarding the shipment of radioactive materials, these shipments understandably raise concerns and queries from the public and interested parties regarding potential incidents or collisions during transport.

This study statistically analyzes and assesses collision data from provincial resources to understand the types of collisions, severity, and potential causes of collisions and to quantify transport collision probabilities based on this information.

This study aims to gather, analyze, and assess available collision data relevant to the modes (road and rail) and types of conveyances proposed to transport used fuel to the DGR. This study statistically analyzes and assesses collision data to understand the types of collisions, severity, and potential causal factors, as well as to quantify transport collision probabilities based on this information. Collision probabilities, patterns, and trends identified in this report will feed into future analyses, which will explore potential preventative and mitigating measures that can be leveraged to reduce the likelihood of transportation collisions. These potential mitigation measures and other good practice operational protocols are discussed in detail in the NWMO Transportation Mitigation Report.

This report intends to analyze historical collision conditions which may apply to road and rail conveyances which NWMO is considering for transporting Type B[2] packages. Using incident and collision data and applying probabilistic assessment methods, collision probabilities are calculated. This report's analyses are generic in nature and not specific to any particular route. Furthermore, these analyses do not assess the likelihood that a collision could lead to a potential consequence (e.g., breach of a Type B package) or potential impact (e.g., environmental impacts, health effects, or injuries). Additionally, the analyses do not consider any security threats or malicious actions.

One of the primary goals of this study is to identify emerging themes that may be of interest to communities and members of the public regarding safety risks associated with transporting radioactive materials using Type B packages.

[1] Used fuel from Whiteshell Laboratories (Manitoba) is anticipated to be consolidated at Canadian Nuclear Laboratories (Ontario) prior to the start of NWMO transportation operations.
[2] Type B packages are among the most protective and transport highly radioactive materials where the content exceeds a prescribed threshold value. They provide containment and a high level of shielding against radiation. They are designed, tested, and certified to ensure they withstand expected incident conditions such as drops, fires, and immersion in water. Type B packages are commonly used to transport used nuclear fuel by road, rail, and water modes of transport.

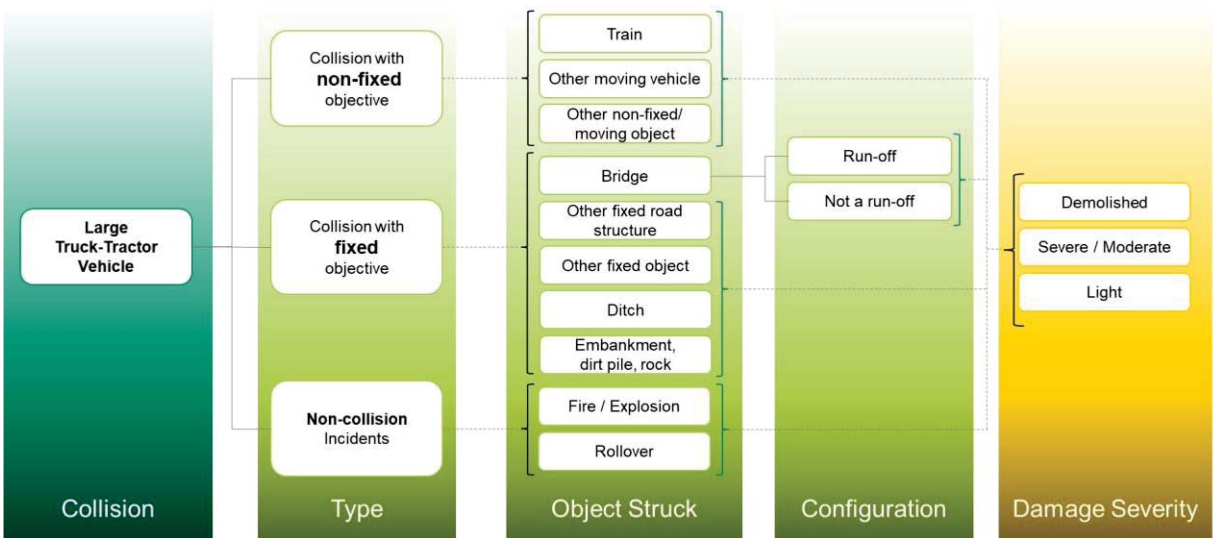
Overview of the methodology

The Used Fuel Transportation System Collision Data Analysis began with a review of available literature to examine (1) historical information on the transportation of spent nuclear fuel statistical and risk analysis and (2) methods used to examine statistical probabilities of road and rail collision scenarios. The literature review identified multiple references describing the exemplary history of spent nuclear fuel transportation and detailing the very low probability of a collision involving road or rail transportation resulting in a radiological dose to a member of the public above regulatory limits.

Additionally, several documents presented similar methodologies of determining the probabilities of specific collision or collision scenarios resulting in various levels of damage to the involved transport vehicles. The common feature of these analyses was using "event trees" for calculating the probability of a series of events. Visually, an event tree displays an event path that starts with the initiating event (trunk of the tree). This then leads to following events like the branch of a tree, and then to the next event, and so on.

Ultimately, an event tree maps out the completely defined collision event scenario in a causal format. When analyzed collectively, the event tree describes the potential outcomes of an initiating event. **Figure ES-1** shows an example of an event tree for truck movements without event probabilities.

Figure ES-1: Example of an Event Tree[3]



The approach for identifying collision types and calculating respective probabilities is based on comprehensive road and rail event data for the conveyances being considered by NWMO for the transport of used fuel. As part of the analyses, collision datasets from different resources, discussed below, were reviewed in detail.

A key study objective was to collect suitable data on which a robust probabilistic assessment may be based. As such, it was determined that ten (10) years of historical collision data from 2010 to 2019 pertaining to relevant road and rail conveyances within the geographic study area would prove suitable.

Following a qualitative and quantitative analysis of the collision data, a breakdown of the percentage of collisions involving conventional shipments by truck and train and those involving dangerous goods by type was prepared. Next, potential screening criteria were identified through a review of similar assessments to understand the nature of the type of collisions that apply to the transport of Type B packages. Screening criteria refer to certain parameters which may be applied to isolate the relevant portion of the dataset utilized for the probabilistic assessment study.

[3] Radioactive Material Transport Probabilistic Risk Assessment – Large Truck Accidents on Canadian Roadways (Lloyd's Register, 2019)

For the purpose of this study, the road portion of the analysis focused on datasets of truck-tractor collision data as this is the type of conveyance that may be used to transport Type B packages by NWMO. The rail portion of the study did not contain train operators' actions and conditions. As such, no screening criteria were applied to pare down the dataset to make it more representative of Type B package transportation.

The next step after identifying screening criteria was to develop event trees to illustrate the possible list of collision scenarios and their resulting probabilities. The probability of a particular collision scenario is calculated as the product of all the branch point fractions on the scenario path. In other words, the probability of a particular collision scenario is the product of the probabilities of all events described in the scenario set out in the event tree. It is important to note that the calculated probabilities refer to a particular collision scenario that assumes a collision has already occurred.

How were key findings derived?

The approach for identifying collision types and calculating incident probabilities is based on a comprehensive review of road and rail event data and the class of highway most likely to be used for the transportation of used nuclear fuel. The data gathered by the following primary sources were utilized to develop collision scenarios and their resulting probabilities, separated for truck and train movements:

- Truck datasets:
  - Ontario Ministry of Transportation (MTO)
  - Québec Ministry of Transportation (MTQ) / Québec Automobile Insurance Company (SAAQ)
  - New Brunswick Transportation and Infrastructure
  - Transport Canada's Dangerous Good Accident Information System (DGAIS), which contains reports provided at the time of a collision if a release (or anticipated release) of the dangerous goods endangers (or could endanger) public safety
  - Canadian Nuclear Safety Commission's Event Information and Tracking System (EITS)
- Train dataset:
  - Transportation Safety Board of Canada (TSB)

The incident data derived from these sources was then segmented into the following categories:

- Transport of dangerous goods vs conventional shipments
- Collision data pertaining to conveyances capable of transporting Type B packages
- Delineation of truck tractor combination vehicle incidents by multiple road types, incident cause, and driving conditions

What are the historical trends?

Used nuclear fuel is transported within and between global jurisdictions. The **U.S. Department of Energy** examined the history of worldwide used fuel transportation[4]. This study concluded that worldwide transportation of used fuel has been accomplished routinely and safely for decades.

It reported that, historically, collisions have been infrequent in used fuel and high-level radioactive waste transportation. When collisions have occurred, most have been minor collisions such as low-speed derailments or minor traffic collisions with little or no damage to the package being transported.

> Collisions involving radioactive material in Type B packages can occur. However, there has thus far been no loss of contents, no loss of life, and no impact on the environment caused by the radioactive nature of the material transported within Canada.

[4] DOE 2016. U.S. Department of Energy Nuclear Fuels Storage and Transportation Planning Project. A Historical Review of the Safe Transport of Spent Nuclear Fuel. FCRD-NFST-2016-000474, Rev. 1. ORNL/SR-2016/261, Rev. 1

Specifically, the study showed that at least 25,400 shipments of used fuel were made worldwide between 1962 and 2016. All of these shipments were undertaken without any injury or loss of life caused by the radioactive nature of the material transported. The worldwide number of Type B package shipments is far greater than used fuel shipments (e.g., approximately 255,000 shipments from 1979 through 1982) and was seen to feature a similar safety record.

What are the key findings?

1. **Historically, there have been very few collisions in Ontario, New Brunswick and Québec involving road transport of radioactive materials.**

Data for collisions during road transportation of dangerous goods, and specifically Class 7 (radioactive) material, in Canada were analyzed. The *Canadian Nuclear Safety Commission (CNSC)* indicates that 492 Class 7 transportation incidents were reported to the CNSC between 2000 and 2022. Of these, 58 incidents involved Type B transportation packages, none of which involved a loss of contents. In addition, none of the recorded incidents involved contents classified as used nuclear fuel.

In Ontario, between 2010 and 2019, 98 out of 38,296 truck-tractor collisions (less than 0.3% of truck-tractor collisions) in Ontario provincial highways involved dangerous goods. Of those 98 recorded collisions involving dangerous goods, only one incident (0.01%) involved a vehicle carrying Class 7 dangerous goods (radioactive materials). In New Brunswick, during the same time period, 27 out of 2,972 reported truck-tractor collisions (less than 1% of truck-tractor collisions) involved vehicles carrying dangerous goods. None of the 27 recorded incidents involving dangerous goods included vehicles carrying Class 7 dangerous goods (radioactive materials). In contrast to Ontario and New Brunswick, the Québec database did not provide a breakdown of the number or the type of dangerous goods carried by trucks in Québec.

For the years 2012 to 2021 inclusive, 1,456 incidents involving dangerous goods were reported by Transport Canada. Of these, 302 incidents were recorded for the provinces of Ontario (177), Québec (113), and New Brunswick (12). It is noted that the numbers reported in the DGAIS data do not necessarily match the provincial numbers discussed in earlier sections. Of those 302 incidents, one event (0.003%) related to Class 7 substances (radioactive materials) and did not result in the release of radioactive material.

2. **The probability of a sequence of events occurring involving truck tractors capable of transporting a Type B used nuclear fuel package that could result in severe damage or complete demolition of the conveyance is very low.**

The conditional probabilities for all truck collision scenarios were calculated using the event tree described above and the probabilistic analysis conducted as part of this project. Next, all truck tractor collision scenarios were ranked in ascending order based on their conditional probabilities, with a ranking index added for each of the collision scenarios.

The conditional probabilities of scenarios for truck tractors carrying dangerous good materials with vehicle damage severity of "demolished" or "severe/moderate damage" ranged from 3.41×10^{-4} to 1.94×10^{-8}. In terms of conditional probabilities, the probability of these scenarios occurring ranged from 1 in 2,930 to 1 in 51,501,511 *if* a truck collision occurred in the first place. These statistics show that the conditional probabilities of truck-tractor collisions carrying dangerous goods with vehicle damage severity of "demolished" or "severe/moderate damage" are very low.

3. **There have been very few incidents involving rail transport of dangerous goods.**

In contrast to multiple data sources for truck collisions, the TSB database was considered the only source of information about train collisions in Canada that could be utilized to calculate probabilities. While the TSB database indicates that train collisions involving the release of dangerous goods do occur, it was found that of the 11,013 train collisions analyzed between 2010 and 2019, only 48 collisions (0.5%) pertained to a release of dangerous goods into the environment).

4. **The probability of a sequence of events occurring involving rail transportation that could result in severe damage or complete demolition of the conveyance is very low.**

Like truck movements, the train event tree was utilized to calculate the conditional probabilities for all train collision scenarios. All train collision scenarios were ranked in ascending order based on their conditional probabilities, with a ranking index added for each of the collision scenarios.

The conditional probabilities of scenarios for trains carrying dangerous good materials and breach of materials ranged from 3.47×10^{-4} to 4.68×10^{-6}. In terms of conditional probabilities, the probability of these scenarios occurring ranged from 1 in 2,884 to 1 in 213,533 *if* a train collision occurred in the first place. As can be seen from these statistics, the conditional probabilities of train collisions carrying dangerous goods with breach of materials are very low.

5. **Certain transportation conditions can lead to a greater probability of a collision involving truck tractors capable of transporting a Type B used nuclear fuel package.**

Contributing factors for collisions involving truck tractors were derived from the Ontario, Québec, and New Brunswick datasets. Overall, when comparing the percentages between Ontario and New Brunswick, similar trends in driver actions and driver conditions were observed for most of the contributing factors, which included inattentive drivers and winter weather/road conditions. Of all truck tractors involved in collisions between 2010 and 2019, close to 20% were involved in collisions on icy/snow/slush surface conditions. 38% of these collisions resulted in vehicle damage categorized as severe/moderate damage, while 6% resulted in vehicle damage categorized as demolished. In contrast, considering all truck tractors involved in collisions (all road conditions), the fraction of those incidents which resulted in a vehicle damage severity that was categorized as severe/moderate or demolished damage was 28% and 4%, respectively.

Additional Conclusions

The analysis provided in this report supports that truck and rail collisions involving radioactive materials (in particular, Type B packages) occur so infrequently that there is insufficient data on which to base a robust statistical analysis specific to these types of transport. Therefore, one must use conventional truck/train collision statistics to construct a data set with a population size sufficient to draw meaningful conclusions on collision probabilities and causal factors.

The road collision datasets used in this analysis are sufficiently large, and the resulting collision probabilities and causal factors map well against previous analyses carried out in Canada as well as internationally.

Additionally, conclusions regarding collision causal factors are reliable enough on which to base future mitigation and control measures. A follow-up report addresses the practices, factors, and technologies that may be useful for addressing causal factors related to transportation collisions for conveyances capable of transporting Type B used nuclear fuel packages.

2 Introduction

2.1 Background

The Nuclear Waste Management Organization (NWMO) is responsible for the long-term management of Canada's used nuclear fuel. Canada's plan for managing used nuclear fuel is known as Adaptive Phased Management (APM). It consists of isolating and containing used nuclear fuel in a Deep Geological Repository (DGR) using a multiple barrier system in a robust host geology.

Canada's used nuclear fuel is currently safely stored on an interim basis in licensed facilities at reactor sites in Ontario, Québec, and New Brunswick, as well as at Atomic Energy of Canada Limited's (AECL) nuclear research laboratories in Ontario and Manitoba. Managing all of Canada's used nuclear fuel in a single repository location will require the transport of used nuclear fuel from these interim storage facilities to the centralized DGR location.

NWMO is currently in the process of identifying a willing and informed host community and region for the APM DGR. The Township of Ignace and Wabigoon Lake Ojibway Nation in Northwestern Ontario, and the Municipality of South Bruce and Saugeen Ojibway Nation in Southern Ontario, are potential host areas for the project. Site selection is currently expected to occur in late 2024. The interim storage sites and candidate DGR sites are outlined in **Figure 1**.

Figure 1: Overview of Existing Interim Storage and Candidate DGR Sites

NWMO's responsibility in spent nuclear fuel management includes designing and developing a transportation system for the safe and secure delivery of used fuel from current interim storage facilities to the DGR. Current plans are to begin operation of a repository facility no sooner than 2043. Once a facility is constructed and licensed, used fuel will be transported from the existing interim storage sites to the repository by road and/or by rail.

The objective of this report is to gather, analyze and assess available accident data relevant to modes and types of conveyances proposed to transport NWMO's used fuel. The purpose of this report is to statistically analyze and assess accident data to understand types of accidents, severity and potential causes of accidents and to quantify transport accident probabilities for two key reasons:

1. To respond to concerns and queries brought up by members of the public and interested parties as they relate to accidents and potential impacts associated with these types of shipments, and,
2. To inform and identify potential mitigating measures which can reduce the likelihood of transportation accidents.

The analyses presented in this report are generic in nature (not route specific) and the analyses do not consider environmental impacts, health effects or injuries resulting from an accidental collision or purposeful security/malevolent acts.

2.2 Objective of the Report

The 'Used Fuel Transportation System's Transportation Collision Data Analysis Study' was prepared by AECOM Nuclear Services Ltd for NWMO's use in addressing the specific needs of the project and their business.

NWMO commissioned the work described in this report in response to queries brought up by interested parties regarding the risk of collisions[5] during the transportation of used nuclear fuel.

This report considered specific issues raised by Canadians and Indigenous peoples related to the types of collisions people are concerned about. One of the objectives of this work is to respond to those concerns at this early stage, acknowledging that the NWMO is still approximately 20 years away from transporting used nuclear fuel to the future DGR.

The Transportation Collision Data and Mitigation Assessment aims to expand upon existing transportation analyses outlined in **Section 4.7 Previous Applications** and provide a specific evaluation of collision types and probabilities for vehicles associated with the transport of Type B transportation packages as outlined in **Section 2.1 Background**.

This entails an analysis of both road and rail transportation in Canada. The conclusion of the work will:

- Quantitatively assess the collision probabilities associated with types of conveyances which may be used by NWMO to transport of Type B packages,
- Establish bounding collision scenarios that could have the potential to translate into damage to and releases of radiation from Type B packages, and
- Establish potential collision mitigation methods that can be implemented within NWMO's transportation program (including conveyance, equipment inspection, maintenance, and operational and administrative controls).

To meet the project objectives, the scope of work has been organized into three distinct and integrated Work Packages which focus on the following:

- Work Package # I: Collection and analysis of existing relevant collision data,
- Work Package # II: Development of event trees and collision probabilities and
- Work Package # III: Identification and assessment of mitigation measures that can reduce risks.

This report encompasses the work completed in Work Packages # I and # II.

The consequences (breach of a Type B transportation package) or potential impacts (environmental impacts, health effects or injuries) of collisions are not considered within the scope of this assessment.

[5] It should be noted that the accepted industry standard and road safety term refers to collisions rather than accidents. The term 'accident' implies that no one is at fault and that no one, including the driver, bears responsibility for the outcome. The term 'collision', on the other hand, is more specific in terms of the action's outcome without the unpreventable implication.

Such analyses, typically referred to as 'risk assessments' or 'consequence analyses', may be conducted in the future utilizing the results of the current report as input for expected initial conditions.

This report intends to analyze historical collision conditions which may apply to road and rail conveyances which are being considered by NWMO for transporting Type B packages. This report does not present the hypothetical consequences which may arise as a result.

Similarly, this assessment does not aim to quantify the radiological dose from incident-free transport of Type B transportation packages. This assessment aims to provide an improved understanding of vehicle collision scenarios that could impact the safe movement of conveyances transporting Type B packages for both road and rail modes of transport.

Using incident and collision data and applying probabilistic assessment methods, event trees and collision probabilities for scenarios of varying severity are to be defined. Following this analysis, mitigating actions will be identified in a separate report under Work Package # III to inform NWMO's future program procedures aimed at reducing or eliminating risks based on potential collision severity levels and probabilities of occurrence.

2.3 Context

2.3.1 Radioactive Material Transportation

The transportation of radioactive materials in Canada is governed jointly by CNSC and Transport Canada (TC) under several pieces of legislation, including, but not limited to, the Transportation of Dangerous Goods Act (S.C. 1992, c. 34), the Packaging and Transport of Nuclear Substances Regulations (PTNSR) (SOR/2015-145), the Nuclear Safety and Control Act (S.C. 1997, c.9), and the Nuclear Security Regulations (SOR/2000-209).

Under the framework set out by the above-noted legislation, radioactive materials are defined as Class 7 Dangerous Goods and can be further categorized according to their specific properties pertaining to the type and level of ionizing radiation that may be applicable. Thousands of shipments of radioactive materials are safely carried out within Canada annually by various industries, including power production, surveying, and nuclear medicine.

Drawing from the International Atomic Energy Agency's *Regulations for the Safe Transport of Radioactive Materials* [1], Canada's PTNSR sets out requirements for the types of packages that must be used to transport various categories of radioactive materials.

This includes the content characteristics and the safety-related performance of packages during normal conditions of transport (NCT) and hypothetical accident conditions (HAC). Different types of packages may be required depending on the nature and form of the content. These include, but are not limited to:

Type IP Packages	Type A Packages	Type B Packages
These packages are utilized for shipping materials considered to pose a low risk or hazard due to the nature and level of the contents (low specific activity or surface contamination). They provide a basic level of protection and shielding and must withstand normal transport conditions, among other requirements.	These packages are designed for the transport of moderately radioactive materials. They provide a higher level of protection compared to Type IP packages. They are rated to contain levels of ionizing radiation below a given threshold value (known as an A_2 value [a]) which varies depending on the nature of the contents.	These packages are among the most protective and transport highly radioactive materials where the content exceeds a prescribed threshold value. They provide containment and a high level of shielding against radiation. They are designed, tested, and certified to ensure they withstand expected incident conditions.

Type IP Packages	Type A Packages	Type B Packages
Common contents include surface-contaminated clothing or PPE.	Common contents found in Type A packages include radiopharmaceuticals and other industrial materials.	Type B packages are commonly used to transport used nuclear fuel.

[a] The A_2 value is the maximum amount of radioactivity of a specific radioisotope measured in terabecquerel (TBq) than can be transported in a Type A package for normal form materials like most radioactive waste. In other words, the amount of radioactivity they contain is limited by regulations and in the event of a release, these limits ensure that the risk from radiation/contamination is managed.

This assessment concerns road and rail conveyances capable of transporting **Type B packages** certified to transport used nuclear fuel.

Safety of Type B Transport Packages for Used Nuclear Fuel

The basic philosophy behind the Canadian transport regulations is that safety heavily relies on the design of the transport package. Used fuel packages, or Type B packages are designed, tested and certified to retain their contents during normal operations and in the event of a credible accident. Under the regulations, the package design has to meet a series of rigorous impact, fire and water immersion tests:

- Two drop tests: 1) a 9 metre drop onto an unyielding surface and; 2) a 1 metre drop onto a steel bar at least 20 centimeters long; conducted in the sequence and orientation that would result in the most damage to the package.
- Following the drop tests, a fire test on the same specimen which the package is subjected to a fully engulfing fire of $800^{O}C$ for 30 minutes.
- Immersion test where the cask is then subjected to conditions equivalent to 15 metre submersion for 8 hours. For casks designed for the more highly radioactive materials there is an enhanced immersion test of 200 metres for 1 hour.

These tests ensure that packages can withstand accidents involving crashes, fires, or submergence under water that can realistically be envisioned.

2.3.2 Type B Transportation Packages and Conveyances

NWMO is currently assessing several conveyance options for transporting various Type B transport packages from interim storage sites to the APM DGR. Types of conveyances being considered include the:

- Truck tractor (see **Figure 2**)
- Rail consist (see **Figure 3** for an image of the rail consists and **Figure 4** for an image of the 8-axle DSC-TP railcar)
- Heavy haul truck (super-load truck).[6]

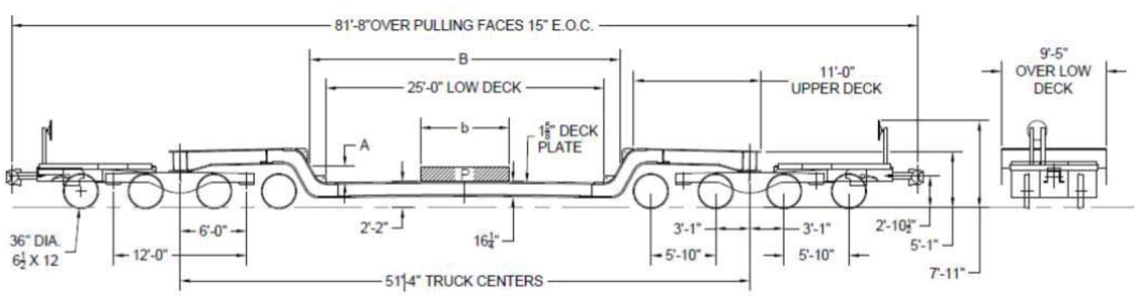
Depending on the final mode chosen and the storage method utilized at the interim storage sites, these conveyances may transport various Type B transportation packages (i.e., the Used Fuel Transportation Package, the Dry Storage Container Transportation Package, the Basket Transportation Package).

[6] Heavy haul truck has been scoped out of this report because there were no databases containing collision information on these types of conveyances, therefore the focus of this report is on truck tractors and rail consists.

Figure 2: An illustration of Road Conveyance with Used Fuel Transportation Package (top) and Basket Transportation Package (bottom)

Figure 3: An illustration of Dry Storage Container Transportation Packages and Supporting Rail Consist

Figure 4: An illustration of the 8-axle Dry Storage Container Transportation Package Railcar



2.4 Content of the Report

This report encompasses the work completed in Work Packages # I and # II. It focuses on event tree development, transportation collision probabilities, and transport safety.

This report intends to analyze historical collision conditions to quantitatively assess collision probabilities which may apply to road and rail conveyances which are being considered by NWMO for transporting Type B packages.

As noted previously, the consequences or potential impacts (environmental impacts, health effects or injuries) following a collision or breached Type B transportation packages are not considered within the scope of this assessment.

Literature Review	Summarizes a review of the technical and scientific literature used to assist in developing the methodology for the risk assessment component related to the transportation of radioactive materials.
Methodology	Outlines and justifies the chosen approach regarding data collection, the applicability of screening criteria, and the development of event trees to assess collision events for road and rail.
Collision Datasets and General Statistics	Provides an overview of the datasets collected as part of the assessment, their contents, and applicability to the project objectives, along with the measures used to ensure that event trees are based on reliable and comprehensive data. This section also provides highlights of the collision databases for the most relevant geographic study areas.
Collision Types and Attributes	Provides a breakdown of the collected datasets regarding collision categories, attributes, and contributing factors. Emergent trends and themes of interest are briefly described in this section.
Screening Criteria	Discusses the applicability of different screening criteria that could be applied to the chosen datasets to account for contributing factors or conveyance types that further define the available data for creating event trees.
Event Trees	Provides a detailed look at the construction of event trees for road and rail conveyances. The event trees are then presented, and the initial general outcomes of the study are touched on.
Calculation of Collision Scenario Probabilities	Provides a further breakdown of the results showcased in the event trees by looking at the specific probabilities and outcomes of the road and tail collision events.
Sensitivity Assessment	Describes what are considered bounding collision scenarios as well as a discussion of the top-probability collision occurrences and scenarios. Based on these, themes of interest are discussed, and a sensitivity analysis is conducted.
Benchmarking	A benchmarking exercise is carried out against previous probabilistic assessments.

2.5 Assumptions

For this report, the following assumptions apply:

- The scope of work on data collection efforts is limited to collecting and analyzing relevant collision datasets based on the road and rail conveyances proposed to transport NWMO's used fuel shipments and does not include discussions on the quality of the data received from different resources.

  It is important to note that various factors can affect the accuracy and completeness of truck and train datasets as applicable to any dataset collected manually.

  For example, collision information for road only transportation collected by police officers following an investigation usually undergoes an internal quality review process. However, this process is not guaranteed for all reported collisions.

  Some of the most common challenges in road collision data collection and reporting include incomplete data, delays in entering data into databases, and errors/inconsistencies in data entries. In the cases of self-reported collisions, errors and inconsistencies are expected to occur more frequently than in forms completed by police officers.

  The project team acknowledges the potential shortcomings in the accuracy and completeness of data and remains unbiased in assessing different resources concerning data quality.

- The timeframe for collision data collection and analysis for truck and train movements was for the years 2010 to 2019 inclusive. Data from 2020 through 2022 were not used because of the transportation-related impacts stemming from the COVID-19 pandemic.

  Data for those years is not considered representative due to economic slowdowns and overall commercial and private transportation reductions that occurred during the time period.

- The development of collision event trees and the calculation of probabilities are not route or location specific.

- It is assumed that the individual events are statistically independent. In other words, the occurrence of one event (e.g., a head-on collision) does not affect the probability of the other (e.g., a collision with a bridge structure).

- The scope of work does not involve analyzing consequences in the event of a road or rail incidents.

3 Literature Review

3.1 Transportation Safety Assessments & Statistics within Canada

Two primary references were identified as being directly applicable to the topic of radioactive material transport in the Canadian context:

- "Radioactive Material Transport Probabilistic Risk Assessment – Large Truck Collisions on Canadian Roadways," as conducted by Lloyd's Register for the CNSC [2], and
- "A Probabilistic Risk Assessment of Truck/Trailer Transportation of Radioactive Material in Canada," summarizing the first report for presentation at PATRAM [3].

Each of these documents considers only truck transportation. Similar or parallel studies have not been conducted for train transport in Canada.

The Lloyd's Register report explored the applicability of probabilistic assessment methods on collisions involving large trucks on Canadian roadways, noting that *"since radioactive material transport collisions are extremely rare, the associated statistics are insufficient as the basis for the collision event tree."* In turn, analogous collision data, in the form of tractor-trailer collisions involving non-radioactive payloads from 2011 – 2015, was utilized to apply probabilistic assessment methods effectively.

The report concluded that "*sufficiently comprehensive and detailed data exist for the creation and use of event trees specific to collision probabilities on Canadian roadways*" to inform the general public of the relative transport collision risks.

To apply Canadian roadway collision data to conveyances transporting Type B packages, screening criteria were applied to the dataset for conveyance type (unit truck >4536 kg, truck tractor) to exclude such contributing factors as, alcohol, drugs, and disobeying of traffic control, etc., as the latter were identified as *"not applicable to drivers of trucks carrying Type B containers."* A similar screening approach was considered for this analysis as outlined in **Section 7 Screening Criteria**.

Among the recommended areas for future study were the development of collision event trees for other modes of transport, the development of guidance on how to reduce the probability of collisions that are more likely to result in severe or demolished vehicles, and how to translate vehicle damage severity to Type B package consequences – topics which informed the scope of the current assessment.

Thus, the Canadian literature, while limited, sets the groundwork for the current assessment. It does this by verifying that probabilistic assessment methods involving conventional transportation collisions may be utilized to assess transportation collision scenarios relevant to Type B packages transported along Canadian highways, laying out a viable methodology and screening criteria, and identifying areas where more research is required.

3.2 Transportation Safety Assessments & Statistics within U.S.

Due to the United States' extensive history of radioactive material transport and infrastructure and legislative similarities to the Canadian context, the United States was identified as a source containing several reports of interest.

3.2.1 Final Environmental Statement on the Transportation of Radioactive Material by Air and Other Modes - 1977 [4]

In 1977, the United States (U.S). Nuclear Regulatory Commission (USNRC) produced the "*Final Environmental Statement on the Transportation of Radioactive Material by Air and Other Modes*."

This report (NUREG-1070) focused on gauging the radiological impacts of shipments of radioactive material within, to, and from the United States.

While the report is primarily concerned with calculating the radiological impact across all modes of transport under incident-free and accident conditions, a portion of it is devoted to identifying the probability and consequence (collision rate per vehicle-kilometer) of transportation collisions for each mode.

Furthermore, the report uses a classification scheme accounting for crush force (road), impact force (rail) and fire duration to assign severity categories and fractional occurrence rates to population density zones. As such, this study is not directly applicable to the current report, which focuses on the factors and statistics leading to a road or rail collision instead of the radiological impacts of such hypothetical collisions.

3.2.2 Modal Study – 1987 [5]

To account specifically for severe highway and railway collisions, the USNRC, in collaboration with Lawrence Livermore National Laboratory (LLNL), conducted the "*Shipping Container Response to Severe Highway and Railway Collision Conditions*" report in 1987. This report (NUREG/CR-4829), known as the "Modal Study," aimed to estimate the adequacy of radiological protection afforded by shipping casks (Type B containers) during highway or rail incidents either within or exceeding regulatory collision conditions.

To screen the collision criteria, collision rates were estimated from historical collision records for truck and train incidents for similar vehicles. Collision data from the Bureau of Motor Carrier Safety was used to identify collision types, build event trees, and identify average collisions/vehicle mile rates. Based on these collision combinations, mechanical and thermal loading scenarios were identified and screened as within or exceeding regulatory collision conditions.

These conditions were then applied to representative spent fuel casks, and the structural and thermal responses were analyzed. The report concluded that based on the screening and assessment of real collision cases and respective collision conditions applied to representative casks, the level of protection afforded by the regulations (U.S. 10 CFR 71) is "*adequate and not in need of immediate change*." Thus, the Modal Study assures that such a probabilistic approach can be applied conservatively to gauge collision probabilities relevant to used fuel shipping casks during transport.

3.2.3 Re-examination of Spent Fuel Shipment Risk Estimates - 2000 [6]

A third study (NUREG/CR-6672) was carried out in 2000 titled "*Reexamination of Spent Fuel Shipment Risk Estimates*" by USNRC in collaboration with Sandia National Laboratories, which aimed to reassess the transportation risks identified in NUREG-1070 and NUREG/CR-4829 utilizing finite element analysis (FEA) and heat transport calculations.

The study carried over collision severity fractions from the Modal Study but augmented the data with geographic information next to potential transport routes (i.e., hard vs soft rock surfaces). It concludes that the previous studies "*made several very conservative assumptions about […] cask response to collision conditions, which caused their estimates of collision source terms, collision frequencies, and collision consequences to also be very conservative*".

This study successfully re-utilizes event tree collision data from the Modal Study and applies the outputs to more advanced analytics methods than previously available, once again demonstrating the validity of probabilistic assessment methods' capability to quantify collision types and likelihoods.

3.2.4 Tractor/Trailer Collision Statistics – 2006 [7]

Sandia National Laboratories published "*Tractor/Trailer Collision Statistics*" in 2006 (SAND2006-7723), in part due to discussions with the public which suggested that the "*Modal Study event tree should be reconstructed using recent truck collision data*." Recent collision highway data (1996 – 2000) is utilized to construct and contrast a collision event to the Modal Study.

The report notes differences between its event tree data and that of the Modal Study but goes on to state that they "*are not so different as to suggest that the nature of truck collisions has changed drastically during the last two decades*" and that "*the probabilities of severe collisions during the transport of spent nuclear fuel by truck have not been found to be significantly greater than those estimated in the Modal Study.*" The report further solidifies that probabilistic methods, particularly event trees, are useful for assessing collision types for used fuel transportation casks shipped over highways and railways.

3.2.5 Spent Fuel Transportation Risk Assessment – 2014 [8]

A third affirmation of the U.S. regulations came in the form of NUREG-2125, *Spent Fuel Transportation Risk Assessment* (2014), which concluded that, with improved analysis tools, techniques, data availability, and reductions in uncertainty, the "*estimate of collision risk from the release of radioactive material in this study [are] approximately five orders of magnitude less than what was estimated in NUREG-0170*".

With regards to collision data, it goes on to state that although "*the most applicable frequency would be the frequency of collisions involving vehicles carrying spent nuclear fuel (SNF), […] there have not been enough collisions worldwide involving spent fuel transportation to provide an adequate statistical database*", and opts to base its assessment on highway collisions involving large semitrailer trucks and freight rail incidents for conventional conveyances obtained from the Department of Transportation (1991 – 2007), further reinforcing the use of probabilistic methods as appropriate for the current report.

3.2.6 Other U.S. Studies

Several smaller U.S.-based studies were queried as part of the literature review; these include:

- *Going the Distance? The Safe Transport of Spent Nuclear Fuel and High-Level Radioactive Waste in the United States* – 2006, Transportation Research Board and National Research Council. [9]

  This compendium of the history of SNF and HLW transportation provides overviews of the many aspects of transportation, such as regulations, testing, notable incidents, and safety cases, as well as summaries and discussions of related studies as outlined above. It makes recommendations regarding the need to assess long-duration, fully engulfing fires, among others. These recommendations were then addressed in the USNRC's NUREG/CR-7209. The work on fire accidents demonstrates that current U.S. regulations and packaging standards provide a high degree of protection to public health and safety against releases of radioactive material in real-world transportation accidents, were such events to involve spent nuclear fuel containers. This report does not delve into probabilistic methods beyond what is outlined in the above-noted studies.

- *Recent Assessments in the U.S. of Type B Packages to Impacts Beyond the Regulatory Package Test Standards* – Ammerman et al., 2007, PATRAM Proceedings. [10]

  This report analyses USNRC and Sandia documents outlined above, among others, and concludes that based on the data presented, *"the analyses and testing of packages to beyond regulatory impact standards has shown that the packages have a considerable margin of safety against the release of radioactive material"*, and that this "*reinforces the adequacy of the packaging requirements of the U.S. NRC and International Atomic Energy Agency (IAEA) and the methods currently used to certify that spent fuel casks meet these requirements*." However, this paper does not relate to probabilistic methods regarding collision event trees.

- *Analysis of Serious Truck Crashes in the United States* – Greenberg et al., 2007, PATRAM Proceedings. [11]

  This study analyzed crashes involving trucks carrying hazardous materials in order to develop associations between impact measures (crash severity and outcome) and explanatory variables (crash characteristics that help explain cause and effect). Although not specific to radioactive material transport, it notes that the most common vehicle configuration used for transporting hazardous materials is the tractor/semi-trailer.

  Many statistically significant correlations are noted between factors relevant to the current report, such as operator experience, driver error, packaging standards, crash configuration, and infrastructure.

- *A Historical Review of the Safe Transport of Spent Nuclear Fuel* – 2016, U.S. Department of Energy. [12]

  This report reviews the history of SNF transportation worldwide, notes the strong safety record of such shipments, and investigates incidents involving HLW and SNF transportation. This is primarily a qualitative assessment of historical data and previously outlined USNRC reports regarding transportation collisions and cask response.

  While this is a good highlight of the history of SNF transport, there are few discussions on probabilistic methods other than summaries of reports outlined above.

- *Freight Facts and Figures* – 2017, U.S. Department of Transportation, Bureau of Transportation Statistics. [13]

  This report provides quantitative summaries of shipments, contents, infrastructure, and conveyance usage for transportation of all type of goods in recent years and provides a good basis for general road and rail transportation statistics and benchmarking. It does not, however, provide insights into probabilistic methods.

- *A Compendium of Spent Fuel Transportation Package Response Analyses to Severe Fire Collision Scenarios* – 2017, USNRC, NUREG/CR-7209. [14]

  This report analyzes notable severe railway and roadway fires' potential impact on transportation packages by recreating the fire collision scenario and applying its parameters to a sample of spent fuel casks. Because this report deals primarily with the outcomes of a collision rather than its causal factors and probability of occurrence during transport, it is not directly applicable to the current report.

3.3 International Transport Safety and Collision Statistics

This literature review also looked at several sources describing transportation safety and collision statistics outside of the U.S. and Canada.

- *Input Data for Quantifying Risks associated with the Transport of Radioactive Material* - 2003, International Atomic Energy Agency. [15]

  This technical document was developed as part of a coordinated research project in 2003 by the IAEA in order to provide guidance on assessment techniques and sources involved in assessing transportation collisions. It is primarily based around the INTERTRAN2 Computer Code System, which is concerned with estimating dose rates for both normal and collision conditions of transport.

  To do so, it must account for probabilities of collisions and associated severities/outcomes in the form of event trees and conditional probabilities for outlined severity levels. Among the potential sources for data input, this report points to "local, regional, and national transport authorities" for highway and rail collision frequency data.

It goes on to state that "*a structured analysis of the type, severity and frequency of transport collisions involving* [radioactive material] *shipments should address the following issues:*

- *Collision assessment approaches and related data requirements*
- *Collision identification*
- *Collision severity categorization*
- *Collision event frequency estimation*
- *Reliability of collision assessment model predictions*."

As further detailed therein, this approach is consistent with the probabilistic safety assessment methods identified in the above-noted U.S.-related literature and the methodology outlined in **Section 4** of this report.

- *Heavy Vehicle Accident Factors* - 2006 - Laboratoire Regional de Lyon. [16]

  This 2006 report provided a statistical analysis of heavy goods vehicle (HGV) collisions in France between 1996 and 2001, including breakdowns of collision-prone manoeuvres, road types, profiles and conditions. It did not feature the use of probabilistic methods. Given that analogous comparisons may be possible (i.e., the overall data is sufficiently comparable), this report may be useful for benchmarking against European HGV vehicle collision causes and outcomes.

- *A Review of 10 Years Radioactive Material Transport Incidents and Accidents Experience in Germany* - 2007 PATRAM Proceedings, Gesellschaft fuer Anlagen-und Reaktorsicherheit (GRS). [17]

  Event collision data from 1995 – 2006 was compiled and categorized according to type, severity (8 broad safety significance categories), and causal factors. A rudimentary analysis was performed to provide general causes and outcomes of collision events for air, road, and rail shipments, as well as to gauge the effectiveness and adequacy of the regulatory environment. Aside from benchmarking overall radioactive material transport statistics, this study is not relevant to the current report.

- *Evaluation of Safety of French Type B Package Designs in Severe Accident Environments Other Than Regulatory* – 2007 PATRAM Proceedings, French Institute for Radiation Protection and Nuclear Safety. [18]

  In this report, cask margins of safety concerning regulatory tests are assessed against real-life collision conditions. Software simulations were carried out on four package models for fires up to 1000˚C and falls from up to 40m onto special targets and surfaces of different hardness. While the report concluded that adequate safety margins existed even for greater-than-regulatory test conditions, it ultimately deals with the effects of collisions and not their causal factors during transport. As such, it does not provide relevant input to the current report.

- *Lessons from Transport Events Involving Radioactive Materials Occurred in France Between 1999 and 2009,* 2009 PATRAM Proceedings, French Institute for Radiation Protection and Nuclear Safety. [19]

  An overview of collisions and more in-depth analyses of significant events are provided. A rudimentary statistical analysis is performed, highlighting causal factors, including human and organizational factors. The general statistics provided in this report may be used for benchmarking, particularly between package types and respective share of incidents experienced. However, this report has no application of probabilistic methods.

- *Characteristics and causes of heavy goods vehicles and buses accidents in Europe* – 2016, National Technical University of Athens, Austrian Road Safety Board. [20]

  This report deals directly with causal factors of HGV and bus/coach collisions. Demographics of HGV and coach/bus collision victims are discussed, particularly in the case of fatalities or serious injuries.

A common methodology is utilized across six (6) major EU nations, including statistical methods aimed to identify non-surface level collision causes specific to HGV and bus/coach operators (i.e., permanent sight obstruction, faulty diagnosis, observation missed, unpredictable system functions/characteristics). While useful for benchmarking, the data utilized in the current report ultimately did not feature the granularity to make one-to-one comparisons for the causal factors listed in the University of Athens' report.

- *Trucks Safety Report* - 2017, Volvo. [21]

  This report provides general collision statistics for HGVs across the EU but also utilizes statistical methods to categorize collision causes (human factors, environment, vehicle).

  While mainly concerned with reducing fatalities in collisions, the report also provides useful 'typical causes' for collision scenarios such as veering off the road, overturning, frontal collisions, etc., and makes suggestions for improved safety features to abate these scenarios (Advanced Emergency Braking System (AEBS), proximity detection systems, Cooperative Intelligent Traffic Systems (C-ITS)) which would be useful to draw from as part of identifying mitigative factors for collisions.

- *Integrated Risk Assessment Method for Spent Fuel Road Transportation Accident under Complex Environment* - 2020, Chinese Institute of Nuclear Energy Safety Technology et al. [22]

  This report utilizes a three-step methodology for assessing collision risks in the form of a comprehensive risk indicator system, event tree modelling, and fault tree analysis of initiating events. It considers road layout, surrounding environment, management, human performance, conveyance specifics and the spent fuel cask. The use of multi-tiered probabilistic risk methods assists in the development of fault conditions upon which a dose assessment is based, further reinforcing the validity of probabilistic risk assessment methods used in the current report.

3.4 Summary

In the reviewed literature, both domestically and abroad, there is significant consensus that the methodology as outlined in **Section 4 Methodology** of this report (that of utilizing general collision statistics involving analogous conveyances to those involved in the transport of Type B packages to develop screening criteria, event trees, and conditional probabilities) is suitable for basing a probabilistic transportation assessment.

Historically, it has been shown suitable for quantifying collision types, the statistical occurrence of those collisions, and their potential impacts on Type B packages during transport. Highly trusted organizations, including national regulatory authorities, have utilized comparable methodologies to accomplish similar goals and have strengthened and reinforced such methods throughout the previous decades.

Regarding data sources, there is consensus among the reports dealing with Type B package transport that due to the historical safety record of such shipments, there is insufficient collision data available to base statistically significant probabilistic assessments.

Rather, collision data pertaining to conventional conveyances, which could be used to transport Type B packages (rail cars, tractor-trailers, and HGVs), should be utilized as input data for the assessment, as a much larger pool of collision data is available to work from. However, it should be acknowledged that additional administrative and technological barriers are applied to Type B shipments that should reduce Type B conveyance collision rates compared to conventional conveyances.

Furthermore, a suitably larger body of knowledge has been developed on tractor-trailer/HGV incidents, collisions, and causal factors from which screening criteria can be identified and conclusions can be drawn regarding the initiating events, exacerbating circumstances and resulting severities of such events.

This pool of knowledge will aid in benchmarking the results of the current report against widely accepted statistics and assist in developing technological or administrative mitigating factors to curtail the probability of collision occurrence or the resulting consequences of such collisions.

4 Methodology

The approach for identifying collision types and calculating respective probabilities is based on comprehensive road and rail event data for the road and rail conveyances which are being considered for use by NWMO to transport used fuel. The information was utilized to develop event trees to demonstrate the possible list of collision scenarios and their resulting probabilities.

The event tree development process is set out in **Sections 4.1** through **Section 4.4** with event trees specifically defined in **Section 4.5**.

4.1 Data Collection

A key report objective was to collect suitable data on which a robust probabilistic assessment may be based. As such, it was determined that ten (10) years of historical collision data pertaining to relevant road and rail conveyances within the geographic study area would prove suitable.

The following relevant sources were identified to support the development of collision even trees:

- Ontario Ministry of Transportation (MTO)
- Québec Ministry of Transportation (MTQ) / Québec Automobile Insurance Company (SAAQ)
- New Brunswick Transportation and Infrastructure
- Transport Canada's Dangerous Good Accident Information System (DGAIS) which contains reports provided at the time of a collision if a release (or anticipated release of the dangerous goods endangers (or could endanger) public safety
- Canadian Nuclear Safety Commission's Event Information and Tracking System (EITS)
- Transportation Safety Board of Canada (TSB)

4.2 Collision Statistics

Following a qualitative and quantitative analysis of the collision data, a breakdown of the percentage of collisions involving conventional shipments by road transport (truck tractor[7]) and rail transport (train) and those involving dangerous goods by type was prepared. **Section 5 Collision Datasets and General Statistics** of the report shows the key highlights of the results of this analysis.

4.3 Screening Criteria

To understand the nature of the collisions that apply to the transport of Type B packages, potential screening criteria were identified through a review of similar assessments (CNSC/Lloyd's Register reports [2] [3]).

Screening criteria refer to certain parameters which may be applied to isolate the relevant portion of the dataset utilized for the probabilistic assessment study.

- For the purpose of this report, the road portion of the analysis focused on datasets of truck tractor collision data as this is the type of conveyance that may be used to transport Type B packages of interest.
- The rail portion of the report did not identify any relevant screening criteria that would warrant application to pare down the dataset to make it more representative of Type B package transportation. Screening criteria are further detailed in **Section 7**.

[7] On occasion this report uses the word 'truck' as a generic reference to a road transportation vehicle not inclusive of the verbiage 'truck tractor'.

4.4 Collision Events and Causes

The set of collision events was defined by applying the screening criterion to develop the subsequent event trees discussed in **Section 5 Collision Datasets and General Statistics**.

For road transportation, three events can result from an incident as follows:

1) A collision with a non-fixed object,

2) A collision with a fixed object, or

3) A non-collision event.

These three events are consistent with the literature and are considered in this analysis with a fourth "other" event category to account for a small fraction of events with no further information regarding the sequence of events or objects struck.

For rail transportation, the initial events evaluated are derailment and non-derailment events. Contributing factors for actual recorded events are not provided in the collision database. Without such detailed information, the contributing factors for all train collisions could not be identified. However, the event tree was constructed to capture the available data that could represent a cause or consequence of the event.

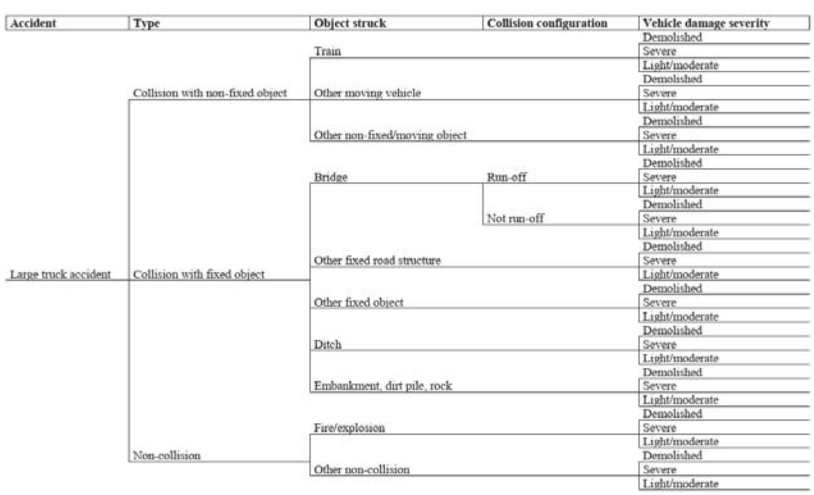
4.5 Event Trees

In probabilistic analysis, various tools and techniques are useful for mapping out and quantifying events of interest, their initiating factors, and subsequent outcomes. One such technique is event tree modelling, which, historically, has been used within the nuclear industry to identify and assess component or system responses to an initiating event.

A collision event tree describes the progressions of a set of collision scenarios. It is a diagram used to visualize the sequence of separate events or descriptors that form the overall description of the collision scenario when assembled one after each other. An event tree displays a path that starts with the initiating event (trunk of the tree). This then leads to the following event if one occurs (like the branch of a tree), and then to the next event, and so on. Ultimately, this maps out the completely defined collision event scenario in a casual format. When analyzed collectively, the event tree describes the potential outcomes of an initiating event.

Figure 5 shows an example of an event tree for truck movements, developed by *Radioactive Material Transport Probabilistic Risk Assessment - Large Truck Collisions on Canadian Roadways* ("Lloyd Study") [2].

Figure 5: Example of an Event Tree



This report aims to develop road and rail collision scenario event trees based on real-life road and rail collision data within the relevant Canadian geographical area pertaining to vehicles analogous to those planned to transport used nuclear fuel. The development of these event trees (form and branching pathways) was influenced by previously established event trees for used fuel transportation in Canada and the U.S., as well as the availability of suitable data from which to conduct the assessment.

Based on the application and makeup of event trees seen within the relevant literature (See **Section 4 Methodology**), the primary elements of the event trees were identified and applied. This began with identifying the first branches associated with tractor-trailer and railcar incidents. Consistent with **NUREG/CR-4829, *Shipping Container Response to Severe Highway and Railway Accident Conditions*** ("Modal Study") [5], they are "collision" or "non-collision" initiating events.

The event trees for road and rail transportation were expanded by subdividing the "collision" and "non-collision" events based on types of objects struck (collisions) and types of non-collision events (e.g., fires, roll-over, etc.), respectively. These subdivisions were commonly seen across the relevant literature and were intended to capture the broadest subcategories of incidents these types of vehicles experience during transportation. Then the type of shipment (i.e., dangerous goods or conventional shipment) and vehicle damage severity were captured in the following branches of the event tree.

For rail transportation, the construction of the event tree was first based on the derailment scenario, as it can be considered a key determinant as to the ultimate severity of the event. This is consistent with event trees created as part of the Modal Study. Next, the event tree was further broken down for different collision types. This included collisions involving track units, fire, explosion, main-track train collisions, etc. The train event tree also included the type of shipment and whether a breach of dangerous goods was noted in the collision, as applicable based on the available data.

The construction of event trees and their branches is tied directly with the selected truck and train movement databases, as discussed in **Section 8 Event Trees** of this report.

The applicable collision data was applied to the individual event tree branches. Where a limiting factor was encountered (lack of sufficient data points, insufficient data parameters, etc.), expert judgement and consultation of the literature for similar challenges was utilized to inform the steps taken. Critical decisions regarding the availability and application of suitable data are discussed in **Section 5 Collision Datasets and General Statistics**.

Within the event tree, the probability of a particular collision scenario is the product of all of the branch point fractions that lie on that scenario path. Therefore, for a total probability in the final column of the event tree, the individual probabilities from each column are multiplied together (moving left to the right). Thus, the branch point fractions must be determined before a particular collision scenario probability can be calculated. The branch point fractions, derived from analysis of the identified data sources, were added following concurrence of the event tree structure.

While the range of types and severity of collisions that could theoretically occur is vast (ranging from minor collisions to incidents with serious outcomes), the analysis does not consider the radiological impact of the collision (e.g., the release of radioactive materials and/or loss of shielding). A full assessment of the potential radiological impacts of a collision entail using models and methods beyond the scope of this assessment.

This report is limited to the probabilistic analysis of incidents and collisions that a conveyance carrying used fuel may reasonably encounter during transport.

4.6 Collision Probabilities

4.6.1 Collision Rate vs Conditional Probability

It is important to note that probabilities calculated using a probabilistic approach are referred to as 'conditional probabilities', which pertain to a particular collision scenario occurring ***if*** a collision happens.

It differs considerably from 'collision rate', which represents the number of collisions that occur at a given geographic location within a certain timeframe.

In roadway safety studies, traffic volume (measured as million vehicle kilometres) can be used to calculate the collision rate. The collision rate is the number of collisions in a given period (e.g., one year) divided by the traffic volume during the same period.

For example, if 230 collisions occurred in a defined geographic area within one year while vehicles covered 2 million kilometres (km), the collision rate could be expressed as 0.00115 collisions per km or 115 collisions per million km travelled.

Collision rates will vary by geographic region such that one cannot confidently apply a province-wide collision rate to specific routes and expect it to accurately represent the situation on the ground. And such geographically localized data may not be available in sufficient amounts or quality to make use of as part of a sound study.

4.6.2 Conditional Probability of a Scenario

The collision scenario probabilities are calculated and presented without considering collision rates (i.e., collisions per kilometer travelled) or the probability that a truck or train collision happens in the first place.

This report only considers the conditional probability of a collision scenario or the probability of a particular collision scenario occurring ***if*** a collision happens in the first place.

Therefore, the resulting probability of the exact sequence of collision events defined by an event tree pathway begins with a starting assumption that a collision has occurred.

It has no bearing on the rate of collisions occurring within any specific geographic area timeframe. It pertains only to the probabilistic nature of the specific events following a collision.

4.7 Previous Applications

Collision scenario event trees for road and rail were developed utilizing previously established event tree assessments within Canada and the U.S. for guidance. The literature review presented in **Section 3 Literature Review** identifies methods and assumptions that can be used to inform the development of generic collision event trees and associated collision probabilities related to the transport of Type B packages for relevant road and rail conveyances.

In particular, the Modal Study was one of the first U.S. government guidance documents to explore the use of event trees to examine general transportation collision probabilities and apply them to the transportation of spent nuclear fuel. The Modal Study used the historical train and truck collision data to develop a suite of collision scenarios and associated probabilities displayed as event trees.

Two primary Canadian references provide examples of the use of event trees for evaluating accident probabilities,

- the first being *Radioactive Material Transport Probabilistic Risk Assessment – Large Truck Accidents on Canadian Roadways* [2], as conducted by Lloyd's Register for the Canadian Nuclear Safety Commission (CNSC), and
- the second being *A Probabilistic Risk Assessment of Truck/Trailer Transportation of Radioactive Material in Canada* [3], a summarization of the first report for presentation at the Packaging and Transportation of Radioactive Materials (PATRAM) Symposium in 2019.

This report aims to go beyond the work conducted within these reports by examining the topic of rail transportation. In addition, given that these studies utilized different databases than those used for this report, there exist opportunities to contrast or justify any deviations in the final event trees.

4.8 Applicability to Type B Package Conveyances

Given that the number of road conveyances of spent nuclear fuel in Type B packages is small within Canada, statistical evaluations and probabilities of collisions must be derived from large datasets of collisions involving other heavy vehicles.

In countries such as France, where spent nuclear fuel is transported more regularly due to active fuel reprocessing operations, reasonably sized datasets for spent fuel shipping do exist and they demonstrate that collisions involving these shipments seldom occur. However, it is not appropriate to extrapolate current spent fuel transportation data from Europe to Canada.

To conduct a robust assessment of the possible collision scenarios in Canada, a larger analogous dataset is preferable to a dataset of Type B-carrying conveyance collisions in Canada for which very little data currently exists.

5 Collision Datasets and General Statistics

To ensure that the event tree analysis carried out as part of this report is based on reliable and comprehensive data, it is paramount that sound and reliable data sources are utilized. In anticipation of this work, several federal and provincial organizations within Canada were contacted to identify viable datasets.

Ontario, Québec, and New Brunswick were targeted as provincial data sources of high importance as these provinces store the majority of used fuel to be transported. Of the resulting datasets, variances were identified concerning data attributes required to carry out an event tree assessment of collated datasets.

An overview of each identified dataset, alongside available and missing attributes, collection dates, and usefulness to the assessment, is provided in the following subsections. The collision datasets and general statistics are provided separately for different modes of transportation.

For this report, in consultation with the NWMO, the timeframe for collision data collection and analysis for truck and train movements was increased from five (5) years[8] to ten (10) years, from 2010 to 2019.

The longer time frame provides an enriched dataset for detailed analysis, aiming to create a better understanding of historical collisions and improve future projection accuracy. It is noted that data from 2020 through 2022 were not used for both road and rail movements because of the impacts stemming from the COVID-19 pandemic. Data for those years is not considered representative due to economic slowdowns and overall commercial and private transportation reductions that occurred during the time period.

5.1 Truck Collision Datasets

Outlined in **Section 2.1 Background**, Canada's plan for the long-term management of used fuel entails transportation from interim storage sites to the DGR location.

Used fuel bundles originate from eight interim storage facilities under the ownership of Ontario Power Generation (OPG) (Pickering, Darlington, and Bruce), Atomic Energy of Canada Ltd. (AECL) or Canadian Nuclear Labs (CNL) (Douglas Point, Chalk River, and Gentilly 1), Hydro-Québec (Gentilly 2), and New Brunswick Power (Point Lepreau), as shown in **Figure 1.**[9]

As such, the following relevant collision statistics in Ontario, Québec, and New Brunswick provinces were reviewed in detail:

- Ontario collision data from the Ministry of Transportation (MTO), from 2010 to 2019, and discussed in detail in **Section 5.1.1 Ontario Collision Data**.
- New Brunswick motor vehicle collision data as reported by the Government of New Brunswick from 2010 to 2019. This database was composed of only motor vehicle collisions involving truck tractors. The details of the New Brunswick database in included in **Section 5.1.2 New Brunswick Collision Data**
- Québec collision data for the Province of Québec, as reported by the Québec Automobile Insurance Company (SAAQ - Société de l'assurance automobile du Québec) from 2010 to 2019. The details of the Québec database in included in **Section 5.1.3 Québec Collision Data**.

[8] According to the Highway Safety Manual (HSM), the typical time period examined to assess collision trends when assessing road safety initiatives is five (5) years [23].

[9] Used fuel from Whiteshell Laboratories (Manitoba) is anticipated to be consolidated at Canadian Nuclear Laboratories (Ontario) prior to the start of NWMO transportation operations.

The following limitations of the collision data sources should be noted when concluding the collision data source:

- Collision data are typically entered manually into the collision database by police officers or individuals involved in a collision, subject to input errors or omissions.
- For self-reported collisions, there may be a bias regarding driver action and condition associated with the at-fault driver.
- For those datasets focused on incidents on provincial highways, the reported collisions will reflect driving characteristics and operating speeds representative of those highways, in contrast to lower-class and municipal roadways.
- Collisions in municipal jurisdictions are excluded from the assessment as no centralized/standardized dataset was identified.

The detailed collision statistics in Ontario, Québec, and New Brunswick include some common data elements. In general, collision attributes in these provinces are reported at two levels:

- **Level #1** - Collision-level attributes, which are those that can be associated with the collision itself, such as impact type, weather condition, and road condition; and
- **Level #2** - Vehicle-level attributes, which are specific for each vehicle involved in a collision, such as a driver condition and driver action.

Table 1 and **Table 2** present the list of collision-level and vehicle-level attributes, their common definitions and availability of information in Ontario, Québec, and New Brunswick datasets, check-marked as “X”.

Table 1: Collision-Level Attributes and Availability of Data

Collision-Level Attributes	Common Definition	Availability of Data		
		Ontario	Québec	New Brunswick
Collision location	Location of the collision in the collision dataset (e.g., intersection, roadway segment, ramp, etc.)	X	X	X
Collision date and time	Date and time of the collision.	X	X	X
Impact type	The impact type describes the general path of the vehicle(s) immediately before the first impact, such as including rear-end, sideswipe, and angle. Detailed information for collision impact type is provided in Section 6.2.1.2 Impact Type.	X	X	X
Collision severity	Collision severity is the quantification of the intensity of an impact, which can result in fatality, injury, or property damage. Detailed information for collision severity data is provided in Section 6.2.1.3 Collision Severity.	X	X	X
Weather condition	The weather conditions at the time of the incident. Detailed information for weather condition is provided in Section 6.2.1.4 Weather Condition.	X	X	X
Road surface condition	The road surface condition at the time of the collision, such as dry, wet, snow, slush, etc. Detailed information for road surface condition is provided in Section 6.2.1.5 Road Surface Condition.	X	X	X
Lighting condition	The type of light that was recorded at the time of the collision, such as daylight, dawn, artificial dawn, dusk, artificial dusk, etc. Detailed information for light condition is provided in Section 6.2.1.6 Lighting Condition	X	X	X

Table 2: Vehicle-Level Attributes and Availability of Data

Collision-Level Attributes	Common Definition	Availability of Data		
		Ontario	Québec[1]	New Brunswick
A sequence of events	The order of events for each motor vehicle during a collision until it came to rest. Detailed information for sequence of events is provided in Section 6.2.1.1 Sequence of Events	X	X[2]	X[3]
Vehicle type	Type of vehicle involved in a collision (e.g., passenger cars, vans, trucks, etc.)	X	X	X
Vehicle damage level	Severity of damage for the vehicle involved in a collision (e.g., light damage, moderate damage, severe damage, demolished). Detailed information for vehicle damage level is provided in Section 6.2.1.7 Vehicle Damage Level.	X	-	-
Driver action	The action each driver made immediately before a collision (e.g., driving properly, excessive speed, improper turn, etc.). Detailed information for driver action is provided in Section 6.2.1.8 Driver Action.	X	-	X
Driver condition	The condition of the driver prior to a collision (e.g., impaired, normal, inattentive, etc.). Detailed information for driver condition is provided in Section 6.2.1.9 Driver Condition.	X	-	X
Dangerous goods number (if applicable)	An identifier whether a vehicle involved in a collision was carrying dangerous goods. The breakdown of collisions involving different dangerous goods for the Ontario and New Brunswick is provided in Section 5.1.1.3 Ontario Dangerous Goods Data and Section 5.1.2.3 New Brunswick Dangerous Goods Data.	X	-	X

[1] The Québec database only included vehicle-level attributes for the first vehicle in a collision. The attributes for other vehicles involved in the same collision were not available to the project team.
[2] The sequence of event attributes in the Québec dataset was only available for the first event of the first vehicle.
[3] Initially, the dataset obtained from the Government of New Brunswick did not include attributes related to the sequence of events and vehicle damage level, as reported in Ontario's database. An updated database was later made available, which included the sequence of event data but not vehicle damage level due to the method through which this attribute is estimated in New Brunswick.

In addition to detailed collision statistics in Ontario, Québec, and New Brunswick, the collision data collection efforts were extended to the following data sources:

- Dangerous Goods Collision Information System (DGAIS) from Transport Canada (TC) from 2012 to 2021. The details of the DGAIS database are included in **Section 5.1.4 Dangerous Goods Collision Information System**.
- Event Information and Tracking System (EITS) database from the Canadian Nuclear Safety Commission (CNSC), from 2000 to 2022. The details of the EITS database are included in **Section 5.1.5 Canadian Nuclear Safety Commission Data**.

Each of the above data sources are discussed in the following subsections.

5.1.1 Ontario Collision Data

5.1.1.1 Overview of the Ontario Dataset

In selecting a dataset and source most appropriate for the estimation of collision probabilities, it was essential to review the historical collision datasets from the selected provinces.

The MTO maintains a dataset of police-reported and self-reported vehicle collisions on provincial highways. It should be noted that collision data for municipal jurisdictions (i.e., municipally-patrolled highways, including expressways such as the Don Valley Parkway and Gardiner) is not captured within this database and thus is not included as part of this assessment.

As part of this report, detailed collision data for provincial highways in Ontario was acquired from MTO for the years 2010 and 2019 inclusive. The following subsection provides an overview of the general collision statistics.

5.1.1.2 Ontario General Statistics

Table 3 provides a summary of road collisions included in the Ontario provincial database. The breakdown refers to annual collisions for conveyance types which are of interest to this report, including truck tractor and heavy vehicles, as they are similar to those which would transport Type B packages.

- Heavy vehicles include all types of heavy-weight vehicles with similar characteristics in Ontario's database, including truck tractors, open trucks, closed trucks, tank trucks, dump trucks, car carriers, and other trucks (i.e., cement mixers or cranes).
- Truck tractors refers specifically to tractor-trailers. Truck tractor collisions are considered a subset of heavy vehicle collisions.

Section 7 Screening Criteria of the report further discusses the selected vehicle type, ensuring that only relevant categories of conveyances applicable to the assessment are included in the analysis.

As outlined previously, the percentage of collisions involving truck tractors and heavy vehicles is specific to the MTO provincial highways and does not represent the incidents on lower-tier municipalities and regional roads in Ontario.

Table 3: Annual Road Collisions (MTO Ontario Database) by Vehicle Type (2010 to 2019)

Year	Frequency of Collisions (All Vehicles)	Frequency and Percentage of Collisions	
		Involving Truck Tractors*	Involving Heavy Vehicles*
2010	33,245	3,642 (10.9%)	4,960 (14.9%)
2011	36,546	4,047 (11.1%)	5,532 (15.1%)
2012	34,104	3,496 (10.3%)	4,956 (14.5%)
2013	38,982	4,088 (10.5%)	5,667 (14.5%)
2014	38,830	4,376 (11.3%)	6,025 (15.5%)
2015	36,885	3,594 (9.7%)	4,939 (13.4%)
2016	36,049	3,480 (9.7%)	4,833 (13.4%)
2017	36,276	3,709 (10.2%)	5,148 (14.2%)
2018	37,969	3,871 (10.2%)	5,482 (14.4%)
2019	39,202	3,993 (10.2%)	6,071 (15.5%)
Total	368,088	38,296 (10.4%)	53,613 (14.6%)

* The percentages noted in brackets represent the proportion of collisions compared to the total values in the second column.

5.1.1.3 Ontario Dangerous Goods Data

The MTO database includes a field that identifies whether a vehicle involved in a collision was carrying dangerous goods. If positive, the Product Identification Number (PIN) obtained from the placards on the vehicle can also be reported in the database. Confirming whether the PIN was recorded for every collision involving dangerous goods is challenging, and this level of verification was not conducted as part of this report.

Table 4 summarizes the total collisions involving different dangerous goods from 2010 to 2019.

Table 4: Breakdown of Collisions by Dangerous Goods Type (Ontario Database)

Dangerous Goods Class	Dangerous Goods Description	Frequency of Recorded Collisions Involving Dangerous Goods
1	Explosives	2
2	Gases	25
3	Flammable Liquids	47
4	Flammable Solids	1
5	Oxidizing Substances	4
6	Poisonous and Infectious Substances	2
7	Radioactive Materials	1
8	Corrosive Substances	14
9	Miscellaneous Dangerous Substances	0
97	Not Applicable	0
98	Unknown	0
99	Other	2
	Total	98

As shown in **Table 4**, less than 0.3% of truck tractor collisions in Ontario provincial highways (98 out of 38,296 truck tractor collisions) involved dangerous goods.

However, as **Section 5.1 Truck Collision Datasets** identified, any attribute included in manually obtained data is subject to omission or input error. The number of collisions involving placarded dangerous goods in provincially patrolled highways in Ontario within the assessed timeframe may differ.

Of those 98 recorded collisions involving dangerous goods, only one incident involved a vehicle carrying Class 7 dangerous goods (radioactive materials). The rarity of such an event is consistent with the findings drawn from the literature review.

The description of this particular event is provided in **Table 8**. In the absence of the total number of dangerous goods shipments in any given year, the frequency of truck collisions involving radioactive materials cannot generate meaningful statistics on the proportion of such incidents in Ontario, and the results should be interpreted with caution.

It is noted that Ontario's database did not provide further details on the type of packages, including Type B transportation packages.

5.1.2 New Brunswick Collision Data

5.1.2.1 Overview of New Brunswick Dataset

New Brunswick motor vehicle collision data from 2010 to 2019, as reported by the Government of New Brunswick, was obtained by project personnel in a spreadsheet format. This database was composed of only motor vehicle collisions involving truck tractors.

In addition, vehicle-level attributes for other types of vehicles involved in a collision with truck tractors were unavailable.

As noted earlier in **Table 2**, initially, the dataset obtained from the Government of New Brunswick did not include attributes related to the sequence of events and vehicle damage level, as reported in Ontario's database. An updated database was later made available, which included the sequence of event data but not vehicle damage level due to the method through which this attribute is estimated in New Brunswick.

Due to the lack of vehicle damage level attributes, this dataset could not be carried forward into the event tree stage of the assessment.

5.1.2.2 New Brunswick General Statistics

As noted above, the Government of New Brunswick only provided motor vehicle collisions involving truck tractors. **Table 5** summarizes annual road collisions for truck tractors in New Brunswick's database.

Table 5: Annual Road Collisions in New Brunswick's Database for Truck Tractors

Year	Frequency of Collisions (Truck Tractor)
2010	332
2011	354
2012	282
2013	4[10]
2014	317
2015	345
2016	282
2017	338
2018	347
2019	371
Total	2,972

5.1.2.3 New Brunswick Dangerous Goods Data

Similar to the data obtained from MTO, the New Brunswick database included a field to identify whether a truck tractor involved in a collision was carrying dangerous goods.

[10] It is noted that the reported truck tractor accidents for 2013 was noticeably less than other years. It is uncertain if the accident dataset is incomplete for 2013.

Table 6 shows collision frequencies from 2010 to 2019 by different dangerous goods classifications.

Table 6: Breakdown of Collisions by Dangerous Goods Class (New Brunswick)

Dangerous Goods Class	Frequency of Recorded Collisions Involving Dangerous Goods
Explosives (Class 1)	-
Gases (Class 2)	6
Flammable Liquids (Class 3)	18
Flammable Solids (Class 4)	1
Oxidizing Substances (Class 4)	-
Poisonous and Infectious Substances (Class 6)	-
Radioactive Materials (Class 7)	-
Corrosive Substances (Class 8)	-
Miscellaneous Dangerous Substances (Class 9)	2
Total	27

Table 6 shows that less than 1% of truck tractor collisions in New Brunswick (27 out of 2,972) involved vehicles carrying dangerous goods.

This is consistent with the collisions involving dangerous goods in the Ontario Dataset. None of the recorded truck tractor collisions involved vehicles carrying Class 7 dangerous goods (radioactive materials).

5.1.3 Québec Collision Data

5.1.3.1 Overview of the Québec Dataset

The detailed collision data for the Province of Québec was acquired from the Québec Automobile Insurance Company (SAAQ - Société de l'assurance automobile du Québec) for the years 2010 to 2019, inclusive. In contrast to the Ontario database for provincial highways, the SAAQ data includes all collisions in the province of Québec on different types of roadways, ranging from local to freeway corridors.

Compared to Ontario's collision database, SAAQ data revealed the following constraints:

- The database only included vehicle-level attributes for the first vehicle in a collision, and the attributes for other vehicles involved in the same collision were not available to the project team. The first vehicle was linked to the first physical event of the collision. The vehicle number for other parties was assigned according to the chronological order in which each vehicle was involved in the collision.
- The sequence of event attributes was only available for the first event of the first vehicle. For example, if a vehicle hit a guard rail (event 1), then ran off-road (event 2), and finally came to rest in a ditch (event 3), only the first event (i.e., hitting a guard rail) was reported in the SAAQ dataset. The information for other events and vehicles could not be provided to the project team.
- Information on collision contributing factors, such as driver action and condition, could not be shared with the project team due to privacy laws in Québec.

5.1.3.2 Québec General Statistics

Based on the available data attributes, the number of road collisions included in the SAAQ database is summarized in **Table 7**. The table also provides a breakdown of annual collisions for relevant conveyance types in the SAAQ database, including a) truck tractors and b) heavy vehicles. Heavy vehicles include all heavy-weight vehicles with similar characteristics in the SAAQ database, including truck tractors and light trucks.

Table 7: Annual Road Collisions in the SAAQ Database for Québec by Vehicle Type (2010 to 2019)

Year	Frequency of Collisions (All Vehicles)	Frequency and Percentage of Collisions	
		Involving Truck Tractors*	Involving Heavy Vehicles*
2010	117,734	4,784 (4.1%)	11,013 (9.4%)
2011	113,127	4,861 (4.3%)	10,512 (9.3%)
2012	104,137	4,442 (4.3%)	9,848 (9.5%)
2013	104,868	4,509 (4.3%)	9,960 (9.5%)
2014	97,686	4,111 (4.2%)	9,320 (9.5%)
2015	98,683	4,134 (4.2%)	9,411 (9.5%)
2016	99,877	4,225 (4.2%)	9,688 (9.7%)
2017	102,698	4,585 (4.5%)	10,608 (10.3%)
2018	100,793	4,721 (4.7%)	11,017 (10.9%)
2019	96,878	4,656 (4.8%)	11,497 (11.9%)
Total	1,036,481	45,028 (4.3%)	102,874 (9.9%)

5.1.3.3 Québec Dangerous Goods Data

In contrast to Ontario and New Brunswick, the SAAQ database did not provide a breakdown of the number or the type of dangerous goods carried by trucks in Québec. As such, no information regarding collision frequencies for truck tractors transporting dangerous goods in Québec is included in this report.

In addition to the above, the percentages of collisions involving truck tractors or heavy vehicles were higher in Ontario's database than in the SAAQ database. This could be attributed to the fact that the MTO database only includes collisions on provincial highways, while the SAAQ database is an all-inclusive database, including collisions on provincial and municipal roadways, with less heavy vehicle and truck tractor traffic on municipal roadways and consequently, fewer collisions.

5.1.4 Dangerous Goods Collision Information System

5.1.4.1 Overview of DGAIS Data

Transport Canada (TC) maintains the Dangerous Goods Collision Information System (DGAIS) to track incidents associated with dangerous goods. DGAIS data was obtained for roads across Canada in a spreadsheet format from 2012 to 2021. This database includes attributes such as incident year, date, time, province, city, location, area, longitude/latitude, initiating event (e.g., loss of control, following too closely, improper loading/unloading/handling), weather condition, presence of spill, leak, fire, or explosion, incident severity (i.e., minor moderate, major, severe), dangerous goods class and quantities leaked (if any), and incident narrative.

5.1.4.2 DGAIS General Statistics

For the years 2012 to 2021 inclusive, 1,456 incidents involving dangerous goods were reported by Transport Canada. Of these, 302 incidents were recorded for the provinces of Ontario (177), Québec

(113), and New Brunswick (12). It is noted that the numbers reported in the DGAIS data do not necessarily match the provincial numbers discussed in earlier sections.

A variety of reasons can contribute to such discrepancies, such as differences in collision data recording, data accuracy and coding errors; study period (i.e., 2010 to 2019 for the provincial data vs. 2012 to 2021 for the DGAIS data); study area (e.g., provincial highway in the MTO database vs. all type of roadways in the DGAIS data); and the absence of the type of dangerous goods information in the SAAQ database.

Reviewing the incident narrative revealed that the database includes both in-transit collisions and other types of incidents, such as those that occurred during transport and handling. Of those 302 incidents, one event from 2012 to 2021 was related to Class 7 substances (radioactive materials).

Table 8 describes the subject event. This confirms the assumption that the event tree in this report needs to be based on general transport collision data since radioactive transport collisions are rare, and as such, associated statistics are insufficient to form the basis of a robust statistical study.

Table 8: Description of an Incident Related to the Transportation of Class 7 Materials in Ontario

Incident Date	Location	Spill, Leak, Fire, or Explosion	Weather Condition	Incident Narrative
Jan 7, 2018	Highway 17, Sault Ste. Marie	No release / anticipated release	Ice and snow buildup	While carrying radioactive material, the driver of a tractor-trailer, while attempting to go around another tractor-trailer, the side wall caught on the corner of the other truck. The collision is due to winter snowing road conditions. There was no release of radioactive material, injuries, or evacuation, and the highway was closed.

5.1.4.3 DGAIS Dangerous Goods Data

Table 9 further summarizes the total events reported by Transport Canada for the provinces of Ontario, Québec, and New Brunswick involving different dangerous goods classifications.

Table 9: Breakdown of Incidents by Dangerous Goods Class (Transport Canada Database)

Dangerous Goods Class	Province			Total
	Ontario	Québec	New Brunswick	
Explosives (Class 1)	5 (2.8%)	11 (9.7%)	0 (0%)	16 (5.3%)
Gases (Class 2)	54 (30.5%)	31 (27.4%)	6 (50%)	91 (30.1%)
Flammable Liquids (Class 3)	74 (41.8%)	39 (34.5%)	2 (16.7%)	115 (38.1%)
Flammable Solids (Class 4)	0 (0%)	1 (0.9%)	0 (0%)	1 (0.3%)
Oxidizing Substances (Class 5)	9 (5.1%)	6 (5.3%)	0 (0%)	15 (5%)
Poisonous and Infectious Substances (Class 6)	1 (0.6%)	1 (0.9%)	1 (8.3%)	3 (1%)
Radioactive Materials (Class 7)	1 (0.6%)	0 (0%)	0 (0%)	1 (0.3%)
Corrosive Substances (Class 8)	25 (14.1%)	14 (12.4%)	3 (25%)	42 (13.9%)
Miscellaneous Dangerous Substances (Class 9)	5 (2.8%)	2 (1.8%)	0 (0%)	7 (2.3%)
Not Available (blank cell)	3 (1.7%)	8 (7.1%)	0 (0%)	11 (3.6%)
Total	177 (100%)	113 (100%)	12 (100%)	302 (100%)

Table 9 shows that most of the incidents involving dangerous goods in Ontario and Québec were associated with gases (Class 2) and flammable liquids (Class 3), followed by corrosive substances (Class 8).

The only Class 7 incident from 2012 to 2021 was recorded in Ontario, with the incident described in **Table 8**. In New Brunswick, the frequency of incidents involving dangerous goods was noticeably lower than in the other two provinces, with 6 out of 12 incidents labelled as gases (Class 2).

5.1.5 Canadian Nuclear Safety Commission Data

5.1.5.1 Overview of CNSC Data

The Canadian Nuclear Safety Commission (CNSC) regulates the use of nuclear energy and materials to protect public health, safety, security, and the environment. The CNSC maintains an Event Information and Tracking System (EITS) in which accidents, which may or may not be motor vehicle collisions, involving radioactive materials are reported.

In support of the current assessment, the CNSC made available data from EITS covering the years 2000 to 2022 inclusive.

The CNSC database includes but is not limited to the following attributes:

- Date Occurred.
- Event Description, which provides a brief description of the recorded event.
- Packaging Type (e.g., Type B).
- Transport Method (i.e., Road, Rail, Air, Marine, or blank).
- Transport Issue Phase(s) (i.e., During Transport, During Handling, In Transit, or blank). Up to two transport issue phases could be reported for each collision.
- Issue(s) (i.e., Content is Damaged, Improper Packaging, Improper Safety Marks/Labels, Loss of Contents, Signs of Damage, Signs of Tampering, Documentation, Package, Motor Vehicle Accident (MVA), Misrouting, Contaminated, or blank). Up to three issues could be reported for each event.

5.1.5.2 CNSC General Statistics

Between 2000 and 2022, 492 incidents were reported by CNSC, out of which 58 involved Type B transportation packages. Further descriptions of those 58 incidents are provided below:

- A review of the “Event Description” attribute in the CNSC database revealed that approximately 77% of these incidents (45 out of 58) pertained to motor vehicle accidents where the package did not showcase any signs of damage.
- Of the remaining incidents, approximately 21% (12 out of 58) pertained to superficial or minor damage on the surface of the package (i.e., package dropped during handling at an airport).
- There was one recorded instance out of 58 incidents of contamination found on the surface of a package during handling.
- There were found to be no recorded Type B package incidents where a loss of content took place. Similarly, there were no recorded incidents of improper packaging, damaged contents, misrouting, or package loss.

In contrast to the detailed collision datasets in Ontario, Québec, and New Brunswick, the CNSC database did not encompass vehicle type, collision type, sequence of events, contributing factors, vehicle damage severity, an object struck, etc., which are required to create the collision probabilities that are the subject of this report.

Other limitations associated with the CNSC database include a lack of total number of shipments in any given year, the shipment percentage for each package type, and events that may go unreported.

5.2 Train Collision Dataset

5.2.1 Transportation Safety Board Data

5.2.1.1 Overview of TSB Data

In Canada, the Transportation Safety Board of Canada (TSB) has been publishing reportable rail 'collisions' and 'incidents' from its Rail Occurrence Database System (RODS) since 1983. Collisions and incidents, which are called occurrences, were reported in accordance with the TSB Regulations that were in effect at the time of the occurrence.

The TSB database was considered the only source of information about train collisions in Canada that could be utilized to calculate probabilities. The details of the historical occurrences are available on the TSB website [24].

The TSB database includes the following relevant attributes. The options available for each of the attributes are presented in brackets.

- Occurrence number
- Occurrence year
- Occurrence date
- Occurrence type (i.e., collision or incident)
- Occurrence description (i.e., main-track train collision, non-main-track train collisions, passenger, trespasser, employee, crossing, a collision involving track unit, rolling stock collision with an abandoned vehicle, rolling stock collision with an object, rolling stock damaged without derailment/collision, fire, explosion, main-track train derailment, non-main-track train derailment)
- Province
- Subdivision name, mileage and owner
- Type of track (i.e., main, yard, other, or left blank)
- Impact type (i.e., struck by a vehicle, struck vehicle, struck pedestrian, or blank)
- Weather conditions at the time of the occurrence (i.e., freezing rain, hail, rain, snow, or blank)
- Light condition (i.e., dawn, daylight, dusk, night, tunnel, or blank)
- Surface condition (i.e., dry, frozen, snow, wet, or blank)
- Derailment occurrence (i.e., yes, or no)
- Dangerous goods involvement (i.e., yes, or no) and the type of dangerous goods
- Dangerous goods released (i.e., yes, or no)
- Fire (i.e., yes, or no)
- Explosion (i.e., yes, or no)
- Total fatalities, serious injuries, and minor injuries, if any

5.2.1.2 TSB General Statistics

During the time period 2010 – 2019, 11,013 collisions were listed in the TSB database.

Table 10 provides a summary of annual train collisions, including the frequency and percentage of collisions involving dangerous goods. It is noted that the classification of dangerous goods is not reported in this database.

Table 10: Annual Train Collisions in the TSB Database

Year	Frequency of Train Collisions	Frequency of Train Collisions Involving	
		Dangerous Goods*	Released Dangerous Goods
2010	1,160	173 (15%)	3
2011	1,077	123 (11%)	2
2012	1,065	121 (11%)	2
2013	1,112	152 (14%)	17
2014	1,084	163 (15%)	4
2015	1,066	131 (12%)	5
2016	916	104 (11%)	1
2017	1,102	118 (11%)	5
2018	1,174	124 (11%)	2
2019	1,257	169 (13%)	7
Total	11,013	1,378 (13%)	48

* The percentages noted in brackets represent the proportion of collisions compared to the total number of collisions in the second column

While the TSB database indicates that train collisions involving the release of dangerous goods do occur, it was found that the likelihood of such occurrences was less than 0.5% (48 out of 11,013 train collisions). **Section 6.2.2 Train Collisions** of this report further analyzes collision attributes for train movements.

5.3 Summary of Collision Datasets

Section 5 Collision Datasets and General Statistics of this report provided an overview and general statistics of available collision datasets. For truck movement, the Ontario, Québec, and New Brunswick datasets encompassed information on vehicle type, collision type, object struck, etc., which was required to create the collision probabilities that are the subject of this report. As such, the Ontario, Québec, and New Brunswick datasets were carried forward for further analysis and identification of collision attributes; for further detail, refer to **Section 6 Collision Types and Attributes**.

In contrast, the DGAIS and CNSC datasets provided generic collision statistics and did not contain detailed information needed to create event trees.

For train movements, the TSB database was considered to be a comprehensive source of information containing sufficient data for creating the train event tree and calculating collision probabilities.

6 Collision Types and Attributes

The objective of this section is to provide a detailed breakdown of the collision statistics, contributing factors and identify the preferred datasets for the development of event trees and the calculation of the probabilities.

This section is structured as follows:

- **Section 6.1 Categories of Collision Types** summarizes categories of collision types for truck and train movements, including the first set of branches following the initiating event, and provides an overview of the collision attributes in the selected datasets, i.e., Ontario, Québec, and New Brunswick datasets for truck tractors and TSB database for train.
- **Section 6.2 Collision Attributes** presents the selected collision data for truck tractor and train movements, broken down into various categories to better illustrate the nature of incidents within the study period.
- **Section 6.3 Collision Contributing Factors** summarizes the collision contributing factors, which can be utilized to select screening criteria and form the basis of the subsequent probabilistic assessment.
- **Section 6.4 Usability of Collision Datasets** provides justifications for selecting the preferred dataset for identification of screening criteria, development of event trees and the calculation of the probabilities.

6.1 Categories of Collision Types

Following the initial overview of available datasets as outlined in **Section 5 Collision Datasets and General Statistics**, a more thorough breakdown of the collision statistics could be conducted. In anticipation of the formal event tree analysis, this breakdown allows for a better understanding of the collision attributes derived from the datasets. In turn, this allows for the refinement of screening criteria, as applicable, and leads to more concise event tree outputs. This process starts with the identification of collision types for road and rail movements, as discussed below.

6.1.1 Road Categories

A review of the published literature revealed that the first set of branches following the initiating event, such as truck tractor collisions, can be represented by the following four types of collisions:

- Collisions with non-fixed objects (e.g., collision with another moving vehicle);
- Collisions with fixed objects (e.g., impact with hard rock or infrastructure);
- Non-collision incidents (i.e., single-vehicle collision without colliding with any objects, such as run off-road, rollover, fire, explosion, jack-knife); and
- Other events, which is comprised a small proportion of truck tractor collisions with no further information regarding the sequence of events or objects struck.

The above-noted collision types were found to be represented as the “sequence of events” attributes in relevant datasets and discussed in detail in **Section 6.2.1.1 Sequence of Events**.

As noted in **Section 5 Collision Datasets and General Statistics**, the sequence of events was only available for the first event of the first vehicle in the Québec dataset. The absence of such critical information in the Québec dataset would create limitations in utilizing these resources to calculate collision probabilities.

This is further discussed in **Section 6.4 Usability of Collision Datasets** of the report.

In addition to the sequence of events, the information from the selected three datasets from Ontario, Québec, and New Brunswick can be further broken down into the following categories. **Section 6.2 Collision Attributes** summarizes the collision attributes for each of these categories.

- Impact type (**Section 6.2.1.2 Impact Type**)
- Collision severity (**Section 6.2.1.3 Collision Severity**)
- Weather condition (**Section 6.2.1.4 Weather Condition**)
- Road surface condition (**Section 6.2.1.5 Road Surface Condition**)
- Lighting condition (**Section 6.2.1.6 Lighting Condition**)
- Vehicle damage level (**Section 6.2.1.7 Vehicle Damage Level**)
- Driver action (**Section 6.2.1.8 Driver Action**)
- Driver condition (**Section 6.2.1.9 Driver Condition**)

Other categories of interest, such as collisions with bridge structures, run-off roads, or incidents in icy/snow-packed surface conditions that might be an interest to communities and members of the public are discussed in **Section 10.3 Emerging Themes of Interest**.

6.1.2 Rail Categories

For train movements, the published literature divided the first set of event tree branches based on the following two derailment categories [8] [7]:

- Train remains on the rail track; and
- Train derails from the rail track.

It is noted that the above train derailment status can be extracted from the TSB dataset.

In addition to the above-noted collision types, further information was available in the selected datasets for truck and train movements, which assists in creating the collision event trees. This information is discussed in the following sub-sections.

Similar to truck movements, the TSB train database can be further broken down into the following categories:

- Province of occurrence (**Section 6.2.2.1 Province of Occurrence**)
- Derailment scenario (**Section 6.2.2.2 Derailment Scenario**)
- Description of collision (**Section 6.2.2.3 Description of Collision**)
- Collision severity (**Section 6.2.2.4 Collision Severity**)
- Type of shipment (**Section 6.2.2.5 Type of Shipment**)
- Weather condition (**Section 6.2.2.6 Weather Condition**)
- Surface condition (**Section 6.2.2.7 Surface Condition**)
- Light condition (**Section 6.2.2.8 Lighting Condition**)

6.2 Collision Attributes

6.2.1 Truck Collisions

The following sections present the selected collision data in Ontario, Québec, and New Brunswick, broken down into various categories to better illustrate the nature of incidents from 2010 to 2019.

6.2.1.1 Sequence of Events

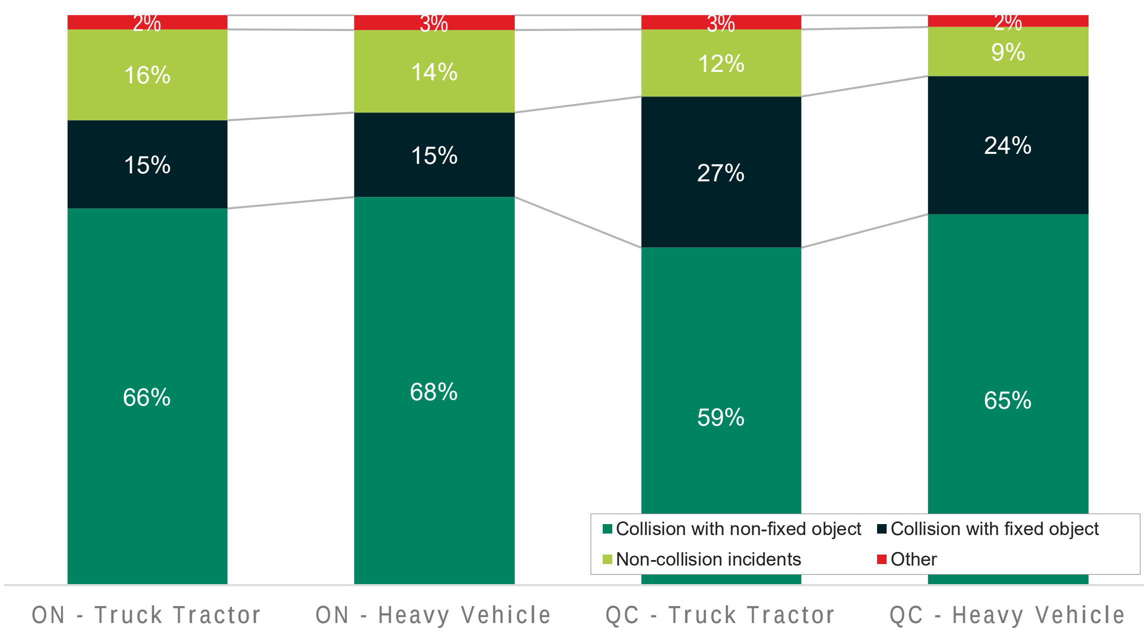
Figure 6 shows the proportion of collisions by the sequence of events, namely collisions with fixed objects, collisions with non-fixed objects, non-collision incidents, and other events. The detailed list of options for each of these collision types is summarized below:

- **Collisions with non-fixed objects**: collision with a train, other motor vehicles, streetcar, farm tractor, other moveable objects, pedestrian, cyclist, animal-domestic, animal-wild.
- **Collisions with fixed objects**: bridge support, building/wall, unattended vehicle, culvert, watercourse, tree/shrub/stump, pole-utility, pole-sign/park meter, submersion, curb, fence/noise barrier, cable guide rail, concrete guide rail, steel guide rail, crash cushion, construction marker, debris on the road, debris off a vehicle, other fixed object, rock face, snow pile, ditch.
- **Non-collision incidents**: fire/explosion, load spill, skidding/sliding, ran off the road, rollover, jack knifing.

The 'other event' category consists of a small proportion of all incidents involving truck tractors for which no further details regarding the sequence of events were provided in the available datasets.

It is noted that initially, the dataset obtained from the Government of New Brunswick did not include attributes related to the sequence of events and vehicle damage level, as reported in Ontario's database. An updated database was later made available, which included the sequence of event data but not vehicle damage level due to the method through which this attribute is estimated in New Brunswick. As such, the attributes related to the sequence of events were not reported for New Brunswick.

Figure 6 Proportion of Truck Tractor and Heavy Vehicle Collisions by Sequence of Events



As shown in **Figure 6**, the majority of truck tractor and heavy vehicle incidents were with non-fixed objects, such as another moving vehicle. As noted earlier, the sequence of events for the Québec dataset was only available for the first event of the first vehicle.

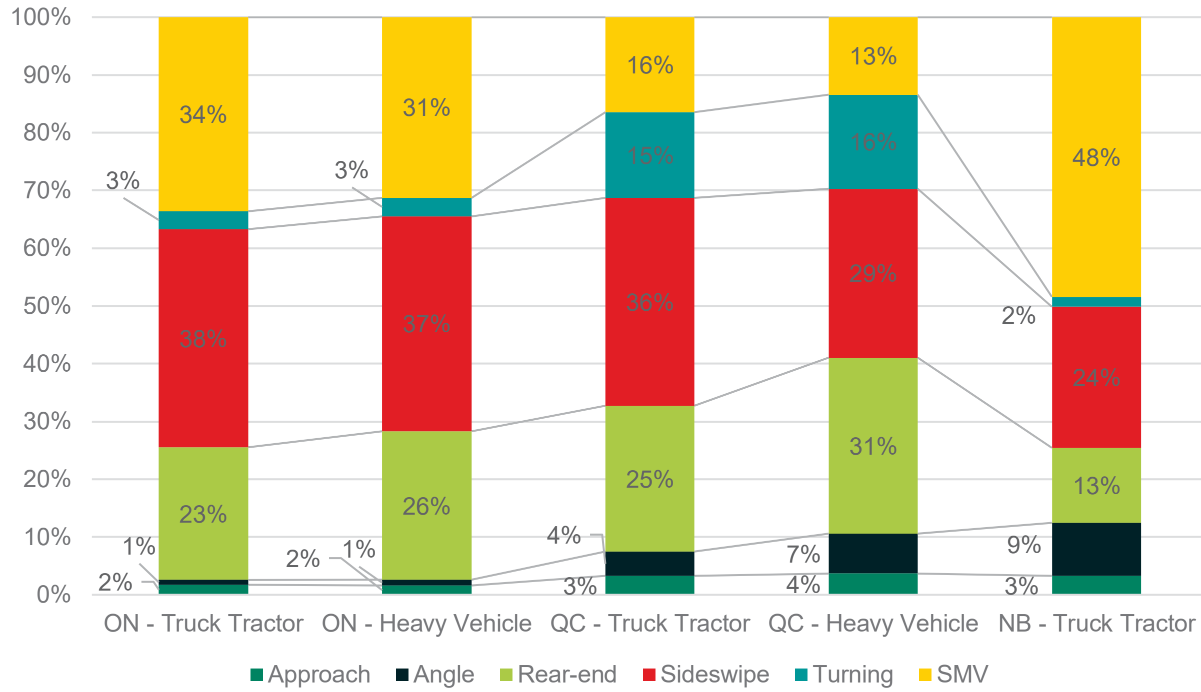
As such, the breakdown of collision data in Québec should be interpreted cautiously.

6.2.1.2 Impact Type

The impact type describes the general path of the vehicle(s) immediately before the first impact, including rear-end, sideswipe, turning, angle, approaching, and Single Motor Vehicle (SMV) collision.

As shown in **Figure 7**, the most common collision impact types for truck tractors and heavy vehicles were sideswipe and SMV, followed by rear-end incidents in all three provinces.

Figure 7: Percentage of Truck Tractor and Heavy Vehicle Collisions by Impact Type

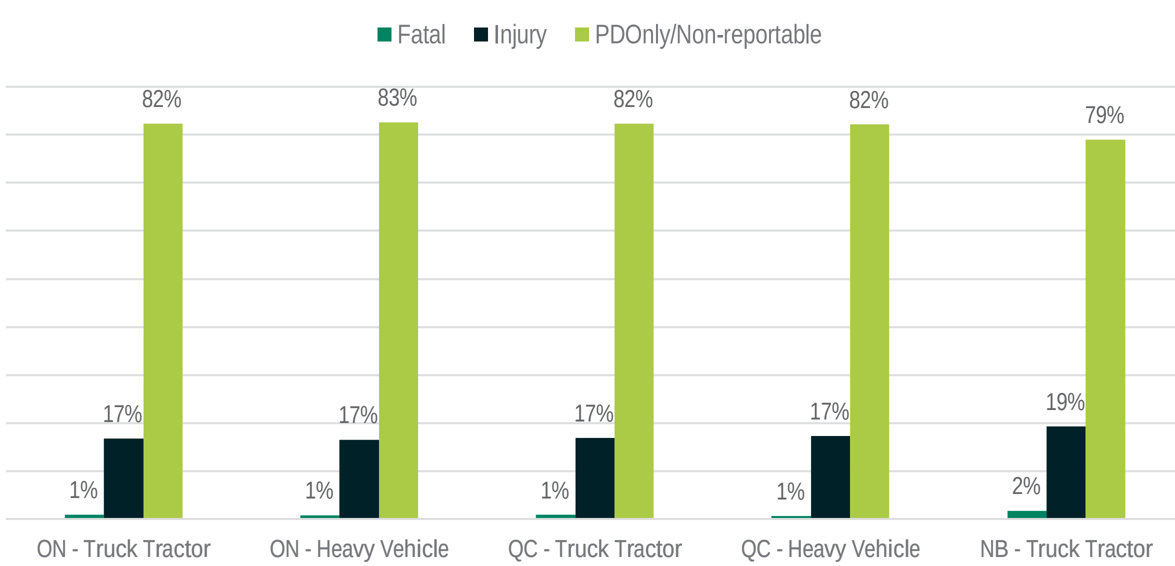


6.2.1.3 Collision Severity

During the study period from 2010 to 2019, 82% of collisions involving truck tractors in Ontario (31,534 out of 38,296 collisions) resulted in Property Damage Only (PDO), approximately 17% (6,405 collisions) resulted in injuries, and less than 1% (357 collisions) resulted in fatalities.

Figure 8 shows that the proportions of collision severities in Québec and New Brunswick were found to be similar to Ontario, with over 79% of collisions resulting in PDO, without any injuries or fatalities. Similar observations were noted for heavy vehicles.

Figure 8: Percentage of Truck Tractor and Heavy Vehicle Collision Severities



6.2.1.4 Weather Condition

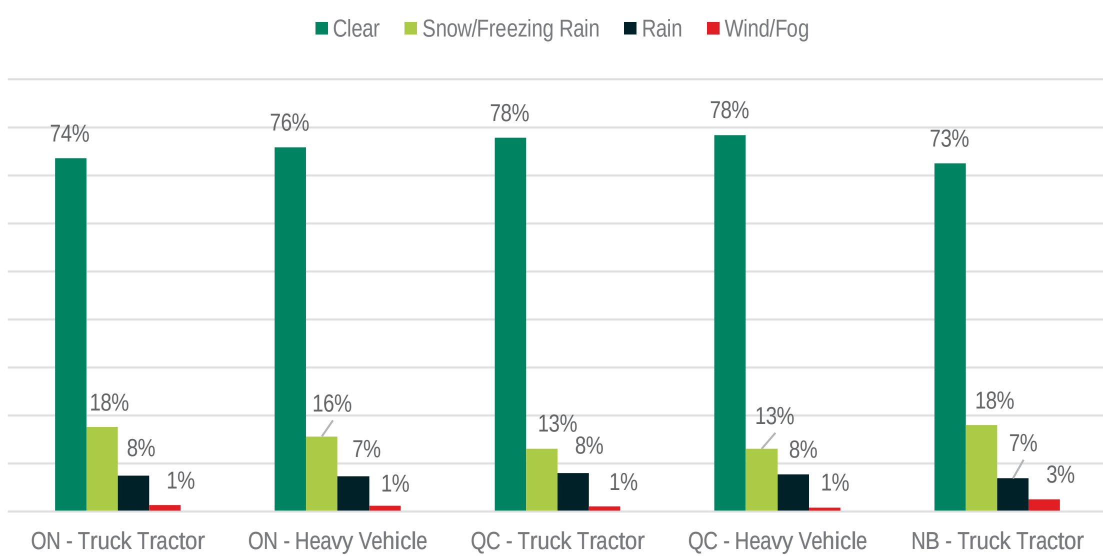
Figure 9 shows the proportion of collisions by weather conditions. For simplicity of reporting, similar weather conditions were grouped as follows:

- Snow, freezing rain, and drifting snow were grouped and labelled as "Snow/Freezing Rain/Drifting Snow."
- Wind and fog were grouped and labelled as "Wind/Fog."

Most collisions involving truck tractors and heavy vehicles in different provinces occurred during clear weather conditions.

The proportion of truck tractor collisions during snow/freezing rain was higher in Ontario and New Brunswick (18%) compared to the Québec statistics (13%), while similar percentages across the board were observed for collisions during rainy weather conditions (7% to 8%). Similar observations were noted for incidents involving heavy vehicles.

Figure 9: Percentage of Truck Tractor and Heavy Vehicle Collisions by Weather Condition



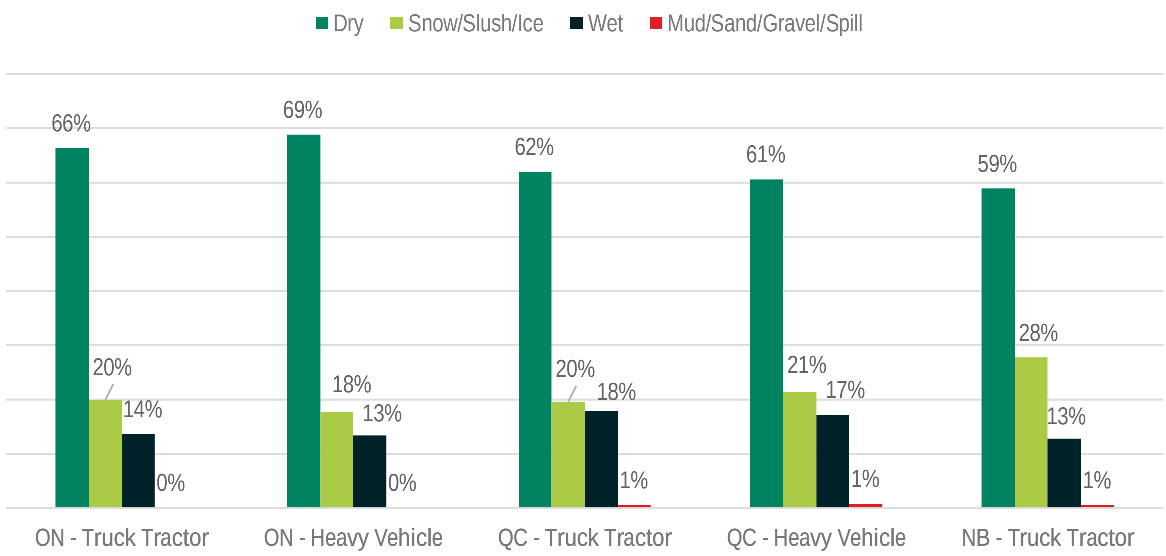
6.2.1.5 Road Surface Condition

Figure 10 shows the proportion of collisions by road surface type. Like weather conditions, similar road surface conditions were grouped as follows:

- Loose snow, slush, packed snow, and ice were grouped and labelled as "Snow/Slush/Ice."
- Mud, sand/gravel, and spill were grouped and labelled as "Mud/Sand/Gravel/Spill."

Approximately 20% of collisions involving truck tractors in in Ontario and Québec occurred under snow, slush, or ice surface conditions. In New Brunswick, this proportion of collisions in Snow/Slush/Ice was higher compared to Ontario and Québec.

Figure 10: Percentage of Truck Tractor and Heavy Vehicle Collisions by Road Surface Condition



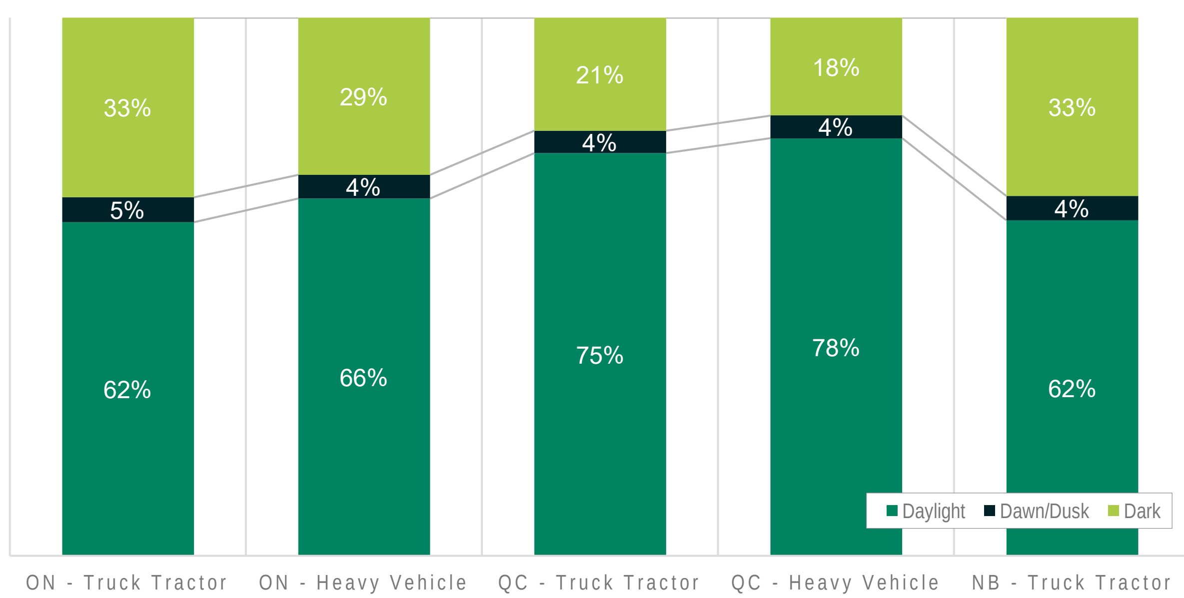
6.2.1.6 Lighting Condition

Figure 11 shows the proportion of collisions by lighting conditions. For simplicity of reporting, similar lighting conditions were grouped as follows:

- Daylight and artificial daylight were grouped and labelled as “Daylight.”
- Dawn, artificial dawn, dust, and artificial dusk were grouped and labelled as “Dawn/Dusk.”
- Dark and artificial dark were grouped and labelled as “Dark.”

The majority of truck tractor and heavy vehicle collisions occurred during daylight. In addition, concerning lighting conditions, the proportion of collisions involving truck tractors followed a similar pattern for Ontario and New Brunswick.

Figure 11: Proportion of Truck Tractor and Heavy Vehicle Collisions by Lighting Condition



6.2.1.7 Vehicle Damage Level

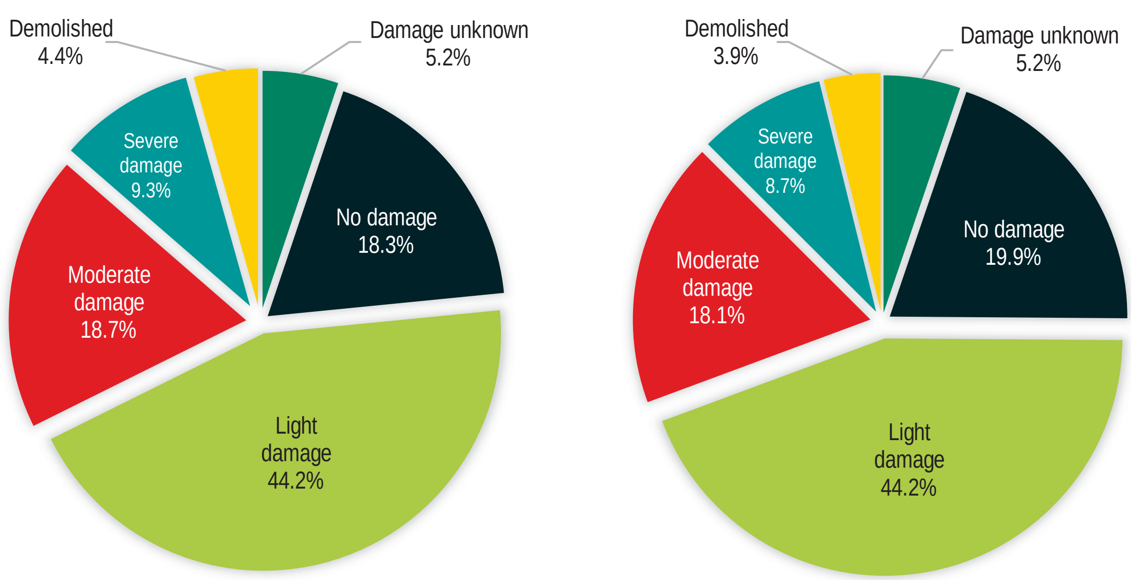
As noted earlier, the vehicle damage level was only available in the MTO's dataset for Ontario. In this database, the vehicle damage level is defined as follows:

- *No damage:* no visible damage to the vehicle involved in a collision.
- *Light damage:* slight or superficial damage. This includes scratches, small dents or minor cracks that do not affect the safety or performance of the vehicle.
- *Moderate damage:* the vehicle must be repaired to make its condition meet the requirements of the law. The vehicle can be driven, but doing so is unsafe.
- *Severe damage:* vehicle cannot be driven and requires towing. The vehicle would normally require repair as a result of the collision.
- *Demolished: the* vehicle was damaged to the extent that repairs would not be feasible.
- *Damage unknown:* this field represents a small proportion of collisions for which the vehicle damage was not recorded.

Figure 12 shows the proportion of truck tractor and heavy vehicle collisions by vehicle damage severity level. As shown in this figure, most collisions resulted in either light damage (44.2%) or no damage (18.3%) to the truck tractor.

It is noted that only 4.4% of truck tractors were demolished as a result of a collision in Ontario's highway network from 2010 to 2019. Similar observations were noted for heavy vehicles.

Figure 12: Proportion of Truck Tractor and Heavy Vehicle Collisions in ON by Vehicle Damage Level



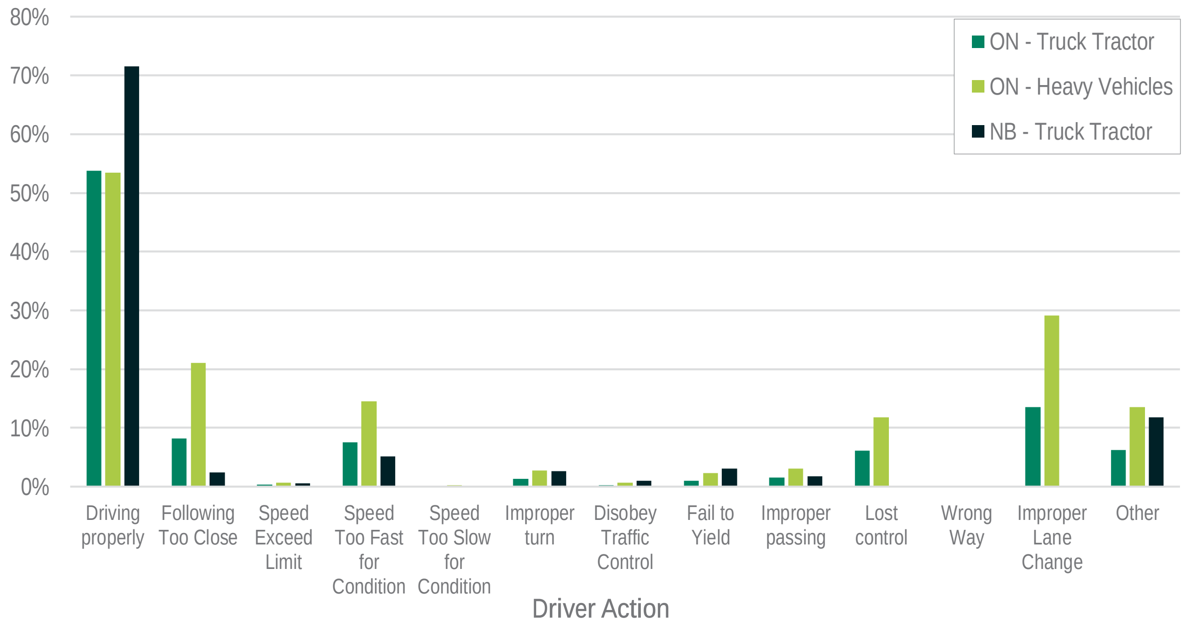
a) Truck Tractor b) Heavy Vehicles

6.2.1.8 Driver Action

Each driver's action immediately before an incident is recorded as driver action in the Ontario and New Brunswick datasets. This information is not available in the Québec dataset due to privacy laws.

As shown in **Figure 13**, the majority of truck tractor and heavy vehicle drivers involved in collisions were driving properly.

Figure 13: Proportion of Truck Tractor and Heavy Vehicle Collisions by Driver Action



Among those drivers that were driving improperly, most of the contributing factors for incidents involving truck tractors in Ontario were improper lane changes (14%), following too closely (8%), and speed too fast for condition (8%).

Similarly, for heavy vehicles, improper lane change (29%) constituted most of the driver actions in improper driving scenarios, followed by following too closely (21%), speed too fast for conditions (14%), and lost control (12%).

It is noted that a fraction of driver actions was coded as 'other' in Ontario (6% for truck tractor and 14% for heavy vehicles) and New Brunswick (12%), with no further details provided in the datasets.

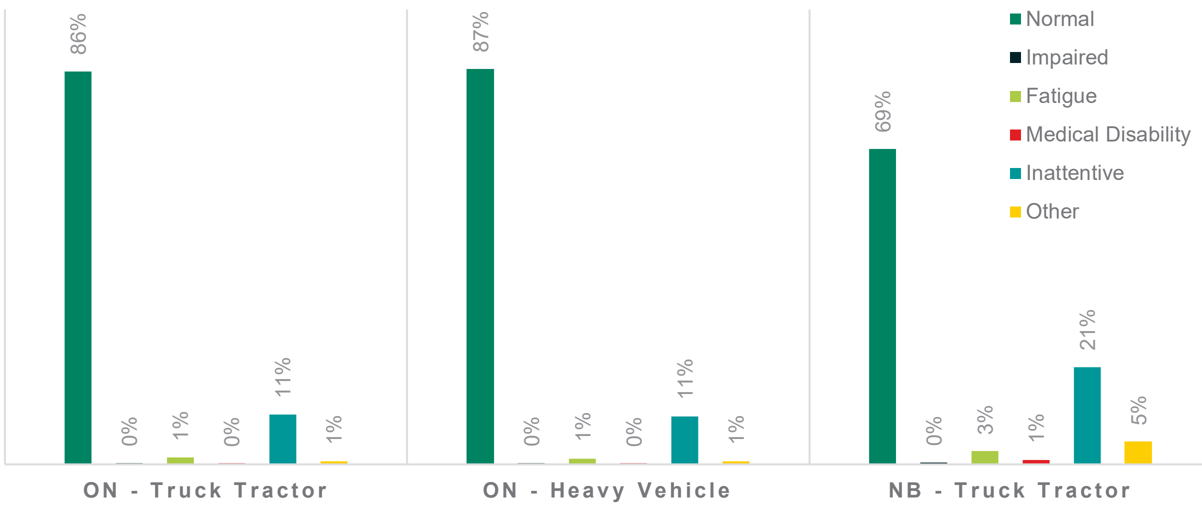
6.2.1.9 Driver Condition

Like driver action, the driver condition attribute was available in the Ontario and New Brunswick datasets, but not available in Québec dataset due to privacy laws.

For simplicity of reporting, similar driver conditions were grouped as follows:

- 'Ability Impaired, Alcohol (over 0.08)',
- 'Ability Impaired, Alcohol,'
- 'Had Been Drinking' and 'Ability Impaired, Drugs' were grouped together and labelled as "Impaired.

Figure 14: Proportion of Truck Tractor and Heavy Vehicle Collisions by Driver Condition



As expected, the driver condition of the majority of truck tractor drivers before the incident was coded as 'normal' (approximately 86% in Ontario and 69% in New Brunswick) shown in **Figure 14.**

As noted, driver inattentiveness was a major contributing factor for incidents involving truck tractors in Ontario (11% of drivers) and New Brunswick (21%). Other factors include fatigue (1% in Ontario and 3% in New Brunswick). Similar observations were noted for heavy vehicles.

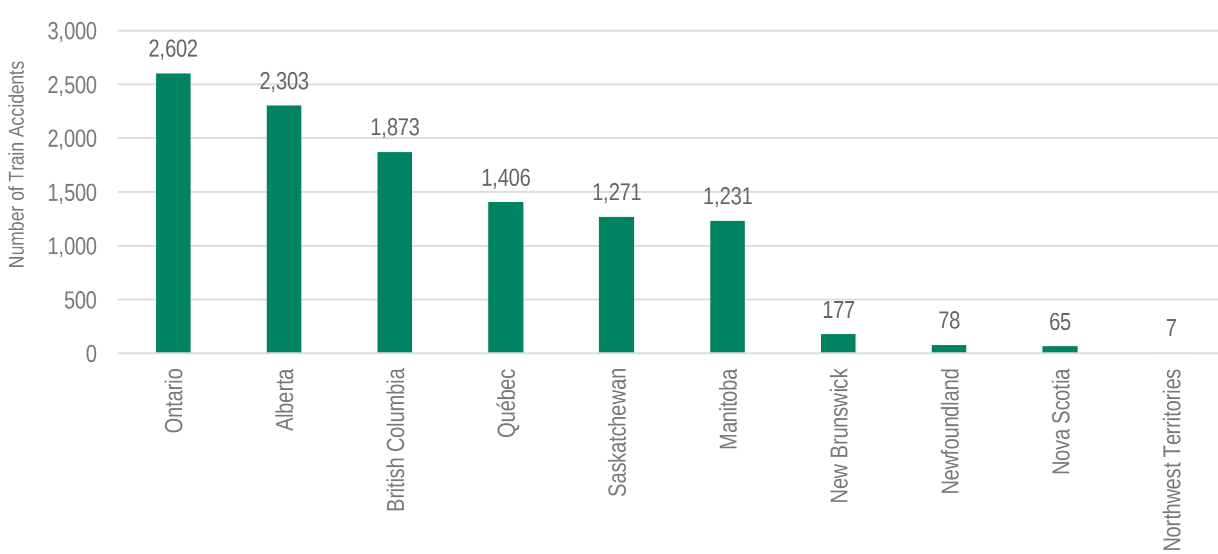
It is noted that a fraction of driver actions was coded as 'other' in Ontario (1%) and New Brunswick (5%) with no further details provided in the datasets.

6.2.2 Train Collisions

6.2.2.1 Province of Occurrence

Figure 15 shows the frequency of train incidents in different provinces and territories in Canada. As shown in this figure, the majority of train collisions occurred in Ontario (24%), followed by Alberta (21%) and British Columbia (17%).

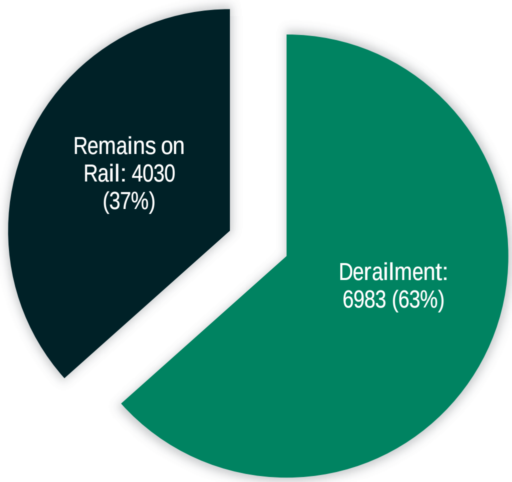
Figure 15: Frequency of Train Collisions in Canada



6.2.2.2 Derailment Scenario

According to the TSB's data dictionary, derailment is defined as any instance where one or more wheels of rolling stock have come off the normal running surface of the rail, including occurrences where there are no injuries and no damage to the track or equipment. As shown in **Figure 16**, most of the train collisions involved derailments (63%).

Figure 16: Proportion of Train Collisions by Derailment Scenario



6.2.2.3 Description of Collision

The description of the collision is one of the main attributes of the TSB database and includes a variety of information, ranging from the location of the incident (such as a railway crossing), to the object struck (such as a rolling stock collision with an abandoned vehicle).

The first set of branches were aligned to the derailment scenario discussed above, and information in the description of the collision attribute was used to create a second set of branches. As such, separate figures (**Figure 17** and **Figure 18**) were created to illustrate the frequency and percentage of collisions under each derailment scenario.

Figure 17: Frequency and Proportion of Train Collisions (Description - Derailment Scenario)

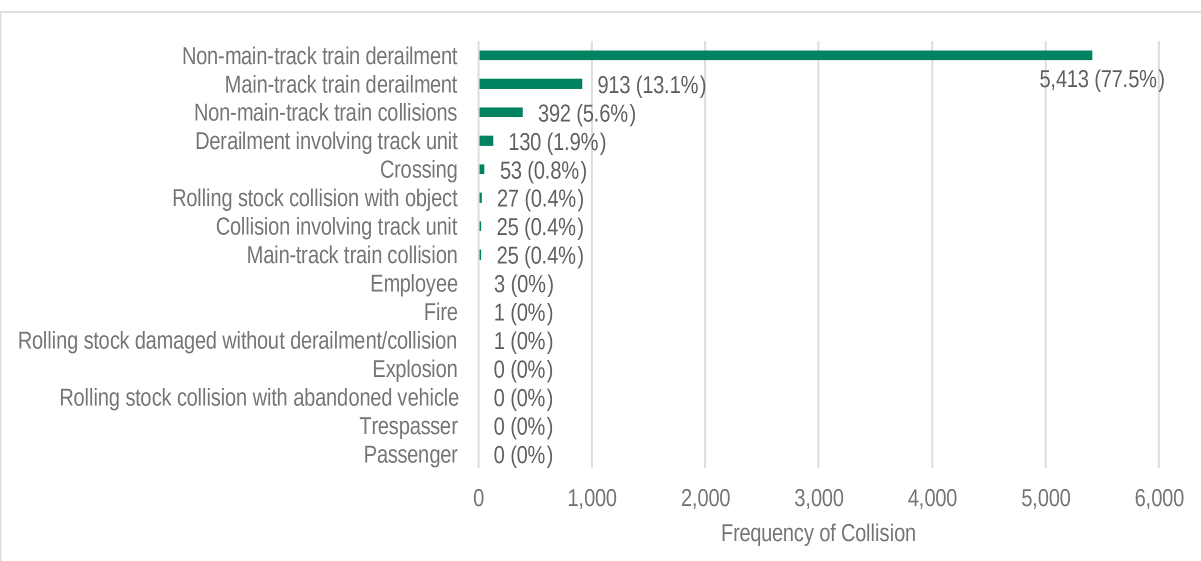
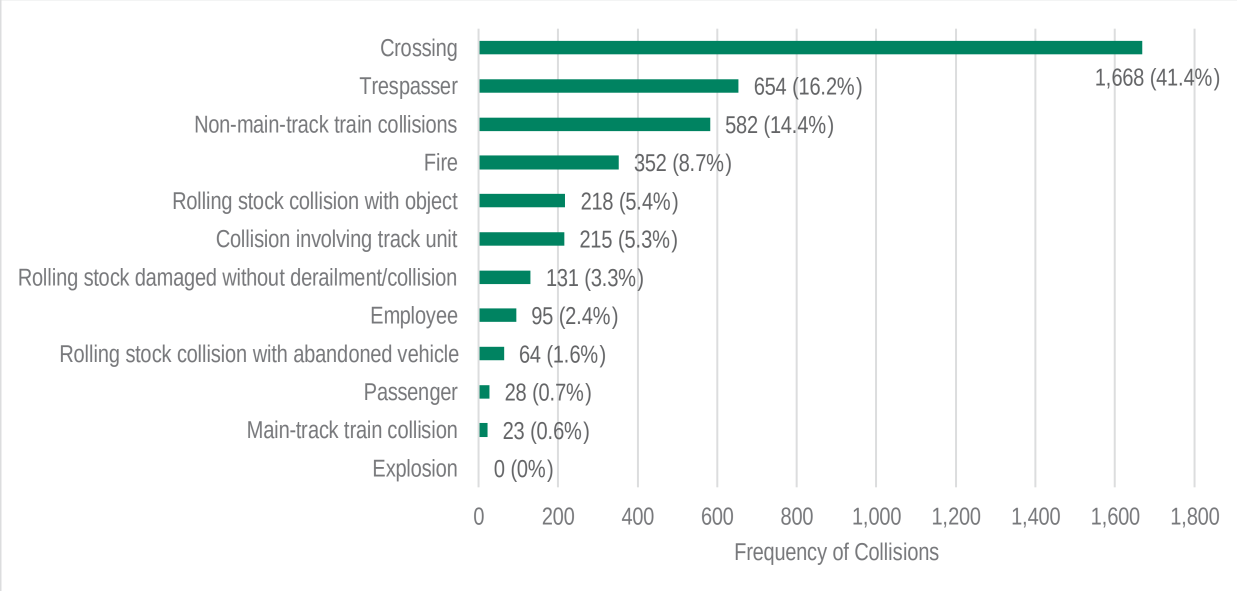


Figure 18: Frequency and Proportion of Train Collisions (Description - Remain on Track Scenario)

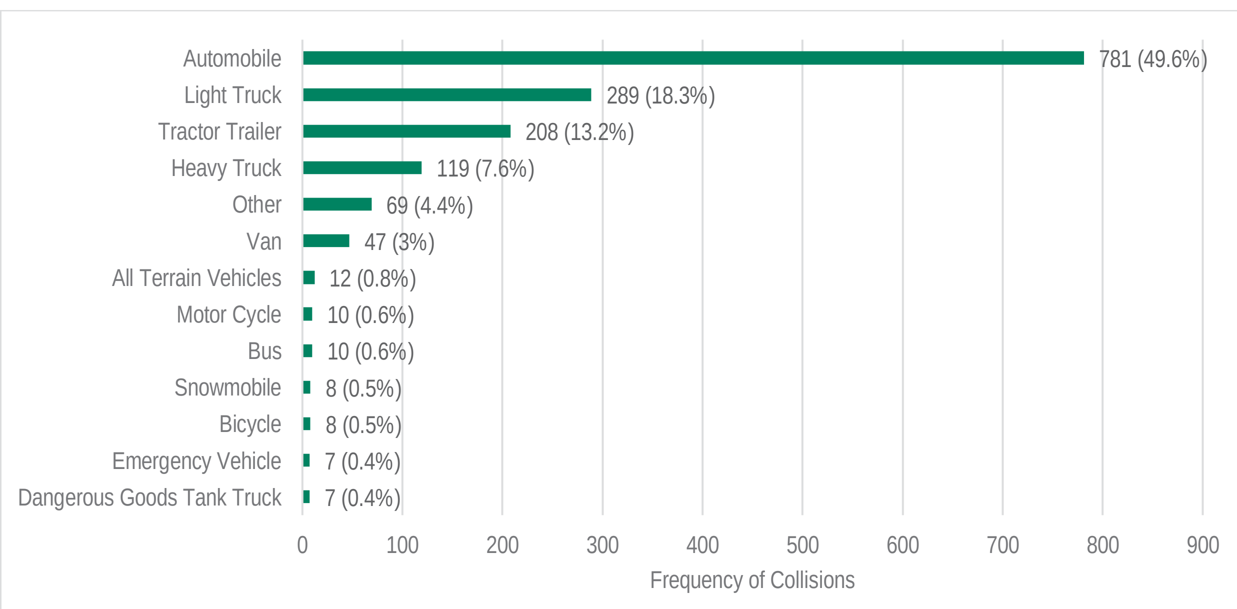


For the derailment scenario, more than 77% of collisions were coded as "non-main track train derailment", followed by "main-track train derailment" and "non-main-track train collision".

As shown in **Figure 18**, incidents at railway grade crossings were the most frequent description of collisions reported in the TSB database for those scenarios when the train remained on the railway track. Out of 1,668 incidents at the crossing, the train collided with a vehicle for 1,522 instances, representing more than 91% of collisions at grade crossings. The train struck a pedestrian at a crossing for the remaining 146 incidents (8.8%).

Figure 19 shows that out of 1,575 train collisions with another vehicle at railway crossings, in most cases, the train collided with a passenger vehicle (49.6%), followed by light trucks (18.3%) and tractor-trailers (referred to herein as truck tractors) (13.2%). For 1,522 out of 1,575 train collisions with another vehicle at railway crossings, the train remained on track, while the remaining 53 incidents resulted in train derailment. See **Figure 17**.

Figure 19: Frequency and Proportion of Train Collisions at Crossings by Vehicle Type

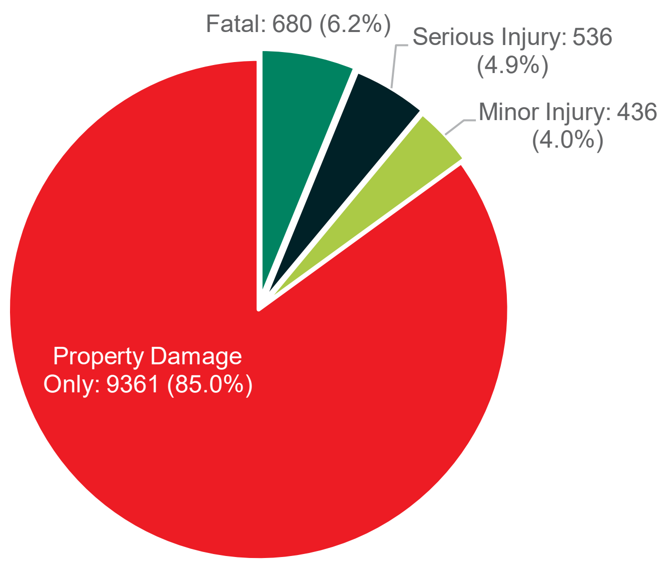


Specifically, for the 208 train collisions with tractor trailers (referred herein as truck tractors) at railway crossings, most of incidents occurred in Alberta (72 collisions or approximately 35%) followed by Saskatchewan (52 collisions or 25%), and only 26 (13%), 19 (9%), and 4 (2%) of incidents occurred in Québec, Ontario, and New Brunswick, respectively.

6.2.2.4 Collision Severity

During the study period from 2010 to 2019, 85% of train collisions (9,361 out of 11,013 collisions) resulted in property damage only and did not result in any fatalities or injuries. **Figure 20** shows a total of 680 fatal collisions during the study period, representing approximately 6% of train collisions. Serious injury collisions accounted for approximately 5% of collisions, followed by 4% of minor injury incidents.

Figure 20: Frequency and Proportion of Train Collisions by Collision Severity



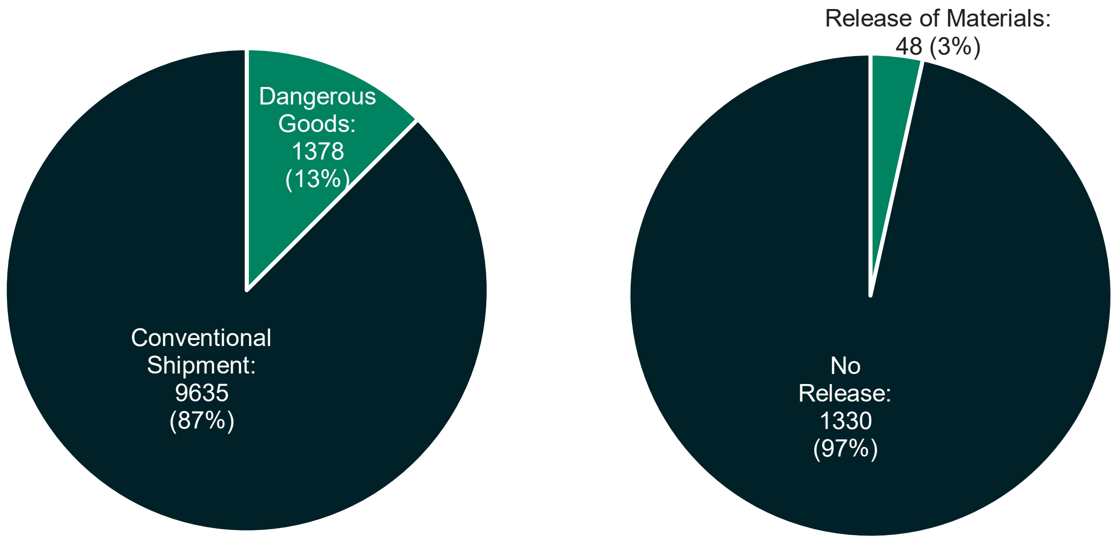
6.2.2.5 Type of Shipment

The TSB database includes a field to indicate whether a train collision included car(s) carrying dangerous goods materials and whether the incident resulted in releasing such materials.

However, the type of dangerous goods, including whether the train incident involved radioactive materials, is not specified in the TSB dataset.

Figure 21a shows 1,378 out of 11,013 train collisions, or approximately 13% of total collisions, involved trains carrying dangerous goods. Out of those 1,378 collisions, 48 (less than 4%) collisions resulted in the release of dangerous goods, as shown in **Figure 21b**. It is noted that no further breakdown of the type of dangerous goods involved in these collisions was available in the TSB database.

Figure 21: Proportion of Train Collisions Involving Dangerous Goods and Release of Materials



a) Type of shipment

b) Release of dangerous goods

6.2.2.6 Weather Condition

In contrast to road vehicle data from the Ontario dataset, the detailed weather condition attributes were only reported for less than 2% of train collisions across Canada. As such, any observations from the available weather conditions would be inconclusive.

Out of 194 incidents with reported weather conditions, 107 or 55% of train collisions occurred during ‘snow’. This was followed by ‘rain’ (74 out of 194 or 38%), ‘freezing rain’ (11 out of 194 or 6%), and ‘hail’ (2 out of 194 or 1%).

6.2.2.7 Surface Condition

Like weather conditions, the information on the surface condition was only available for less than 1% of train collisions. Out of 97 incidents with available data, 37 or 38% of train collisions occurred during ‘dry’ surface, followed by ‘frozen’ (21 out of 97, or 22%), ‘wet’ (21 out of 97, or 22%), and ‘snow’ (18 out of 97, or 19%).

In the absence of a complete dataset, the collision attributes for the surface condition should be interpreted with caution.

6.2.2.8 Lighting Condition

Lighting condition was reported for 896 incidents, representing approximately 8% of total train collisions from 2010 to 2019. The majority of train collisions occurred during ‘day’ (489 out of 896, or 54%).

Incidents at ‘night’ followed this (343 out of 896, or 38%), ‘dusk’ (50 out of 896, or 6%), and ‘dawn’ (14 out of 896, or 2%).

6.3 Collision Contributing Factors

6.3.1 Truck Collisions

This section summarizes the collision contributing factors discussed in **Section 6.2.1 Truck Collisions**, which can be utilized to select screening criteria and form the basis of the subsequent probabilistic assessment.

Table 11 lists truck tractors' contributing factors derived from the Ontario, Québec, and New Brunswick datasets. The percentages noted in brackets represent the proportion of collisions compared to the total number of truck tractor collisions within each province.

Overall, when comparing the percentages between Ontario and New Brunswick, similar trends in driver actions and driver conditions were observed for most of the contributing factors. It is noted that the weather and road surface conditions were labelled as potential factors, as these conditions may or may not have contributed to a subject incident.

Table 11: Summary of Collision Contributing Factors (Truck Tractor)

Category of Contributing Factor	Contributing Factors	Frequency and Percentage of Occurrence[11] (2010 to 2019)		
		Ontario	New Brunswick	Québec
Driver Action	Following Too Close	3,318 (8.2%)	63 (2.4%)	The information on the driver's actions and conditions could not be shared with the project team, due to privacy laws in Québec
	Speed Exceed Limit	145 (0.4%)	16 (0.6%)	
	Speed Too Fast for Condition	3,048 (7.6%)	136 (5.1%)	
	Speed Too Slow for Condition	52 (0.1%)	0	
	Improper turn	522 (1.3%)	71 (2.7%)	
	Disobeying Traffic Control Devices	104 (0.3%)	25 (0.9%)	
	Fail to Yield	393 (1.0%)	80 (3.0%)	
	Improper passing	620 (1.5%)	48 (1.8%)	
	Lost control	2,447 (6.1%)	0	
	Wrong Way	25 (0.1%)	1 (0.04%)	
	Improper Lane Change	5,448 (13.5%)	0	
Driver Condition	Impaired	112 (0.3%)	11 (0.4%)	
	Fatigue	572 (1.5%)	79 (2.9%)	
	Medical Disability	84 (0.2%)	26 (1.0%)	
	Inattentive	4,167 (10.9%)	584 (21.4%)	
Weather Condition (Potential Factor)	Snow/Freezing Rain	6,724 (17.6%)	530 (18.0%)	5,904 (13.1%)
Road Surface Condition (Potential Factor)	Snow/Slush/Ice	7,615 (19.9%)	821 (27.7%)	8,751 (19.6%)

[11] The values presented in the table only represent a subset of the total dataset which exclude some factors that are not likely to contribute to the collisions (e.g., Driver Action of "Driving Properly", Driver Condition of "Normal", Weather Condition of "Clear", and Road Surface Condition of "Dry"). Therefore, the percentages do not sum up to 100%.

6.3.2 Train Collisions

The train operators' actions and conditions were not recorded in the TSB dataset for train collisions. In addition, and as stated in **Section 6.2.2 Train Collisions**, environmental conditions, including weather, surface, and lighting conditions, were only available for a small fraction of train collisions in Canada. In the absence of such detailed information, the contributing factors for train collisions could not be identified.

6.4 Usability of Collision Datasets

6.4.1 Truck Database

Section 6 Collision Types and Attributes of the report provided the collision data analysis findings, aiming to better understand the collision attributes derived from each of the available datasets. A detailed review of the attributes revealed the strengths and shortcomings of the Ontario, Québec, and New Brunswick datasets, as summarized in **Table 12**.

Table 12: Summary of Available Information from Ontario, Québec, and New Brunswick Datasets

Collision Attribute	Ontario	Québec	New Brunswick
Vehicle Involved	All vehicles	Vehicle 1 only[12]	Truck tractor only[13]
Vehicle Type	All vehicles	All vehicles	Truck tractor only
Sequence of Events	Up to three events are reported for each incident	The sequence of events was only available for the first event of the first vehicle.	Truck tractor only
Vehicle Damage Level	All vehicles	-	-
Driver Action	All drivers	-	Truck tractor only
Driver Condition	All drivers	-	Truck tractor only
Type of Shipment	Available	-	Available

- Not Available

As shown in **Table 12**, some of the essential collision attributes that are key in assessing screening criteria and developing event trees are not available in the Québec and New Brunswick datasets. For example, the sequence of all events would be needed to create the first branches following an incident.

This information was only partially provided in the Québec dataset for the first event of only one of the vehicles involved in a collision, which may or may not include a truck tractor that was part of the subject collision. As such, the statistics and probabilities generated from the Québec dataset would be largely skewed due to incomplete information.

Similar observations were made for the vehicle damage severity level, which was only available in Ontario's database. The type of shipment was found to be one of the essential elements included as part of the event trees, noted in the literature. Such information was not available in the Québec dataset. Other limitations include information on driver action and condition in the Québec database, which is critical in assessing screening criteria, discussed in **Section 7 Screening Criteria**.

The New Brunswick database only reported collisions attributes for the truck tractor vehicles involved in a collision and did not include the vehicle damage level due to the method through which this attribute is estimated.

[12] The Québec database only included vehicle-level attributes for the first vehicle in an accident, and the attributes for other vehicles involved in the same accident were not available.
[13] The New Brunswick data only included the collision attributes for the truck tractor vehicles involved in a collision.

Based on the above assessment and considering the limitations of the Québec and New Brunswick datasets, it became evident that the Ontario dataset was the most comprehensive, with sufficient information required for detailed assessment. As such, only the Ontario dataset was carried forward to the next step of the project, including the selection of screening criteria, development of event trees, and calculation of the probabilities, as outlined in the later sections of the report.

6.4.2 Train Database

As for train transport, the TSB database was the only source of information about train collisions in Canada, with available collision attributes like the ones in the literature that can be utilized to develop event trees and calculate collision probabilities.

7 Screening Criteria

It was identified during the literature review stage that certain studies opted to apply screening criteria to their respective datasets to exclude collisions with certain characteristics to more accurately represent the desired data at the event tree analysis stage.

In this context, screening criteria may be considered any significant attribute applicable to a subset of the total data that would warrant inclusion or removal from the subsequent analysis stages.

This section details the process of identifying and justifying selective screening criteria (as seen in the literature or as developed from expert judgement and collaborative discussions) considered relevant and appropriate for the current topic of study.

Furthermore, the calculation of the baseline frequency for contributing factors to be eliminated from the assessment is outlined, and the final screening criteria being carried forward are presented.

7.1 Truck Screening Criteria

On reviewing the Ontario data, an effort was made to review the applicability of various collision attributes to the transportation of Type B packages and “screen” the long list of attributes in Ontario. The following screening criteria were then developed based on the information provided in the literature [2] and previous experience in probabilistic assessment studies:

7.1.1 Conveyance Used

The vehicle classification in this category ranges from heavy transport vehicles and farm vehicles to motorcycles and bicycles. From the long list of vehicle classifications, the following two categories were deemed applicable to this report:

- *Heavy vehicles* include all types of heavy-weight vehicles with similar characteristics. These include truck tractors, open trucks, closed trucks, tank trucks, dump trucks, car carriers, and other trucks (types of heavy trucks, including cement mixers or cranes).
- *Truck tractors* include tractor trailers, with or without a semi trailer. The truck tractors would represent the vehicle type that can transport road-going Type B packages. Truck tractors are a subset of heavy vehicles.

7.1.2 Disobeying Traffic Control Devices

While driver errors can lead to collisions during radioactive material transport, some of the contributing factors listed in **Table 11** may not apply to truck drivers employed to transport Type B packages.

Literature [2] [3] suggests that disobeying traffic control devices can be classified as one of the screening criteria (i.e., some studies have excluded collisions in which the driver’s condition was recorded as “disobeying traffic control devices”) given that truck drivers transporting Type B packages are subject to much more rigorous training requirements.

Applying the same logic, some other driver actions noted in **Table 11** can also be among the candidate screening criteria, such as driving the “Wrong Way.” However, without precedence or evidence from the literature, such contributing factors were not considered screening criteria.

In other words, collisions in which the driver’s condition was recorded as “disobeying traffic control devices” were included in the database and data was carried forward to create event trees and in calculating collision probabilities.

7.1.3 Impaired Driving

It is assumed that drivers of trucks transporting Type B packages are to be held to higher standards than other truck drivers, with extensive training and fitness for duty requirements for operating the vehicle.

This will ensure that such drivers are not operating the vehicle under the influence of drugs or alcohol. Other attributes of driver condition in **Table 11**, such as “Fatigue,” “Medical Disability,” and “Inattentive,” can potentially occur during the transportation of Type B packages and, as such, were not considered as screening criteria. These collisions were included in the database and data was carried forward to create event trees and in calculate collision probabilities.

7.1.4 Other Conditions

Other potential collision contributing factors, including different types of weather and road surface conditions can occur during the transportation of Type B packages; and hence, they were not included in the list of proposed screening criteria.

7.2 Truck Baseline Frequency of Screening Criteria

Once the screening criteria were identified, the next step in selecting the final criteria was to calculate the baseline frequency of contributing factors that could be eliminated from further assessment. **Table 13** shows the proportion of collisions and/or drivers associated with each screening criteria discussed above for truck movements in Ontario.

Table 13: Baseline Frequency of Truck Screening Criteria in Ontario (Truck)

Screening Criteria	Subcategory	Frequencies
Conveyance Used	Heavy Truck	53,613 out of 368,088 total collisions in Ontario (14.5%)
	Truck Tractor	38,296 out of 368,088 total collisions in Ontario (10.4%)
Disobeying Traffic Control Devices	Heavy Truck Driver	174 out of 59,087 heavy truck drivers (0.3%)
	Truck Tractor Driver	104 out of 41,879 truck tractor drivers (0.2%)
Impaired Driving	Heavy Truck Driver	168 out of 59,087 heavy truck drivers (0.3%)
	Truck Tractor Driver	112 out of 41,879 truck tractor drivers (0.3%)

Table 13 shows that truck tractors were involved in approximately 10.4% of collisions in Ontario provincial highways from 2010 to 2019. As expected, the proportion of collisions involving heavy trucks, which included truck tractors, was at a higher level of 14.5%. In addition, 0.3% or less of heavy truck and truck tractor drivers involved in collisions disobeyed traffic control devices. Similar proportions were noted for impaired driving.

These numbers represent a small fraction of truck tractor drivers in Ontario and reiterate that truck tractor drivers are subject to a high level of training and requirements regarding being fit for duty and following the rules of the road.

7.3 Truck Selected Screening Criteria

Once the baseline frequency of screening criteria is defined, the screening criteria selection must be finalized. The applicability of each criterion shown in **Table 13** was assessed via workshops and discussions amidst the project team using expert judgement and leveraging industry experience as well as supported approaches from the literature review.

Regarding conveyance, the truck tractor was more representative of the type of vehicle used to transport Type B packages. The other vehicles included in the 'heavy vehicle' subcategory may be subject to different operating behaviours or route utilization that may not be as representative for these types of shipments.

As such, the truck tractor was chosen as the vehicle type for the probabilistic assessment. This results in a smaller population of data points that are more representative of the types of vehicles of interest to this report.

As for the other screening criteria listed in **Table 13**, a sensitivity analysis was conducted to assess the overall impact of applying the proposed criteria on the probabilities of collision scenarios. The sensitivity analysis was intended to compare the conditional probability of the following two alternatives, using three example scenarios with different vehicle severity damage and object struck:

- **Alternative 1: all-inclusive database**, which includes all truck tractor collisions in Ontario.
- **Alternative 2: subset of database**, which includes all truck tractor collisions in Ontario, excluding the ones with truck tractors drivers disobeying traffic control devices or driving impaired (under the influence of drug and/or alcohol).

As discussed earlier in **Section 4 Methodology**, the probability of a particular collision scenario is the product of all of the branch point fractions that lie on the scenario path, which can be calculated as follows:

$$P_{scenario} = \prod_{i=1}^{n} P_{Event_i} \quad \textbf{(1)}$$

Where:

$P_{scenario}$	=	The conditional probability of a particular collision scenario
P_{Event_i}	=	The probability of event i
n	=	Total number of events in a scenario

An illustrative example is the calculation of the conditional probability of a truck tractor colliding with a concrete guide rail, which resulted in light damage to the truck. The probability of this particular collision can be calculated as follows:

$$P_{scenario_1} = P_{Collision\ with\ fixed\ object} \times P_{Other\ fixed\ object} \times P_{Light\ damage} \quad \textbf{(2)}$$

Where:

$P_{scenario_1}$	=	The conditional probability of a particular collision scenario (i.e., Scenario 1)
$P_{Collision\ with\ fixed\ object}$	=	The probability of a collision with a fixed object
$P_{Other\ fixed\ object}$	=	The probability of a collision with other fixed objects (i.e., concrete guard rail)
$P_{Light\ damage}$	=	The probability of a light damage level

A second example is the calculation of the conditional probability of a truck tractor colliding with another motor vehicle, which resulted in moderate/severe damage to the truck. The probability of this particular collision can be calculated as follows:

$$P_{scenario_2} = P_{Collision\ with\ non-fixed\ object} \times P_{Other\ moving\ vehicle} \times P_{Moderate\ damage} \quad \textbf{(3)}$$

Where:

$P_{scenario_2}$	=	The conditional probability of a particular collision scenario (i.e., Scenario 2)
$P_{Collision\ with\ non-fixed\ object}$	=	The probability of a collision with a non-fixed object
$P_{Other\ moving\ vehicle}$	=	The probability of a collision with another moving vehicle
$P_{Moderate\ damage}$	=	The probability of a moderate/severe damage level

Finally, a third example is calculating the conditional probability of a truck tractor running off the road, which resulted in the truck being demolished. The probability of this particular collision can be calculated as follows:

$$P_{scenario_3} = P_{Non-collision\ incident} \times P_{Run\ off\ road} \times P_{Severe\ damage} \quad \textbf{(4)}$$

Where:

$P_{scenario_3}$	=	The conditional probability of a particular collision scenario (i.e., Scenario 3)
$P_{Non-collision\ accident}$	=	The probability of a non-collision incident
$P_{Run\ off\ road}$	=	The probability of other non-collision incident (i.e., running off the road)
$P_{Severe\ damage}$	=	The probability of a demolished damage level

As shown in **Equation (1)**, the conditional probability of a particular collision scenario depends on calculating the event probabilities that constitute the collision scenarios. Therefore, the collision scenarios were broken down into a series of events that comprise a particular collision scenario.

The details for the construction of truck event trees that were used for the basis of conditional probabilities are presented in **Section 9 Calculation of Collision Scenario Probabilities**. Based on the calculated probabilities for each of the events discussed in **Section 9**, an effort was made to compare the probabilities of the above scenarios with and without applying the screening criteria.

Table 14 summarizes the impact of screening criteria on each tree branch and the scenario's final probability.

Table 14: Sensitivity Analysis of Screening Criteria on Sample Scenarios (Tractor Truck)

Scenario No.	Tree Branch	Branch Probability*		Difference in Probabilities
		Alternative 1: All Inclusive Database	Alternative 2: Subset of Database	
Scenario 1	Collisions with a fixed object	0.15417	0.15304	0.7%
	Other fixed object	0.58601	0.58523	0.1%
	Light damage	0.39554	0.39633	0.2%
	Event Probability	0.035735	0.035497	0.7%
Scenario 2	Collisions with a non-fixed object	0.66295	0.66427	0.2%
	Other moving vehicle	0.90733	0.90721	0.0%
	Moderate/severe damage	0.22017	0.21995	0.1%
	Event Probability	0.13243	0.13254	0.1%
Scenario 3	Non-collision incident	0.15886	0.15839	0.3%
	Other non-collision	0.66421	0.66354	0.1%
	Demolished damage	0.16661	0.16545	0.7%
	Event Probability	0.01758	0.01739	1.1%

* Alternative 1 includes all truck tractor collisions in Ontario whereas Alternative 2 includes all truck tractor collisions in Ontario, excluding the ones with truck tractors drivers disobeying traffic control devices or impaired (driving under the influence of drug and/or alcohol).

Table 14 shows that the difference in the impact of applying the screening criteria on the final probabilities of any of the three scenarios provided was less than 1.1%.

These observations were as expected because a small proportion of collisions was associated with each screening criterion, as shown in **Table 13**.

Considering the negligible impact of the screening criteria on the event probabilities, the report utilized a dataset consisting of only truck tractor collisions in Ontario, including instances of truck tractor drivers disobeying traffic control devices or impaired driving, as summarized in **Table 15**.

Table 15 Decision on Screening Criteria

Initial Screening Criteria	Decision
Conveyance Used – Heavy Vehicles vs. Truck Tractors	Applied – Truck tractors only
Driver Action – Disobeying Traffic Control Devices	Not applied – No collisions were excluded by driver action
Driver Condition – Impaired (Influence of Drugs / Alcohol)	Not applied – No collisions were excluded by driver condition

This results in a decrease in the overall data available for use in the event tree analysis stage but falls on the side of conservatism by accounting for more representative conveyances (truck tractors vs all heavy vehicles) and including instances that are unlikely to occur within a used fuel transportation program (e.g., disobeying traffic control signals, impaired driving).

7.4 Train Screening Criteria

In accordance with the analysis of truck movements, a similar approach was employed to review the train collision attributes in the TSB database and determine whether any part of the database should be screened before calculating probabilities.

However, it was determined that unlike trucks (which feature a variety of options for different attributes, including vehicle type, driver action, and driver condition), transportation of Type B packages by trains is subject to fewer variables.

For example, a review of the historical collisions in the TSB database revealed that train collisions involving the transportation of dangerous goods occurred among different subdivision owners, such as CN, CP, Metrolinx, and Ottawa Central Railway, among others.

In addition, there are no specific train or track classifications in the TSB database that would warrant exclusion. It is also noted that the TSB dataset does not provide detailed information regarding factors contributing to collisions, such as the condition or actions of train conductors.

In addition to the above, no evidence exists in the literature for identifying or applying screening criteria for train movements. As such, and based on the above-noted observations, no screening criteria were developed for the transportation of Type B packages using trains. Therefore, the entire dataset of train collisions was utilized for the detailed probabilistic analysis.

8 Event Trees

8.1 Construction of Event Trees

An event tree is a diagram used to visualize the chronological sequence of separate events that form the overall description of the collision scenario when assembled, one after the other. Like branches of a tree, an event tree path can be followed that starts with the initiating event, then leads to the following event if one occurs, and then to the next event, and so on, ultimately ending with the final end-state of the collision scenario.

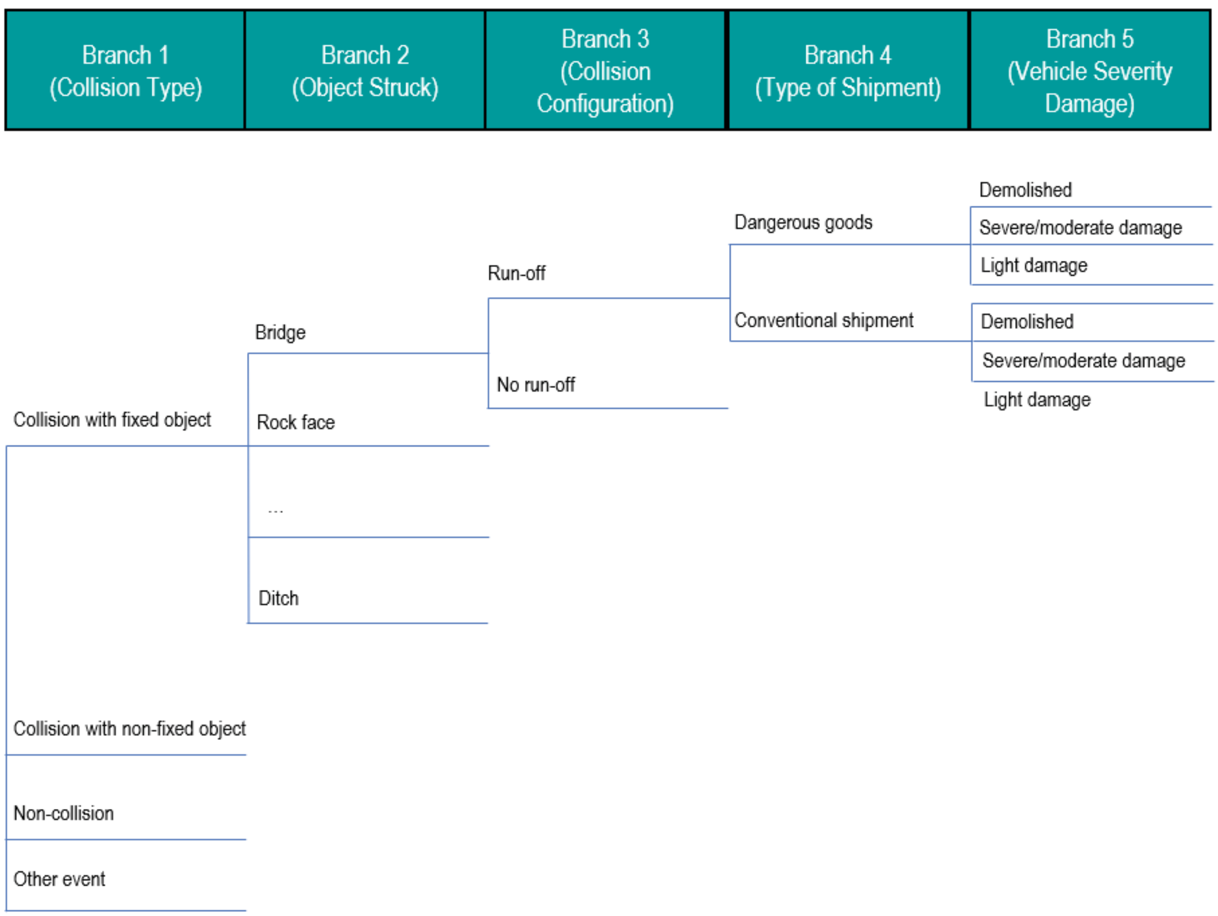
The use of event trees in the probabilistic analysis of the transport of used nuclear fuel has previously been documented [2] [7] [4] [6].

The following sub-section outlines the production of a logical structure using a defined event tree to create a comprehensive list of collision scenarios. To facilitate benchmarking against previous assessments seen in the literature, efforts were made to maintain consistency between the event trees where possible.

8.1.1 Consolidation of Truck Collision Events

The truck event tree is comprised of different sets of branches, as visually shown as an example in **Figure 22**. Each of the tree branches are described in the following section.

Figure 22: Visual Illustration of Truck Event Tree branches



Branch 1: Collision Type

For transportation involving truck tractors on Ontario's provincially-managed roadways, all possible events were divided into the following collision types, as discussed in **Section 6.1 Categories of Collision Types:**

- Collisions with non-fixed objects;
- Collisions with fixed objects;
- Non-collision incidents; and
- Other events.

The above collision types form the first branch of the truck event tree, as shown in **Figure 22**.

It is noted that an outlier category ("other event") was comprised of a small proportion of truck tractor collisions with no further information regarding the sequence of events or objects struck. **Section 9 Calculation of Collision Scenario Probabilities** of this report provides the statistics for such events.

Branch 2: Object Struck

The first set of branches was aligned with information in the vehicle event category and was used to create a second set of branches referring to the object struck.

Some categories were consolidated to maintain a manageable number of branches and retain consistency with the event trees in the literature, as illustrated in **Table 16**. An effort was made to combine vehicle event categories with similar characteristics and potential impact on the transport package, as shown in **Table 16**.

Discussions were had regarding areas of interest obtained through consultation with the general public and individuals interested in the transportation of used fuel.

Where it was possible to separate these areas of interest, efforts were made to maintain them as individual branches within the event tree. These topics include incidents involving farm tractors, wild animals, rock faces, snow piles, watercourse, submersion, ditch, rollover, and jackknifing.

Table 16: Consolidation of Ontario Vehicle Event Categories into Object Struck

Branch 1 (Collision Type)	Ontario Vehicle Event Categories	Branch 2 (Consolidated Vehicle Event Category – Object Struck)
Collision with non-fixed object	Railway train struck	Train
Collision with non-fixed object	Other motor vehicles	Other moving vehicle
Collision with non-fixed object	Streetcar	Other moving vehicle
Collision with non-fixed object	Farm Tractor	Farm Tractor
Collision with non-fixed object	Other moveable objects	Other non-fixed/moving objects
Collision with non-fixed object	Pedestrian	Other non-fixed/moving objects
Collision with non-fixed object	Cyclist	Other non-fixed/moving objects
Collision with non-fixed object	Animal-domestic	Other non-fixed/moving objects
Collision with non-fixed object	Animal-wild	Animal-wild
Collision with a fixed object	Bridge support	Bridge
Collision with a fixed object	Building/Wall	Other fixed road structure
Collision with a fixed object	Unattended vehicle	Other fixed object
Collision with a fixed object	Culvert	Other fixed object
Collision with a fixed object	Tree/Shrub/Stump	Other fixed object
Collision with a fixed object	Pole-utility	Other fixed object
Collision with a fixed object	Pole-sign/park meter	Other fixed object
Collision with a fixed object	Curb	Other fixed object
Collision with a fixed object	Fence/Noise barrier	Other fixed object
Collision with a fixed object	Cable guide rail	Other fixed object
Collision with a fixed object	Concrete guide rail	Other fixed object
Collision with a fixed object	Steel guide rail	Other fixed object
Collision with a fixed object	Crash cushion	Other fixed object
Collision with a fixed object	Construction marker	Other fixed object
Collision with a fixed object	Debris on road	Other fixed object
Collision with a fixed object	Debris off vehicle	Other fixed object
Collision with a fixed object	Other fixed object	Other fixed object
Collision with a fixed object	Rock face	Rock face
Collision with a fixed object	Snow pile	Snow pile
Collision with a fixed object	Watercourse	Watercourse
Collision with a fixed object	Submersion	Submersion
Collision with a fixed object	Ditch	Ditch
Non-collision	Fire/Explosion	Fire/Explosion
Non-collision	Load spill	Load spill
Non-collision	Skidding/Sliding	Other non-collision
Non-collision	Ran off-road	Other non-collision
Non-collision	Rollover	Rollover
Non-collision	Jackknifing	Jackknifing
Other Event	Other Event	Other Event

Branch 3: Collision Configuration

For collisions where the object struck was identified as "bridge support," it was of particular interest to assess whether the vehicle colliding with the bridge structure left the bridge (run-off) or not (not run-off).

As such, the branch associated with a bridge structure being struck was subdivided into the collision configurations of "run-off" vs. "not run-off."

The run-off road collision scenario at a bridge represents an extreme scenario of a truck falling some distance. The Lloyd's Register and Sandia Study [2] [7] noted a similar breakdown of collisions on bridges.

Branch 4: Type of Shipment

As indicated in **Section 5.1.1.3 Ontario Dangerous Goods Data**, the MTO database includes a field that identifies whether a vehicle involved in a collision was carrying dangerous goods. As such, the fourth branch of the event tree provides a further breakdown of the truck tractor collisions in terms of type of shipment, by separating collisions involving dangerous goods vs. collisions involving conventional shipments.

Branch 5: Vehicle Severity Damage

The final branch of the event tree categorizes the collisions in terms of vehicle damage severity, which indicates the degree of impact the vehicle was subject to due to the initiating event. As indicated in **Section 6.2.1 Truck Collisions**, six main classifications of vehicle damage severity were available in Ontario's collision dataset, including:

- No damage
- Light damage
- Moderate damage
- Severe damage
- Demolished
- Damage unknown

For the event tree, collisions leading to severe or moderate vehicle damage severity were consolidated and labelled as "Severe/Moderate Damage." Collisions with demolished vehicle damage severity were grouped separately, representing the most severe incidents with potentially higher impacts on the transport package.

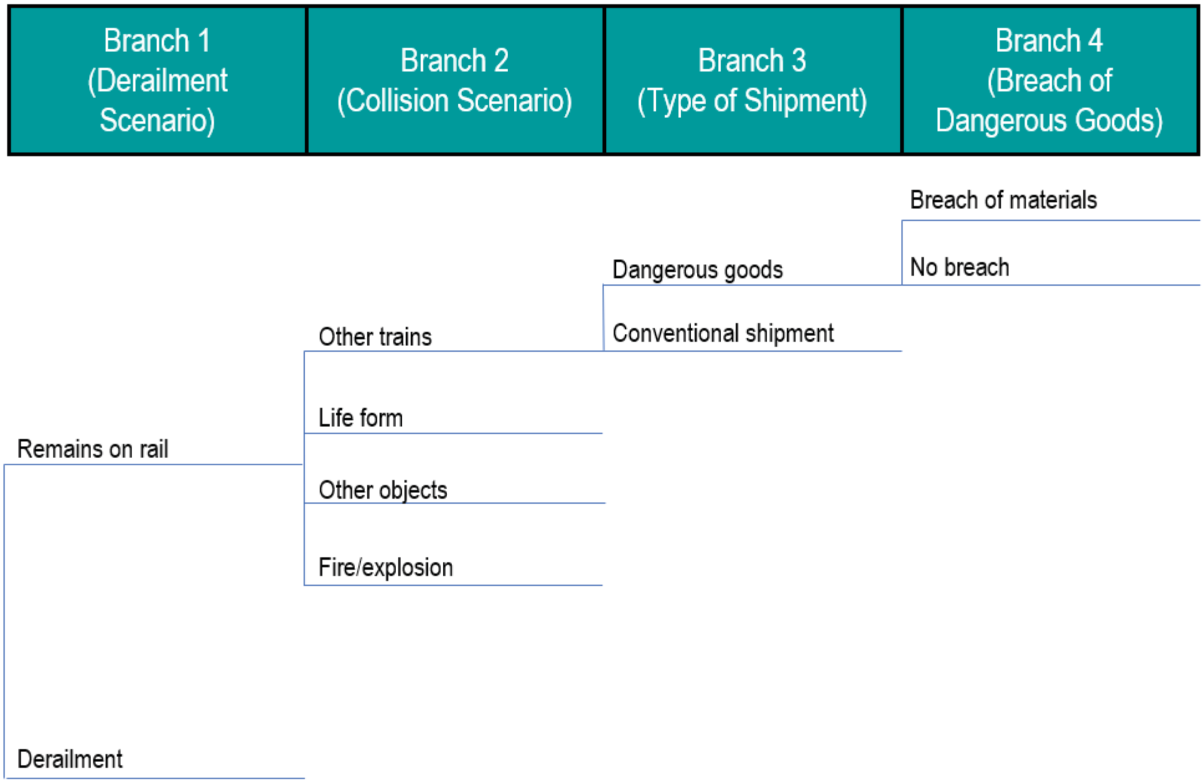
Lastly, incidents leading to no, light, and unknown damage were grouped together, indicative of incidents with less severe impact on the truck tractors and labelled as "Light Damage".

The resulting truck event tree is shown in **Section 8.2 Truck Event Tree**.

8.1.2 Consolidation of Train Collision Events

The train event tree is comprised of different sets of branches, visually shown as an example in **Figure 23**. Each of the tree branches are described in the following section.

Figure 23: Visual Illustration of Train Event Tree Branches



Branch 1: Derailment Scenario

As noted in **Section 6.1 Categories of Collision Types**, the first set of train event tree branches is based on the following derailment categories:

- The train remains on the rail track; and
- The train derails from the rail track.

Branch 2: Collision Scenario

The first set of branches was aligned with information in the collision description category, which was used to create a second set of branches referring to collision type.

For consistency with the truck event tree and those noted in the literature, some collision scenarios were consolidated, as shown in **Table 17**.

Table 17: Consolidation of TSB Collision Type Categories into Collision Scenarios

Branch 1 (Derailment Scenario)	Collision Type	Branch 2 (Consolidated Collision Scenario)
Remains on rail	Main-track train collision	Other trains
	Non-main-track train collisions	
	Passenger	Life form
	Trespasser	
	Employee	
	Crossing	Other objects
	A collision involving a track unit	
	Rolling stock collision with an abandoned vehicle	
	Rolling stock collision with an object	
	Rolling stock damaged without derailment/collision	
	Fire	Fire/Explosion
	Explosion	
Derailment	Main-track train collision	Other trains
	Non-main-track train collisions	
	Passenger	Life form
	Trespasser	
	Employee	
	Crossing	Other objects
	A collision involving a track unit	
	Rolling stock collision with an abandoned vehicle	
	Rolling stock collision with an object	
	Rolling stock damaged without derailment/collision	
	Fire	Fire/Explosion
	Explosion	
	Main-track train derailment	Main-track train derailment
	Non-main-track train derailment	Non-main-track train derailment

Branch 3: Type of Shipment

The third branch of the event tree provides a breakdown of shipment types, namely dangerous goods and conventional shipments.

Branch 4: Breach of Dangerous Goods

For those collisions involving dangerous goods, the event tree was further broken down to separate those collisions that resulted in the release of materials.

It is noted that the breakdown of shipment types and breach of materials were not included in the train event trees in the Volpe [25] and USNRC studies [8]. In contrast, additional attributes noted in the Volpe Study [25], including speed distribution and surface struck, were unavailable in the TSB dataset and thus not included in the event tree branches of this assessment.

8.2 Truck Event Tree

Based on the above discussion in **Section 8.1.1 Consolidation of Truck Collision Events** and branches of the event tree, the resulting truck event tree is shown in **Table 18**.

Table 18: Truck Event Tree

Collision	Branch 1 (Collision Type)	Branch 2 (Object Struck)	Branch 3 (Collision Configuration)	Branch 4 (Type of Shipment)	Branch 5 (Vehicle Severity Damage)
Truck Collision	Collision with non-fixed object	Train		1) Dangerous goods 2) Conventional shipment	1) Demolished 2) Severe / Moderate Damage 3) Light Damage
		Other moving vehicle			
		Farm tractor			
		Other non-fixed/ moving object			
		Animal-wild			
	Collision with fixed object	Bridge	Run-off		
			No run-off		
		Other fixed road structure			
		Other fixed object			
		Rock face			
		Snow pile			
		Water course			
		Submersion			
		Ditch			
	Non-collision	Fire/Explosion			
		Load spill			
		Other non-collision			
		Rollover			
		Jack knifing			
	Other Event	Other Event			

8.3 Train Event Tree

Based on the above discussion in **Section 8.1.2 Consolidation of Train Collision Events** and branches of the event tree, the resulting truck event tree is shown in **Table 19**.

Table 19: Train Event Tree

Collision	Branch 1 (Derailment Scenario)	Branch 2 (Collision Scenario)	Branch 3 (Type of Shipment)	Branch 4 (Breach of Dangerous Goods)
Train Collision	Remains on rail	Other trains	Dangerous goods	Breach of materials
				No breach
			Conventional shipment	
		Life form	Dangerous goods	Breach of materials
				No breach
			Conventional shipment	
		Other objects	Dangerous goods	Breach of materials
				No breach
			Conventional shipment	
		Fire/Explosion	Dangerous goods	Breach of materials
				No breach
			Conventional shipment	
	Derailment	Other trains	Dangerous goods	Breach of materials
				No breach
			Conventional shipment	
		Life form	Dangerous goods	Breach of materials
				No breach
			Conventional shipment	
		Other objects	Dangerous goods	Breach of materials
				No breach
			Conventional shipment	
		Fire/Explosion	Dangerous goods	Breach of materials
				No breach
			Conventional shipment	
		Main-track train derailment	Dangerous goods	Breach of materials
				No breach
			Conventional shipment	
		Non-main-track train derailment	Dangerous goods	Breach of materials
				No breach
			Conventional shipment	

9 Calculation of Collision Scenario Probabilities

Once the branches of the truck and train event trees are identified, the next phase is to describe the steps involved in populating the branches of truck and train event trees with probabilities. This probabilistic analysis informs identifying bounding scenarios, discussed in **Section 10 Sensitivity Assessment & Bounding Scenarios**. In the following sections, the steps involved in the calculation of branch point fractions and conditional probabilities for truck and train movements are discussed.

9.1 Truck Collision Events

9.1.1 Truck Conditional Probabilities

As discussed in **Section 4 Methodology**, the conditional probability of a particular collision scenario is the product of all of the branch point fractions that lie on the scenario path. For example, consider the following collision scenario:

A truck tractor carrying a conventional shipment collided with another moving vehicle. As a result of the collision, the truck was lightly damaged.

The conditional probability of this collision scenario can be expressed as follows:

$$P_{scenario} = P_{Collision\ with\ non-fixed\ object} \times P_{Other\ moving\ vehicle} \times P_{Conventional\ shipment} \times P_{Light\ damage} \quad \textbf{(5)}$$

Where:

$P_{scenario}$	=	The conditional probability of the collision scenario
$P_{Collision\ with\ non-fixed\ object}$	=	The average probability of a collision with non-fixed object
$P_{Other\ moving\ vehicle}$	=	The average probability of a collision with other moving vehicle
$P_{Conventional\ shipment}$	=	The average probability of a collision involving truck tractor carrying conventional shipment
$P_{Light\ damage}$	=	The average probability of a light damage level

Based on **Equation (5)**, for a total conditional probability in the final column of the event tree, the individual average probabilities from each column are multiplied together. Thus, the average probabilities must be determined before a particular conditional probability of a scenario can be calculated. It is important to note that this report only considers the conditional probability of a collision scenario or the probability of a particular collision scenario occurring ***if*** a collision happens in the first place.

The average probability of each branch of the event tree within the study period is the average of annual collision probabilities within that particular branch. In the example above, the annual probability of a collision with "non-fixed object" for a particular year was calculated as the frequency of truck tractor collisions with non-fixed objects divided by the total number of truck tractor collisions for that specific year. Following the same logic, the annual probability of a collision with "other moving vehicle" for a particular year was calculated as the frequency of truck tractor collisions with "other moving vehicle" (as a subset of non-fixed object) divided by the total number of truck tractor collisions with non-fixed objects.

Based on the above discussion, the following steps were taken to calculate the conditional probabilities of all scenarios:

- Step 1: Calculate annual probabilities for all branches of the event tree.
- Step 2: Calculate the average probability of each branch of the event tree within the study period as the average of annual collision probabilities within that particular branch.

- Step 3: Calculate the conditional probability of a particular scenario as the product of all of the branch average probabilities that lie on the scenario path.

Using the truck tractor data from MTO's collision database from 2010 to 2019 and the consolidated vehicle event categories in **Table 16**, the annual, average, and conditional probabilities for all collision scenarios were calculated. The above-noted steps are explained further below using an example for illustration purposes.

Step 1: Calculate Annual Collision Probabilities

To provide further details on the calculation process, **Table 20** shows the frequency and probability of truck tractor collisions with "other moving vehicles" as part of "collisions with non-fixed objects."

As shown in **Table 20**, the first step of the process is to calculate the annual collision probabilities for the "other moving vehicles". The annual probability of a collision with "other moving vehicle" for each year in the sixth column of **Table 20** was calculated as the frequency of truck tractor collisions with "other moving vehicle" (fourth column of **Table 20**) divided by the total number of truck tractor collisions with "non-fixed object" (fifth column of **Table 20**). For example, in this table, the annual collision probability of 89.2% in 2010 is the frequency of truck tractor collisions with "other moving vehicle" in 2010 (i.e., 2,850 collisions) divided by the total number of truck tractor collisions with "non-fixed object" in 2010 (i.e., 3,196 collisions).

Following the same process, the annual collision probabilities were calculated for all branches of the truck event tree.

Step 2: Calculate Average Collision Probabilities

The average probability of collisions with "other moving vehicles" during the whole of the study period (i.e., 90.7%) is calculated as the average annual probabilities, listed in the sixth column of **Table 20**. The last column represents the standard deviation of the annual probabilities listed in the sixth column, which will be used for sensitivity analysis. This is discussed in **Section 10 Sensitivity Assessment & Bounding Scenarios** of the report.

As noted earlier in this report, the calculated probabilities do not represent the probability of a truck collision occurring. Rather, they state the probability of the exact sequence of collision events happening, with a starting assumption that a truck collision has taken place.

Table 20: Example Calculation of Truck Collision Probability (with Other Moving Vehicles)

Collision Type	Object Struck	Year	Frequency of Collisions		Annual Probability	Average Probability	Standard Deviation of Probability
			Other moving vehicle	All collisions with a non-fixed object			
Collision with a non-fixed object	Other moving vehicle	2010	2,850	3,196	89.2%	90.7%	1.48%
		2011	3,229	3,596	89.8%		
		2012	2,716	3,071	88.4%		
		2013	3,228	3,611	89.4%		
		2014	3,540	3,866	91.6%		
		2015	2,982	3,290	90.6%		
		2016	2,855	3,127	91.3%		
		2017	3,186	3,456	92.2%		
		2018	3,359	3,604	93.2%		
		2019	3,367	3,693	91.2%		

Following the same approach, the average probabilities for different collision types, object struck, collision configuration, type of shipment, and vehicle damage severity were calculated. The results are shown in **Table 21**.

The average probabilities for vehicle damage severity correlate to the object struck. For example, the proportion of trucks being “demolished” as a result of a collision with a “train” is 33.3%, while the same damage level for truck collisions with “other moving vehicles” is 2.7%.

In other words, the likelihood of demolished collisions depends on the impact object. In contrast, the type of shipment is not correlated with the object struck, and as such, the conditional probabilities for this branch remained the same for different scenarios.

As noted in **Section 4 Methodology**, a key feature of an event tree is that the sum of all fractions at a given branch point equals one. However, some exceptions may occur due to rounding the calculated results to three decimal points. For example, the fractions for the “collision with non-fixed object” in **Table 21** are:

- Collision with train = 0.00009 (0.009%)
- Collision with other moving vehicle = 0.907 (90.7%)
- Collision with farm tractor = 0.00029 (0.029%)
- Collision with other non-fixed / moving object = 0.030 (3.0%)
- Collision with animal-wild = 0.063 (6.3%)

Based on the above, the sum of all fractions for collision with non-fixed object type is:

$$0.00009 + 0.907 + 0.00029 + 0.030 + 0.063 = 1.00038$$

For the purpose of this report, the above-noted discrepancies were considered acceptable, representing the errors in the magnitude of 0.001 (or 0.1%) in the calculation of conditional probabilities.

Table 21: Calculated Collision Probabilities for Different Branches of the Event Tree (Truck Tractor)

Collision Type	Average probability	Object Struck	Average probability	Collision Config.	Average probability	Type of Shipment	Average probability	Vehicle Severity Damage	Average probability
Collision with a non-fixed object	66.3%	Train	<0.1% (0.009%)			Dangerous goods Conventional shipment	Dangerous goods (0.3%) Conventional shipment (99.7%)	Demolished	33.3%
								Severe/Moderate Damage	66.7%
								Light Damage	0.0%
		Other moving vehicle	90.7%					Demolished	2.7%
								Severe/Moderate Damage	22.0%
								Light Damage	75.3%
		Farm Tractor	<0.1% (0.029%)					Demolished	14.3%
								Severe/Moderate Damage	57.1%
								Light Damage	28.6%
		Other non-fixed / moving objects	3.0%					Demolished	2.1%
								Severe/Moderate Damage	36.3%
								Light Damage	61.6%
		Animal-wild	6.3%					Demolished	1.2%
								Severe/Moderate Damage	54.4%
								Light Damage	44.5%
Collision with a fixed object	15.4%	Bridge	1.0%	Run-off	4.0%			Demolished	25.0%
								Severe/Moderate Damage	58.3%
								Light Damage	16.7%
				No run-off	96.0%			Demolished	8.8%
								Severe/Moderate Damage	35.6%
								Light Damage	55.6%
		Other fixed road structure	0.2%					Demolished	0.0%
								Severe/Moderate Damage	71.9%
								Light Damage	28.1%
		Other fixed object	58.7%					Demolished	15.0%
								Severe/Moderate Damage	45.5%
								Light Damage	39.6%
		Rock face	3.2%					Demolished	44.3%
								Severe/Moderate Damage	46.7%
								Light Damage	9.1%

Collision Type	Average probability	Object Struck	Average probability	Collision Config.	Average probability	Type of Shipment	Average probability	Vehicle Severity Damage	Average probability
		Snow pile	3.4%					Demolished	4.2%
								Severe/Moderate Damage	54.5%
								Light Damage	41.2%
		Watercourse	0.1%					Demolished	21.4%
								Severe/Moderate Damage	42.9%
								Light Damage	35.7%
		Submersion	0.1%					Demolished	93.8%
								Severe/Moderate Damage	6.3%
								Light Damage	0.0%
		Ditch	33.2%					Demolished	17.2%
								Severe/Moderate Damage	58.2%
								Light Damage	24.6%
Non-collision	15.9%	Fire / Explosion	2.8%					Demolished	52.3%
								Severe/Moderate Damage	33.6%
								Light Damage	14.1%
		Load spill	2.8%					Demolished	19.4%
								Severe/Moderate Damage	42.0%
								Light Damage	38.6%
		Other non-collision	66.4%					Demolished	16.7%
								Severe/Moderate Damage	56.1%
								Light Damage	27.2%
		Rollover	12.8%					Demolished	36.1%
								Severe/Moderate Damage	56.4%
								Light Damage	7.5%
		Jackknifing	15.2%					Demolished	11.2%
								Severe/Moderate Damage	65.5%
								Light Damage	23.3%
Other Event	2.4%	Other Event	100%					Demolished	1.3%
								Severe/Moderate Damage	6.8%
								Light Damage	91.9%

Step 3: Calculate Conditional Probabilities

After the calculation of the branch point fractions and collision scenario probabilities for all the branches, the conditional probabilities for all collisions scenarios were calculated using **Equation (6)** below:

$$P_{scenario} = \prod_{i=1}^{n} \bar{P}_{Event_i} \quad \textbf{(6)}$$

Where:

$P_{scenario}$ = The conditional probability of a particular collision scenario

$\bar{P}_{Event_i}$ = The average probability of event i

n = Total number of events in a scenario

9.1.2 Top Five Scenarios with Highest Conditional Probabilities for Truck Collisions

The full list of 120 truck tractor scenarios, including the average and conditional probabilities, can be found in **Appendix A**. It is noted that all truck tractor scenarios were ranked in ascending order based on their conditional probabilities, with a ranking index added for each of the collision scenarios.

Table 22 presents the top five scenarios with the highest conditional probabilities for collisions involving truck tractors. These scenarios comprise 71.9% of the total conditional probabilities of truck tractor collisions.

Given the low occurrence of truck tractor collisions carrying dangerous goods in Ontario (less than 0.3%, as shown in **Table 21**), the conditional probability of those scenarios involving dangerous goods were generally lower than those scenarios involving conventional shipments, and as such, did not appear among the top five scenarios in **Table 22.**

Table 22: Top Five Scenarios with Highest Conditional Probabilities (Truck Tractor)

Collision Type	Object Struck	Type of Shipment	Vehicle Severity Damage	Conditional Probability	Ranking
Collision with a non-fixed object	Other moving vehicle	Conventional	Light	45.2%	1
Collision with a non-fixed object	Other moving vehicle	Conventional	Severe / Moderate	13.2%	2
Non-collision	Other non-collision (skidding/sliding or running off-road)	Conventional	Severe / Moderate	5.9%	3
Collision with a fixed object	Other fixed objects (e.g., tree, culvert, guide rail)	Conventional	Severe / Moderate	4.1%	4
Collision with a fixed object	Other fixed object	Conventional	Light	3.6%	5

9.2 Train Collision Events

9.2.1 Train Conditional Probabilities

The respective branches' fraction of the train event tree was calculated using the train data from the TSB collision database from 2010 to 2019 and the consolidated event categories in **Table 17**.

The average train collision probabilities for the train event tree branches were calculated in a similar approach to those for trucks discussed above in **Section 9.1.1** and the example shown in **Table 20**. The results are shown in **Table 23**.

Table 23: Calculated Collision Probabilities for Different Branches of the Event Tree (Train)

Derailment Scenario	Average Probability	Collision Scenario	Average Probability	Type of Shipment	Average Probability	Breach of Dangerous Goods	Average Probability
Remains on rail	36.6%	Other trains	15.0%	Dangerous goods Conventional shipment	Dangerous goods (12.5%) Conventional shipment (87.5%)	Breach	0.0%
						No breach	100.0%
		Life form	19.4%			Breach	0.0%
						No breach	100.0%
		Other objects	57.1%			Breach	1.2%
						No breach	98.8%
		Fire/Explosion	8.5%			Breach	0.3%
						No breach	99.7%
Derailment	63.4%	Other trains	6.0%			Breach	0.1%
						No breach	99.9%
		Life form	<0.1% (0.04%)			Breach	0.0%
						No breach	100.0%
		Other objects	3.4%			Breach	0.2%
						No breach	99.8%
		Fire/Explosion	<0.1% (0.01%)			Breach	0.0%
						No breach	100.0%
		Main-track train derailment	13.0%			Breach	2.9%
						No breach	97.1%
		Non-main-track train derailment	77.6%			Breach	0.6%
						No breach	99.4%

In the absence of collision damage level in the TSB database, the breach of materials can be a surrogate measure for the damage taken by trains carrying dangerous goods. The proportion of collisions with and without breach of dangerous goods differed for various derailment and collision scenarios.

After calculating the branch point fractions and collision scenario probabilities for all the branches, the conditional probabilities for all collision scenarios were calculated using **Equation (6)**.

9.2.2 Top Five Scenarios with Highest Conditional Probabilities for Train Collisions

The full list of 30 train scenarios, including the average and conditional probabilities, can be found in Appendix B. Like truck tractors, all train scenarios were ranked in ascending order based on their conditional probabilities, with a ranking index added for each collision scenario.

Table 24 presents the top five scenarios with the highest conditional probabilities for collisions involving trains. These scenarios comprise 80.9% of the total conditional probabilities of train collisions.

Table 24: Top Five Scenarios with Highest Conditional Probabilities (Train)

Derailment Scenario	Collision Scenario	Type of Shipment	Breach of Dangerous Goods	Conditional Probability	Ranking
Derailment	Non-main-track train derailment	Conventional	-	43.0%	1
Remains on rail	Other objects (e.g., abandoned vehicle, track unit)	Conventional	-	18.3%	2
Derailment	Main-track train derailment	Conventional	-	7.2%	3
Remains on rail	Life form	Conventional	-	6.2%	4
Derailment	Non-main-track train derailment	Dangerous goods	No breach	6.1%	5

10 Sensitivity Assessment & Bounding Scenarios

Once the conditional probabilities are calculated, the next step is determining the potential bounding collisions. The bounding collision scenarios are the most probable and severe transportation collisions that would encompass, or 'bound,' other transportation-related incidents that might occur, including those of lesser severity. This is discussed in **Section 10.1 Potential Bounding Collision Scenarios**.

In conjunction with identification of bounding scenarios, an effort was made to conduct a sensitivity analysis and calculate an upper bound of the probabilities, representing the worst-case outcomes of the probabilistic assessments. The sensitivity analysis was conducted for all incidents involving truck tractors and trains, including bounding scenarios. The discussion on sensitivity analysis is presented in **Section 10.2 Sensitivity Analysis**. This is followed by discussions on emerging themes in **Section 10.3 Emerging Themes of Interest** that may be of interest to communities and members of the public regarding safety aspects associated with transporting Type B packages and radioactive materials.

10.1 Potential Bounding Collision Scenarios

Two components should be considered in the development of bounding collisions:

1) the probability of a collision scenario occurring, and

2) the resulting outcomes or consequences of a collision if it were to occur.

The first component can be captured in conditional probabilities, while the severity of consequences can be represented by parameters such as "vehicle damage severity".[14]

10.1.1 Potential Bounding Truck Scenarios

The potential bounding collision scenarios for tractor trucks were selected from the long list of 120 truck scenarios with the highest likelihood of occurrence, combined with the best estimation of the severity of outcome, which can be expressed by vehicle damage severity for truck tractors.

Building on the above and for the purpose of this report, five scenarios with the highest conditional probabilities with vehicle damage severity of "demolished" and "severe/moderate damage" levels were selected. Collisions with "demolished" and "severe/moderate damage" levels refer to those which are more severe than collisions resulting in "light damage" to the truck tractor.

Different attributes of the potential bounding scenarios are shown in **Table 25.**

[14] While this analysis is focused on the severity of damage to the conveyance, it is important to note that damage to a conveyance does not necessarily translate to damage or breach of a Type B package. Type B transport packages are designed, tested, and certified by the Canadian nuclear regulator (CNSC) to withstand credible accident conditions i.e., they must shield and contain contents under hypothetical accident conditions for all modes of transport and meet stringent regulatory requirements based on international standards.

Table 25: Potential Bounding Scenarios (Truck Tractor)

Collision Type	Object Struck	Type of Shipment	Vehicle Severity Damage	Conditional Probability	Ranking
with a non-fixed object	Other moving vehicle	Conventional shipment	Severe / Moderate	13.2%	2
Non-collision	Other non-collision			5.9%	3
with a fixed object	Other fixed object			4.1%	4
with a fixed object	Ditch			3.0%	6
with non-fixed object	Animal-wild			2.3%	8
Non-collision	Other non-collision	Conventional shipment	Demolished	1.8%	11
with non-fixed object	Other moving vehicle			1.6%	12
with a fixed object	Other fixed object			1.4%	14
with fixed object	Ditch			0.9%	18
Non-collision	Rollover			0.7%	19

10.1.2 Potential Bounding Train Scenarios

The potential train bounding scenarios can be selected from the long list of 30 train scenarios based on the following rules:

- Derailment scenarios may have a more severe impact on the package than those scenarios where the train remained on the rail.
- Among derailment scenarios, the impact of those carrying "dangerous goods" would be higher than conventional shipments. Given the nature of the shipment, dangerous goods may have a higher capacity to cause harm to life forms and the environment when involved in uncontrolled spills and/or collisions than conventional goods.
- Collision scenarios involving "main track train derailment," "other trains," "other objects," and "fire/explosion" supersede those scenarios with "life form" and "non-main-track train derailment" collisions.

It is assumed that "non-main-track train derailment" collisions are mostly those incidents that occur at rail yards, with lower speeds, and as such, the potential impact on the packages in question would be minimal. In contrast, collisions involving "main track train derailment" would occur at higher speeds, which could translate to a potentially more severe impact on the Type B packages.

Collisions involving "life form", as tragic as they may be, would have a minimal impact on the Type B packages, and as such, were replaced by more severe scenarios, such as collisions involving "other trains," "other objects," and "fire/explosion".

Table 26 shows the potential bounding train scenarios with the highest conditional probabilities.

Table 26: Potential Bounding Scenarios (Train)

Derailment Scenario	Collision Scenario	Type of Shipment	Breach of Dangerous Goods	Conditional Probability	Ranking
Derailment	Main-track train derailment	Dangerous goods	No breach	1.0%	11
Derailment	Other trains		No breach	0.5%	14
Derailment	Other objects		No breach	0.3%	16
Derailment	Main-track train derailment		Breach of materials	<0.1% (0.03%)[15]	18
Derailment	Fire/Explosion		No breach	<0.1% (0.001%)	24
Derailment	Other trains		Breach of materials	<0.1% (0.0007%)	25
Derailment	Other objects		Breach of materials	<0.1% (0.0005%)	26
Derailment	Fire / Explosion		Breach of materials	0.0	27

10.2 Sensitivity Analysis

10.2.1 Sensitivity Analysis Objective and Approach

The sensitivity analysis aims to calculate an upper bound of the probabilities, representing the worst-case outcomes of the probabilistic assessments. The results of the sensitivity analysis provide insights for the degree of uncertainty in the probabilistic analysis.

To achieve this, the associated average for the branch point probabilities (e.g., 90.7% in **Table 20**) was added with the standard deviation of the annual branch probabilities (e.g., 1.48% in **Table 20**) to calculate the upper bound of probabilities.

Next, the upper bound probabilities that constitute a scenario were multiplied together to calculate the upper bound of the conditional probabilities, as shown in the proceeding equations:

$$P_{Event_i}^{Upper} = \bar{P}_{Event_i} + SD_{Event_i} \quad \textbf{(7)}$$

$$P_{scenario}^{Upper} = \prod_{i=1}^{n} P_{Event_i}^{Upper} \quad \textbf{(8)}$$

Where:

$\bar{P}_{Event_i}$	=	The average probability of event i
SD_{Event_i}	=	The standard deviation of event i
$P_{Event_i}^{Upper}$	=	The upper bound probability of event i
$P_{scenario}^{Upper}$	=	The upper bound of the conditional probability of a particular collision scenario
n	=	Total number of events in a scenario

[15] The Lac-Mégantic rail incident is classified as the "main-track train derailment" scenario, involving dangerous goods, and breach of materials. The creation of the event tree is based on identification of contributing factors and causes of collisions, rather than consequences. The fire and explosion that occurred during the Lac-Mégantic incident was a consequence of train derailment, and as such, was not classified as "fire/explosion" collision scenario.

The above calculations are shown in an example scenario in **Table 27**, which includes a truck tractor collision with another moving object carrying a conventional shipment, resulting in severe/moderate damage to the truck tractor.

The average (third column) and standard deviation of probabilities (fourth column) were calculated separately for different events in this scenario, following the same process shown in **Table 20**.

The upper bound of event probabilities (fifth column) and upper bound of conditional probability (seventh column) were calculated using the formulas in **Equations (7)** and **(8)**, respectively.

Table 27: Example Calculation of Upper Bound Probabilities

Event Attributes	Example Scenario Attributes	Average Probability	Standard Deviation	Upper Bound Probability	Conditional Probability	Upper Bound of Conditional Probability
Collision Type	Collision with a non-fixed object	66.3%	3.0%	69.3% (66.3%+3.0%)	13.2% (66.3%×90.7% × 99.7%×22.0%)	15.4% (69.3%×92.2% × 99.9%×24.0%)
Object Struck	Other moving vehicle	90.7%	1.5%	92.2% (90.7%+1.5%)		
Type of Shipment	Conventional shipment	99.7%	0.2%	99.9% (99.7%+0.2%)		
Vehicle Severity Damage	Severe/Moderate Damage	22.0%	2.0%	24.0% (22.0%+2.0%)		

Based on the calculations shown in **Table 27**, the upper bound of the conditional probability for this scenario was increased by approximately 15%, from 13.2% to 15.4%.

10.2.2 Upper Bound Probability of Bounding Scenarios

Following the approach discussed above, **Appendix A** and **Appendix B** summarize the upper bound of conditional probabilities for all incidents involving truck tractors and trains. For brevity, the sensitivity analysis was focused on potential bounding scenarios.

Table 28 and **Table 29** present a one-to-one comparison between the conditional probabilities and the upper bound values for truck and train bounding scenarios.

The difference between the two values for each bounding scenario was also reported in these tables, representing a degree of uncertainty in calculating probabilities.

Table 28: Sensitivity Analysis on Truck Bounding Scenarios

Collision Type	Object Struck	Type of Shipment	Vehicle Severity Damage	Conditional Probability	Upper Bound of Conditional Probability	Difference (%)	Rank
Collision with a non-fixed object	Other moving vehicle	Conventional shipment	Severe / Moderate Damage	13.2%	15.4%	16.3%	2
Non-collision	Other non-collision			5.9%	7.4%	24.5%	3
Collision with a fixed object	Other fixed object			4.1%	4.9%	19.0%	4
Collision with a fixed object	Ditch			3.0%	3.7%	25.2%	6
Collision with a non-fixed object	Animal-wild			2.3%	4.4%	93.6%	8
Non-collision	Other non-collision	Conventional shipment	Demolished	1.8%	2.5%	41.8%	11
Collision with a non-fixed object	Other moving vehicle			1.6%	2.0%	23.1%	12
Collision with a fixed object	Other fixed object			1.4%	1.8%	30.1%	14
Collision with a fixed object	Ditch			0.9%	1.2%	40.5%	18
Non-collision	Rollover			0.7%	1.1%	48.2%	19

Table 29: Sensitivity Analysis on Train Bounding Scenarios

Derailment Scenario	Collision Scenario	Type of Shipment	Breach of Dangerous Goods	Conditional Probability	Upper Bound of Conditional Probability	Difference (%)	Rank
Derailment	Main-track train derailment	Dangerous goods	No breach	1.0%	1.4%	41.2%	11
Derailment	Other trains		No breach	0.5%	0.6%	31.1%	14
Derailment	Other objects		No breach	0.3%	0.4%	37.5%	16
Derailment	Main-track train derailment		Breach of materials	<0.1% (0.03%)	<0.1% (0.09%)	186.8%	18
Derailment	Fire/Explosion		No breach	<0.1% (0.001%)	<0.1% (0.005%)	383.1%	24
Derailment	Other trains		Breach of materials	<0.1% (0.0007%)	<0.1% (0.003%)	306.6%	25
Derailment	Other objects		Breach of materials	<0.1% (0.0005%)	<0.1% (0.002%)	328.6%	26
Derailment	Fire / Explosion		Breach of materials	0.0	0.0	-	28

For truck bounding scenarios, collisions with wild animals with severe/moderate impact on the truck carrying conventional shipment show the largest relative increase, by 93.6%, which indicates the highest uncertainty. The level of uncertainty for other truck-bounding scenarios ranged from 16.3% to 48.2%.

For train scenarios with conditional probabilities higher than 0.1%, the upper bound of conditional probabilities was between 31.1% to 41.2% higher than conditional probabilities.

As expected, the uncertainties for those scenarios with very low probabilities were significantly higher than other bounding scenarios. This is due to such events occurring so rarely that a one or two instance increase per year may double or triple the conditional probability of that event for that given year.

In summary, the percent difference in the conditional probability and the upper bound represents a degree of uncertainty, and very low conditional probabilities come with a high degree of uncertainty.

10.3 Emerging Themes of Interest

One of the primary goals of this report was to identify emerging themes that may be of interest to communities and members of the public regarding the safe transport of Type B packages and radioactive materials. The themes identified from the available data are discussed below.

10.3.1 Emerging Themes of Interest for Trucks

The analysis below considers conditional probability of collisions scenarios involving a truck tractor. It is important to note that conditional probability is the probability of a particular collision scenario occurring if a collision happens in the first place. The conditional probability discussed herein does not represent the likelihood that a collision could lead to a consequence (such as breach of a Type B transportation package) or potential impact (e.g., environmental impacts, health effects or injuries). The estimated number of events are determined by applying the highest range of conditional probabilities to the approximate average of truck tractor collisions per year in Ontario.

10.3.1.1 Incidents on Bridges

It is of particular interest to assess the probabilities of collisions on bridges, including the probability that a collision leads to run-off from the bridge. In accordance with this interest, the analysis captured collisions with bridge supports in the truck event tree, including run-off vs. non-run-off scenarios.

According to the long list of scenarios in Appendix A, the conditional probability of truck tractor collisions on bridges, resulting in a “run-off-road” event, ranged from 2.77×10^{-8} to 3.75×10^{-5}, depending on the collision configuration, type of shipment, and vehicle severity damage. For “non-run-off road” events, the conditional probability ranged between 3.48×10^{-7} and 8.49×10^{-4}. As shown in **Table 21**, 96% of collisions with bridge structure result in non-run-off road, and as such, the conditional probabilities of scenarios with non-run-off road events were higher than those scenarios with run-off road events.

The non-run-off road scenario with the highest probability of 8.49×10^{-4} and ranking of 35 out of 120 scenarios was as follows:

A truck tractor carrying a conventional shipment collided with a bridge structure with no run-off-road. As a result of the collision, the truck was lightly damaged.

In terms of conditional probabilities, the probability of this non-run-off scenario occurring was approximately 1 in 1,177 if a truck collision occurred in the first place. An approximate average of 4,000 truck tractor collisions per year in Ontario, as noted in **Table 3**, would amount to 3 to 4 events per year in Ontario.

The run-off road scenario with the highest probability of 3.75×10^{-5} and ranking of 65 out of 120 scenarios was as follows:

A truck tractor carrying a conventional shipment collided with a bridge structure. As a result of the collision, the truck ran off-road and was severely/moderately damaged.

In terms of conditional probabilities, the probability of this scenario occurring was approximately 1 in 26,694 if a truck collision occurred in the first place. An approximate average of 4,000 truck tractor collisions per year in Ontario, as noted in **Table 3**, would amount to 0.15 events per year in Ontario, or one event per 6 to 7 years in Ontario.

10.3.1.2 Collisions Resulting in Run-off into Bodies of Water

Collisions resulting in run-off-road and into bodies of water were captured in the truck event tree as incidents resulting in "watercourse" and "submersion."

For collisions involving "watercourse," the conditional probability of truck tractor collisions ranged from 9.85×10^{-8} to 7.62×10^{-5}, depending on the type of shipment and vehicle severity damage. The scenario with the highest probability of 7.62×10^{-5} and ranking of 53 out of 120 scenarios was as follows:

A truck tractor carrying a conventional shipment ran into the watercourse. As a result of the collision, the truck was severely/moderately damaged.

In terms of conditional probabilities, the probability of this scenario occurring was approximately 1 in 13,118 if a truck collision occurred in the first place. This probability was a fraction of the probability of the scenario with the highest ranking (0.495), or 0.015%.

Similarly, for collisions involving "submersion," the conditional probability ranged from zero to 1.13×10^{-4}. The scenario with the highest probability of 1.13×10^{-4} and ranking of 47 out of 120 scenarios was as follows:

A truck tractor carrying a conventional shipment submerged into the water. As a result of the collision, the truck was demolished.

In terms of conditional probabilities, the probability of this scenario occurring was approximately 1 in 13,118 if a truck collision occurred in the first place. Given an approximate average of 4,000 truck tractor collisions per year in Ontario, as noted in **Table 3**, this would result in approximately one collision every three years.

10.3.1.3 Collisions along Significant Bodies of Water

The location of the collision concerning the bodies of water is not reported in the Ontario collision database and could not be included in the event tree. Collisions along significant bodies of water would be a subset of the entire collision datasets, and the conditional probability of all scenarios for truck tractor collisions along bodies of water would be less than the probabilities listed in **Appendix A**.

In other words, truck tractors' all-inclusive data generate higher probabilities than a subset of data and supersedes scenarios generated from a smaller database.

10.3.1.4 Collisions in Urban vs. Rural Areas

Like above, the land use attributes are not reported in the Ontario collision database and could not be included in the event tree. However, collisions occurring on provincial highways within urban or rural areas would be a subset of the collision dataset.

As such, the conditional probability of all scenarios involving truck tractor collisions, specifically in an urban or a rural setting would be less than the probabilities listed in **Appendix A**, including collisions in urban and rural areas. The all-inclusive data for truck tractors generate higher probabilities than a subset of data and supersede scenarios generated from smaller databases within either urban or rural areas.

10.3.1.5 Collisions in Icy/Snow/Slush Conditions

The Ontario dataset includes information on the road surface condition during the collision. As noted in **Section 7 Screening Criteria**, this information has not been used in the event tree, but given the cold winter climate throughout Canada, it is important to discuss such collision statistics in the context of this project.

As shown in **Table 30**, of all truck tractors involved in collisions between 2010 and 2019, close to 20% were involved in collisions on icy/snow/slush surface conditions. Of these, 6% and 38% resulted in a vehicle damage severity that was demolished and severe/moderate damage, respectively.

In contrast, considering all truck tractors involved in collisions, the fraction of those incidents which resulted in a vehicle damage severity that was demolished, and severe/moderate damage was 4% and 28%, respectively.

Based on these statistics, it can be concluded that the likelihood of demolished or severely damaged vehicles is higher on icy/snowy/slushy roads compared to the entire dataset. It is important to note that these results do not indicate that the conditional probability of truck tractors on icy/snowy/slushy roads is higher than the values listed in **Appendix A**.

It simply suggests that if a truck tractor were involved in a collision on icy/snowy/slushy roads, the likelihood of the truck being demolished or severely/moderately damaged would be higher.

Table 30: Summary of Truck Tractor Involved in Collisions Icy/Snow/Slush Surface Condition

Year	Percentage of Truck Tractor involved in Collisions on Icy/Snow/Slush Surface Condition	Percentage of Truck Tractor involved in Collisions		Percentage of Truck Tractor involved in Collisions on Icy/Snow/Slush Surface Condition	
		Demolished	Severe/Moderate Damage	Demolished	Severe/Moderate Damage
2010	16%	5%	26%	5%	36%
2011	20%	4%	27%	6%	32%
2012	19%	5%	27%	7%	35%
2013	25%	5%	30%	4%	37%
2014	30%	5%	31%	6%	42%
2015	17%	4%	25%	5%	38%
2016	18%	4%	28%	5%	42%
2017	17%	4%	27%	8%	39%
2018	19%	4%	29%	5%	39%
2019	23%	4%	28%	5%	40%
Average	20%	4%	28%	6%	38%

10.3.1.6 Collisions in Two-Lane vs. Multi-Lane Highways

The Ontario dataset includes information regarding the roadway type, i.e., two-lane vs. multi-lane and the presence of a physical barrier between the two directions of traffic, i.e., divided[16] vs. undivided[17] highways. Like road surface conditions, this information has not been used in the event tree, but it is essential to create a better understanding of the percentage of truck tractor involved in collisions in Ontario using different approaches.

As shown in **Table 31** and **Table 32**, of all truck tractors that were involved in collisions between 2010 and 2019, 26% of them were involved in collisions that occurred on 2-lane roadways (i.e., 1 lane per direction), and 61% of them were involved in collisions that occurred on multi-lane roadways (i.e., 2 or more lanes per direction). These observations are as expected since multi-lane roadways carry higher traffic volumes, increasing the likelihood of collisions.

[16] A highway divided into separate streams by a median strip with a physical barrier (e.g., guide rails, fences, walls) or median stripe(s) of unpaved ground without restraining barriers (e.g., grass median with drainage ditch)
[17] An undivided highway for traffic in opposite directions includes roads with only serrated concrete strips (singing medians) or painted lines between opposing lanes.

In terms of the vehicle damage severity, the statistics listed in the tables suggest that:

- The proportion of truck tractors involved in demolished and severe/moderate damage collisions on 2-lane roadways was higher than in multi-lane roadways.
- Collisions occurring on undivided roadways are more severe when compared to the ones that occurred on divided roadways, presumably because truck tractors involved in collisions on undivided roadways are more likely to collide with vehicles from opposing roadway's travel directions.

Table 31: Summary of Truck Tractors Involved in Collisions Occurred on 2-Lane Roadways

Year	Percentage of Truck Tractor Involved in Collisions on 2-lane Roadways			Percentage of Truck Tractor Involved in Collisions on Undivided 2-lane Roadways			Percentage of Truck Tractor Involved in Collisions on Divided 2-lane Roadways		
	Total[18]	Demolished	Severe / Moderate Damage	Total	Demolished	Severe / Moderate Damage	Total	Demolished	Severe / Moderate Damage
2010	26%	10%	40%	20%	11%	42%	6%	6%	33%
2011	27%	8%	38%	21%	8%	41%	6%	6%	30%
2012	29%	8%	37%	23%	7%	39%	6%	10%	30%
2013	29%	8%	40%	23%	9%	42%	7%	5%	33%
2014	27%	7%	42%	20%	7%	43%	7%	6%	38%
2015	25%	8%	40%	19%	8%	42%	6%	8%	33%
2016	24%	7%	43%	17%	8%	45%	7%	5%	38%
2017	25%	9%	42%	18%	9%	42%	7%	7%	39%
2018	25%	8%	43%	17%	8%	45%	8%	8%	38%
2019	27%	6%	42%	18%	6%	46%	9%	6%	33%
Average	26%	8%	41%	19%	8%	43%	7%	7%	35%

[18] The "Total" presented in Table 31 and Table 32 are the total percentages of truck tractors that were involved in collisions under the described scenario (e.g., Collisions on Undivided 2-lane Roadways)

Table 32: Summary of Truck Tractors Involved in Collisions Occurred on Multi-Lane Roadways

Year	Percentage of Truck Tractors Collisions on Multi-Lane Roadways			Percentage of Truck Tractors Collisions on Undivided Multi-Lane Roadways			Percentage of Truck Tractors Collisions on Divided Multi-Lane Roadways		
	Total	Demolished	Severe / Moderate Damage	Total	Demolished	Severe / Moderate Damage	Total	Demolished	Severe / Moderate Damage
2010	56%	3%	24%	6%	7%	31%	50%	3%	23%
2011	54%	4%	25%	5%	6%	36%	48%	3%	24%
2012	54%	4%	26%	6%	7%	29%	48%	4%	25%
2013	57%	4%	26%	5%	5%	32%	52%	4%	26%
2014	63%	4%	30%	5%	6%	33%	58%	4%	29%
2015	66%	2%	22%	4%	4%	35%	62%	2%	21%
2016	67%	3%	23%	3%	1%	29%	63%	3%	23%
2017	65%	3%	22%	4%	4%	35%	61%	3%	22%
2018	65%	2%	25%	4%	4%	28%	61%	2%	25%
2019	62%	3%	23%	4%	4%	31%	59%	3%	23%
Average	61%	3%	25%	5%	5%	32%	56%	3%	24%

10.3.2 Emerging Themes of Interest for Trains

The emerging themes for train movements are mainly focused on derailments with mixed materials and or collisions between multiple trains that have mixed materials, such as the 1979 Mississauga train derailment.

While the importance of such events is recognized, the TSB database does not provide the breakdown of collisions with mixed materials, or the UN number recorded as part of the breached dangerous goods parameter on the rail dataset. Having said that, any specific collision scenario (such as the 1979 Mississauga train derailment) is a subset of the entire collision datasets, and the conditional probability of those scenarios would be less than the probabilities listed in **Appendix B**.

In other words, train's all-inclusive data generate higher probabilities than a subset of data and supersedes scenarios generated from a smaller database.

11 Benchmarking

11.1 Benchmarking Against Similar Road Transportation Assessments

As a benchmarking exercise, this report compares the results of the road transportation analyses described in the previous sections with other studies described in the literature review. These comparisons included an examination of the probabilities of collision types compared to other data sets in the first and second branches of the report event trees, the probabilities of like sequences of events along similar event tree pathways, and the rankings of analogous sequences of events among different studies. There were no applicable rail transportation analyses to provide an acceptable benchmark.

The benchmarking exercises considered the initial branch (Collision Type) and second branch (Object Struck) for the Modal Study from 1987 [5], NUREG/CR-6672 from 2000, and the Lloyd's Register report from 2019 [2]. The Modal Study is the oldest of the studies and uses data from U.S. roadways. NUREG/CR-6672 uses U.S. truck collision data from 1996 through 2000.

The Lloyd's Register report uses data from 2011-2015 from Transport Canada's National Collision Database.

A summary of the collision probabilities from these and the current report is provided in **Table 33**. The data indicate good agreement with the newer NUREG/CR-6672 and Lloyd's Register reports and suggest that the Ontario data used for the current report is reasonably representative of truck collision data in the U.S. and Canada as a whole.

Table 33: Summary of Truck Collision Benchmarking

<table>
<tr><th>Branch 1: Collision Type</th><th>Branch 2: Object Struck</th><th>Modal Study (1987)</th><th>NUREG/CR-6672 (Sandia, 2000)</th><th>Lloyd's Register (2019)</th><th>NWMO (Current Report, 2023)</th></tr>
<tr><td rowspan="3">Collision with a non-fixed object</td><td>Train</td><td>1.0%</td><td>0.1%</td><td>0.1%</td><td>0.01%</td></tr>
<tr><td>Other vehicles</td><td>88.0%</td><td>94.1%</td><td>88.1%</td><td>90.7%</td></tr>
<tr><td>Other non-vehicle</td><td>11.0%</td><td>5.8%</td><td>11.8%</td><td>9.3%</td></tr>
<tr><td rowspan="5">Collision with a fixed object</td><td>Bridges</td><td>6.0%</td><td>6.4%</td><td>2.5%</td><td>1.0%</td></tr>
<tr><td>Ditch/culvert</td><td>42.0%</td><td>24.4%</td><td>20.3%</td><td>33.2%</td></tr>
<tr><td>Embankment/water</td><td>-</td><td>4.6%</td><td>1.4%</td><td>6.8%</td></tr>
<tr><td>Other road structure</td><td>6.0%</td><td>-</td><td>4.2%</td><td>0.2%</td></tr>
<tr><td>Other fixed object</td><td>46.0%</td><td>63.6%</td><td>72.0%</td><td>58.7%</td></tr>
<tr><td rowspan="3">Non-collisions</td><td>Fire/explosion</td><td>4%</td><td>5%</td><td>2.6%</td><td>2.8%</td></tr>
<tr><td>Other non-collision</td><td>35.0%</td><td rowspan="2">95%</td><td rowspan="2">97.4%</td><td>66.4%</td></tr>
<tr><td>Rollover/jackknife</td><td>53.0%</td><td>28.0%</td></tr>
</table>

The proceedings graphs also represent these comparisons in **Figure 24**, **Figure 25** and **Figure 26**. Figure 24 demonstrates that collisions with other vehicles are the dominant collision type for the three past studies and current report.

Figure 25 demonstrates that most fixed objects struck in truck collisions fall into the "Other fixed objects" category. The data also show that collisions with defined structures such as bridges (discussed as a theme of interest in **Section 10.3.1.1 Incidents on Bridges**) are generally consistent and within the same order of magnitude for each dataset. However, there is greater inconsistency concerning the range of collision probabilities with other fixed objects.

These greater inconsistencies are likely more of a function of the definition or grouping of the "Objects struck" than reduced collision probabilities in the geography or time period covered by the data.

Figure 26 addresses non-collision incidents that could damage a heavy truck and its payload. As shown in **Table 33**, The NUREG/CR-6672 and Lloyd's Register studies considered only fire/explosions and "other" non-collisions.

The Modal Study and the current NWMO report included rollover and jackknife collisions as a subset of other non-collision collisions. All three previous studies generally align with the findings from the current NWMO report when combining "Other non-collision" and "Rollover/Jackknife" incidents.

Figure 24: Benchmarking Heavy Truck Collision Probabilities with Non-fixed Objects

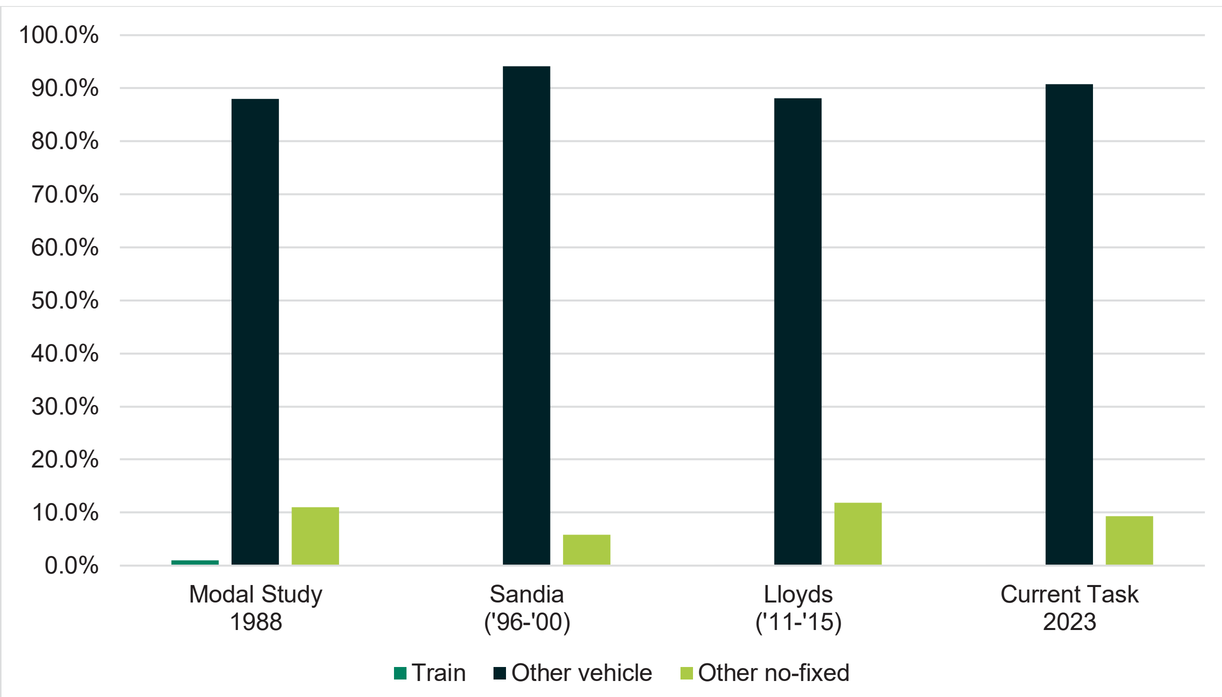


Figure 25: Benchmarking Heavy Truck Collision Probabilities with Fixed Objects

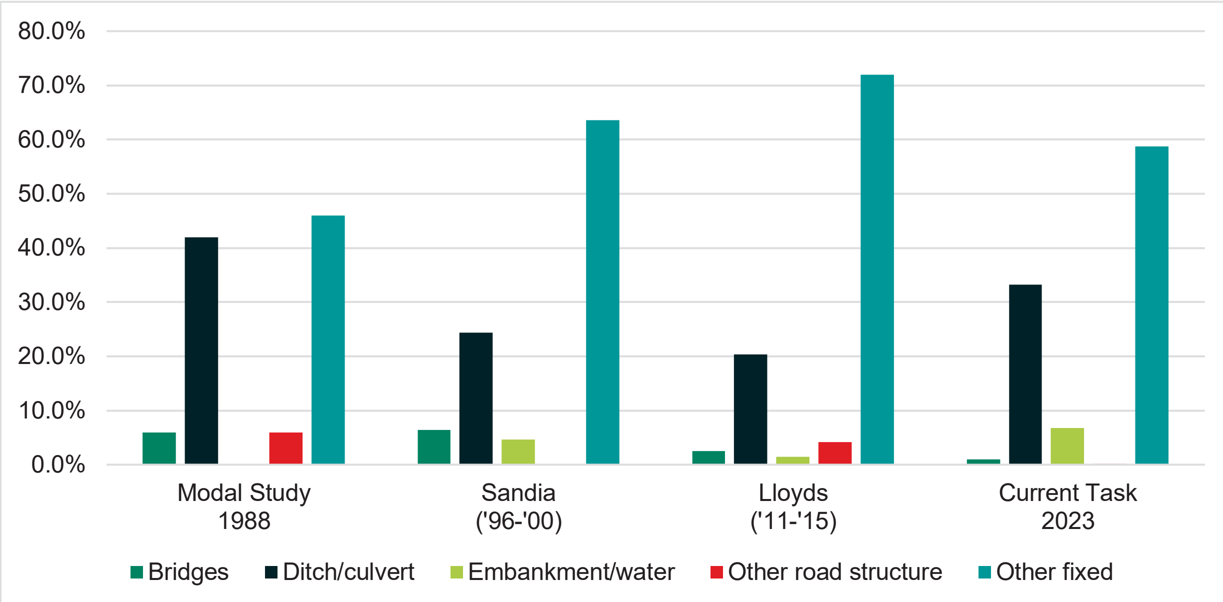
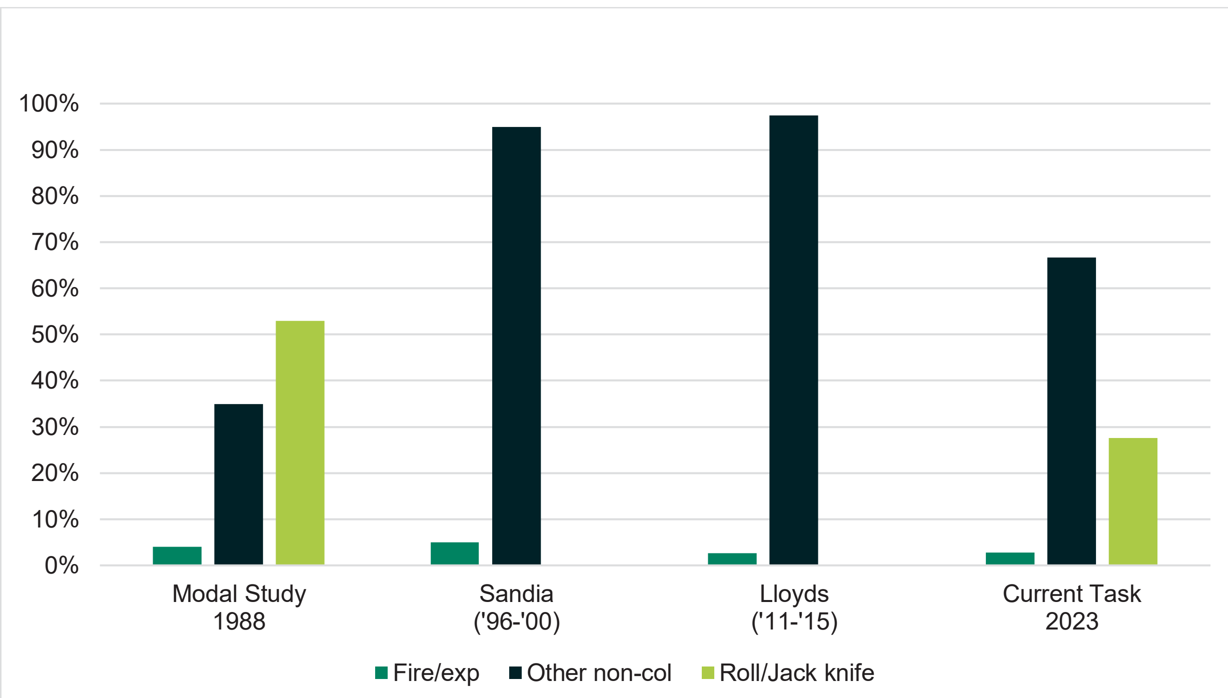


Figure 26: Benchmarking Heavy Truck Non-collision Collision Probabilities



From the comparisons provided in **Figure 24** through **Figure 26**, the heavy truck collision analysis presented in this report provides similar results to benchmarking studies in other reports. This demonstrates that heavy truck collision event causes and outcome probabilities in Ontario are similar to those in the U.S. and all of Canada.

11.2 Benchmarking for Rail Transportation

Previous reports were not found to provide meaningful benchmarks for rail transportation beyond the initial event tree branch of derailment and non-derailment. The current report considered a derailment probability of 63% and a non-derailment probability of 37% following a collision.

Appendix E of NUREG/CR-2125 [8] references a 2006 draft report from the Volpe National Transportation Systems Center, "Spent Nuclear Fuel Transportation Risk" [25]. This report provided a derailment probability of 73.6% and a non-derailment probability of 26.4% following a collision [25]. The derailment and non-derailment probabilities provided in the Volpe Center report are generally consistent with the Canadian data showcased in this report.

11.3 Benchmarking Conventional and TDG, Class 7, & Type B Shipments

The benchmarking described in the previous section considers conventional conveyances capable of transporting Type B packages but was not limited to any actual material transported. However, there is interest in understanding the differences in the safety record, if any, between different types of shipments such as conventional, Dangerous Goods (Class 7 materials specifically), and Type B packages. If there are differences, one should consider the catalyst for these difference (e.g., more stringent regulations).

Collision probabilities per shipment of Dangerous Goods or Class 7 materials in Canada have not been compiled by applicable agencies and only the total number of incidents are reported. As shown in **Table 4**, **Table 6**, and **Table 9**, the numbers of incidents in Ontario, Quebec, and New Brunswick for Dangerous Goods and Class 7 materials are small, but incident rates or probabilities are needed to draw comparisons against different shipment types and shipments in other countries. Therefore, the province-specific number of incidents cannot be benchmarked against other data sets or other data points.

For safety record benchmarking, data on the total kilometers travelled by conveyances carrying each type of good in a geographic region and time span, along with accident data, outcomes, and causal factors would be needed to conduct comparative assessments. However, while specific benchmarking of multiple studies of Dangerous Goods (total), Class 7 materials, and Type B shipments collision probabilities is not feasible at this time, a demonstration of the low numbers of incidents involving Type B shipments in Canada and worldwide is provided in the following paragraphs.

As described in **Section 5.1.5 Canadian Nuclear Safety Commission Data**, 492 radioactive material (Class 7) transportation incidents were reported to the CNSC between 2000 and 2022. Out of these, 58 incidents involved Type B transportation packages, of which none involved a loss of contents. While it was not possible to draw out specific conditional probabilities from the CNSC data, it further exemplifies the safety record of Type B shipments. However, this safety record also means that there is insufficient data on which to base statistical analyses for collisions involving conveyances transporting Type B packages alone.

The U.S. Department of Energy produced a study involving the history of worldwide used fuel transportation [12]. This study concluded that transportation of used fuel has been accomplished routinely and safely in many countries around the world for decades. It reported that, historically, collisions have been infrequent in used fuel and high-level radioactive waste transportation, and that when collisions have occurred, most have been minor collisions such as low-speed derailments or minor traffic accidents with little or no damage to the package being transported.

Specifically, the study showed that at least 25,400 shipments of used fuel were made worldwide between 1962 and 2016, and that all of these shipments were undertaken without any injury or loss of life caused by the radioactive nature of the material transported. The worldwide number of Type B package shipments is far greater than used fuel shipments (e.g., approximately 255,000 shipments from 1979 through 1982) and were seen to feature a similar safety record.

12 Summary of Findings and Future Considerations

The literature review provided in this report confirms that truck and rail collisions involving radioactive materials and Type B packages are rare. Furthermore, not only are the worldwide number of shipments of Type B packages low, but only a few collisions involving shipments of Type B packages have ever occurred.

Finally, construction standards supported by collision and drop testing indicate that even in the event of a severe collision, a release of radioactive materials is unlikely. Therefore, the radiological risk of transporting Type B packages in compliance with transportation regulations is very low.

The analysis presented in this report also demonstrates that conventional truck/train collisions statistics must be used to construct a data set with a population size sufficient to draw meaningful conclusions on collision probabilities, causal factors, and accident severity.

The road collision datasets included in this analysis are sufficiently large and the resulting collision probabilities and causal factors map well against previous analysis carried out in Canada as well as internationally. Based on the statistical power of the large data sets, conclusions regarding collision causal factors are reliable enough on which to base future mitigation and control measures.

The predominant causal factors are being analyzed for a future mitigation report that will examine:

1. How the probability of a collision involving the transport of a Type B package can be reduced, and;
2. How the severity of an accident involving the transport of a Type B package can be mitigated.

13 References

[1] International Atomic Energy Agency, *Regulations for the Safe Transport of Radioactive Materials, Specific Safety Requirements No. SSR-6 (Rev. 1),* Vienna, Austria: International Atomic Energy Agency, 2018.

[2] M. Kumar, *Radioactive Material Transport Probabilistic Risk Assessment - Large Truck Accidents on Canadian Roadways,* Lloyd's Register Group Limited, 2019.

[3] J. Ramsay, M. Kumar, S. Yalaoui and C. Cavanagh-Dollard, *A Probabilistic Risk Assessment of Truck/Trailer Transportation of,* Proceedings of the 19th International Symposium on the Packaging and Transportation of Radioactive Materials, PATRAM 2019, 2019.

[4] Nuclear Regulatory Commission, *Final Environmental Statement on the Transportation of Radioactive Material by Air and Other Modes - NUREG-0170 (VOL. 1),* Nuclear Regulatory Commission, 1977.

[5] L. E. Fischer, C. K. Chou, M. A. Gerhard, C. Y. Kimura, R. W. Martin, R. W. Mensing, M. E. Mount and M. C. Witte, *Shipping Container Response to Severe Highway and Railway Accident Conditions - NUREG/CR-4829,* Washington, D.C.: U.S. Nuclear Regulatory Commission, 1987.

[6] H. R. Weiner, K. S. Mills, J. L. Sprung, D. J. Ammerman, N. L. Breivik, R. J. Dukart, F. L. Kanipe, J. A. Koski, K. S. Neuhauser and R. F. Radloff, *Reexamination of Spent Fuel Shipment Risk Estimates - NUREG-6672. (SAND2000-0234),* Albuquerque, NM (United States): Sandia National Lab. (SNL-NM), 2000.

[7] G. S. Mills, J. L. Sprung and D. Osborn, *Tractor/Trailer Accident Statistics. SAND2006-7723,* Albuquerque, NM (United States): Sandia National Labs (SNL-NM), 2006.

[8] J. Cook, *Spent Fuel Transportation Risk Assessment. NUREG-2125,* U.S. Nuclear Regulatory Commission.

[9] Committee on Transportation of Radioactive Waste, *Going the Distance? The Safe Transport of Spent Nuclear Fuel and High-Level Radioactive Waste in the United States,* National Academic Press, 2006.

[10] D. J. Ammerman, J. R. Cook, A. Murphy and R. Kalan, *Recent Assessments in the U.S. of Type B Packages to Impacts Beyond the Regulatory Package Test Standards,* Proceedings of the 15th International Symposium on the Packaging and Transportation of Radioactive Materials, PATRAM 2007, 2007.

[11] A. Greenberg, T. McSweeney, D. Blower, M. Abkowitz and M. Lepofsky, *Analysis of Serious Truck Crashes in the United States,* Proceedings of the 15th International Symposium on the Packaging and Transportation of Radioactive Materials, PATRAM 2007, 2007.

[12] U.S. Department of Energy, *A Historical Review of the Safe Transport of Spent Nuclear Fuel. FCRD-NFST-2016-000474, Rev. 1. ORNL/SR-2016/261, Rev. 1,* U.S. Department of Energy, 2016.

[13] The Bureau of Transportation Statistics, *Freight Facts and Figures,* U. S. Department of Transportation, 2017.

[14] J. A. Fort, J. M. Cuta and H. E. Adkins Jr., *A Compendium of Spent Fuel Transportation Package Response Analyses to Severe Fire Accident Scenarios - NUREG/CR-7209, PNNL-24792,* Washington, D.C.: U. S. Nuclear Regulatory Commission, 2017.

[15] International Atomic Energy Agency, *Input Data for Quantifying Risks associated with the Transport of Radioactive Material - IAEA-TECDOC-1346,* Vienna, Austria: International Atomic Energy Agency, 2003.

[16] M. Gothié, *Heavy Vehicle Accident Factors,* Lyon, France: Laboratoire Régional de Lyon, 2006.

[17] G. Schwarz and F. N. Sentuc, *A Review of 10 Years Radioactive Material Transport Incidents and Accidents Experience in Germany,* Proceedings of the 15th International Symposium on the Packaging and Transportation of Radioactive Materials, PATRAM 2007, 2007.

[18] O. Doare, G. Sert and M. T. Lizot, *Evaluation of Safety of French Type B Package Designs in Severe Accident Environments Other Than Regulatory,* Proceedings of the 15th International Symposium on the Packaging and Transportation of Radioactive Materials, PATRAM 2007, 2007.

[19] L. Carenini, G. Sert, M. T. Lizot and C. Sauron, *Lessons from Transport Events Involving Radioactive Materials Occurred in France Between 1999 and 2009,* Proceedings of the 16th International Symposium on the Packaging and Transportation of Radioactive Materials, PATRAM 2009, 2009.

[20] P. Evgenikos, G. Yannis, K. Folla, R. Bauer, K. Machata and C. Brandstaetter, *Characteristics and Causes of Heavy Goods Vehicles and Buses Accidents in Europe,* 6th Transport Research Arena, TRA 2016, 2016.

[21] S. Kockum, R. Ortlund, A. Ekfjorden and P. & Wells, *Volvo Trucks Safety Report.,* Gothenburg, Sweden: Volvo Truck Corporation, 2017.

[22] L. Tao, L. Chen, L. Pengcheng, C. Chen and J. Wang, *Integrated Risk Assessment Method for Spent Fuel Road Transportation Accident under Complex Environment.,* Hefei, China: Nuclear Engineering and Technology, 2020.

[23] American Association of State Highway and Transportation Officials, *Highway Safety Manual,* Washington, D.C.: American Association of State Highway and Transportation Officials, 2010.

[24] Government of Canada., *Rail Occurence Data from January 1983 to Present. Available at: https://open.canada.ca/data/en/dataset/4f8d9b0d-c4af-4be2-b751-3f5a403993ff.*

[25] Volpe National Transportation Systems Center, *Spent Nuclear Fuel Transportation Risk,* Cambridge, MA, USA: Volpe National Transportation Systems Center, 2006.

[26] International Atomic Energy Agency, *Deterministic Safety Analysis for Nuclear Power Plants, IAEA Safety Standards, Specific Safety Guide No. SSG-2,* Vienna, Austria: International Atomic Energy Agency, 2009.

Appendix A

Conditional Probabilities for Incidents Involving Truck Tractors

Collision	Collision Type	Average probability (%)	Std. Dev.	Upper Bound Probability	Object Struck	Average probability (%)	Std. Dev.	Upper Bound Probability	Collision Configuration	Average probability (%)	Std. Dev.	Upper Bound Probability	Type of Shipment	Average probability (%)	Std. Dev.	Upper Bound Probability	Vehicle Severity Damage	Average probability (%)	Std. Dev.	Upper Bound Probability	Conditional Probability	Upper Bound of Conditional Probability	Ranking
Truck Collision	Collision with non-fixed object	66.3%	3.0%	69.3%	Train	<0.1% (0.009%)	<0.1% (0.014%)	Less than 0.1% (0.023%)		100.0%			Dangerous goods	0.3%	0.2%	0.50%	Demolished	33.3%	58%	91.1%	4.99E-08	7.22E-07	111
Truck Collision	Collision with non-fixed object	66.3%	3.0%	69.3%	Train	<0.1% (0.009%)	<0.1% (0.014%)	Less than 0.1% (0.023%)		100.0%			Dangerous goods	0.3%	0.2%	0.50%	Severe/Moderate Damage	66.7%	58%	124.4%	9.98E-08	9.86E-07	107
Truck Collision	Collision with non-fixed object	66.3%	3.0%	69.3%	Train	<0.1% (0.009%)	<0.1% (0.014%)	Less than 0.1% (0.023%)		100.0%			Dangerous goods	0.3%	0.2%	0.50%	Light Damage	0.0%	0%	0.0%	0.00E+00	0.00E+00	117
Truck Collision	Collision with non-fixed object	66.3%	3.0%	69.3%	Train	<0.1% (0.009%)	<0.1% (0.014%)	Less than 0.1% (0.023%)		100.0%			Conventional shipment	99.7%	0.2%	99.98%	Demolished	33.3%	58%	91.1%	1.93E-05	1.45E-04	72
Truck Collision	Collision with non-fixed object	66.3%	3.0%	69.3%	Train	<0.1% (0.009%)	<0.1% (0.014%)	Less than 0.1% (0.023%)		100.0%			Conventional shipment	99.7%	0.2%	99.98%	Severe/Moderate Damage	66.7%	58%	124.4%	3.86E-05	1.97E-04	63
Truck Collision	Collision with non-fixed object	66.3%	3.0%	69.3%	Train	<0.1% (0.009%)	<0.1% (0.014%)	Less than 0.1% (0.023%)		100.0%			Conventional shipment	99.7%	0.2%	99.98%	Light Damage	0.0%	0%	0.0%	0.00E+00	0.00E+00	117
Truck Collision	Collision with non-fixed object	66.3%	3.0%	69.3%	Other moving vehicle	90.7%	1.5%	92.2%		100.0%			Dangerous goods	0.3%	0.2%	0.50%	Demolished	2.7%	0%	3.1%	4.14E-05	9.83E-05	61
Truck Collision	Collision with non-fixed object	66.3%	3.0%	69.3%	Other moving vehicle	90.7%	1.5%	92.2%		100.0%			Dangerous goods	0.3%	0.2%	0.50%	Severe/Moderate Damage	22.0%	2%	24.0%	3.41E-04	7.66E-04	41
Truck Collision	Collision with non-fixed object	66.3%	3.0%	69.3%	Other moving vehicle	90.7%	1.5%	92.2%		100.0%			Dangerous goods	0.3%	0.2%	0.50%	Light Damage	75.3%	2%	77.6%	1.17E-03	2.47E-03	33
Truck Collision	Collision with non-fixed object	66.3%	3.0%	69.3%	Other moving vehicle	90.7%	1.5%	92.2%		100.0%			Conventional shipment	99.7%	0.2%	99.98%	Demolished	2.7%	0%	3.1%	1.60E-02	1.97E-02	12
Truck Collision	Collision with non-fixed object	66.3%	3.0%	69.3%	Other moving vehicle	90.7%	1.5%	92.2%		100.0%			Conventional shipment	99.7%	0.2%	99.98%	Severe/Moderate Damage	22.0%	2%	24.0%	1.32E-01	1.54E-01	2
Truck Collision	Collision with non-fixed object	66.3%	3.0%	69.3%	Other moving vehicle	90.7%	1.5%	92.2%		100.0%			Conventional shipment	99.7%	0.2%	99.98%	Light Damage	75.3%	2%	77.6%	4.52E-01	4.95E-01	1
Truck Collision	Collision with non-fixed object	66.3%	3.0%	69.3%	Farm tractor	<0.1% (0.029%)	Less than 0.1% (0.027%)	Less than 0.1% (0.056%)		100.0%			Dangerous goods	0.3%	0.2%	0.50%	Demolished	14.3%	38%	52.1%	7.10E-08	1.00E-06	110
Truck Collision	Collision with non-fixed object	66.3%	3.0%	69.3%	Farm tractor	<0.1% (0.029%)	Less than 0.1% (0.027%)	Less than 0.1% (0.056%)		100.0%			Dangerous goods	0.3%	0.2%	0.50%	Severe/Moderate Damage	57.1%	53%	110.6%	2.84E-07	2.13E-06	102
Truck Collision	Collision with non-fixed object	66.3%	3.0%	69.3%	Farm tractor	<0.1% (0.029%)	Less than 0.1% (0.027%)	Less than 0.1% (0.056%)		100.0%			Dangerous goods	0.3%	0.2%	0.50%	Light Damage	28.6%	49%	77.4%	1.42E-07	1.49E-06	106
Truck Collision	Collision with non-fixed object	66.3%	3.0%	69.3%	Farm tractor	<0.1% (0.029%)	Less than 0.1% (0.027%)	Less than 0.1% (0.056%)		100.0%			Conventional shipment	99.7%	0.2%	99.98%	Demolished	14.3%	38%	52.1%	2.75E-05	2.01E-04	70
Truck Collision	Collision with non-fixed object	66.3%	3.0%	69.3%	Farm tractor	<0.1% (0.029%)	Less than 0.1% (0.027%)	Less than 0.1% (0.056%)		100.0%			Conventional shipment	99.7%	0.2%	99.98%	Severe/Moderate Damage	57.1%	53%	110.6%	1.10E-04	4.27E-04	48
Truck Collision	Collision with non-fixed object	66.3%	3.0%	69.3%	Farm tractor	<0.1% (0.029%)	Less than 0.1% (0.027%)	Less than 0.1% (0.056%)		100.0%			Conventional shipment	99.7%	0.2%	99.98%	Light Damage	28.6%	49%	77.4%	5.49E-05	2.99E-04	58
Truck Collision	Collision with non-fixed object	66.3%	3.0%	69.3%	Other non-fixed/moving object	3.0%	3.1%	6.1%		100.0%			Dangerous goods	0.3%	0.2%	0.50%	Demolished	2.1%	2%	3.8%	1.07E-06	7.93E-06	96
Truck Collision	Collision with non-fixed object	66.3%	3.0%	69.3%	Other non-fixed/moving object	3.0%	3.1%	6.1%		100.0%			Dangerous goods	0.3%	0.2%	0.50%	Severe/Moderate Damage	36.3%	17%	53.7%	1.85E-05	1.12E-04	74
Truck Collision	Collision with non-fixed object	66.3%	3.0%	69.3%	Other non-fixed/moving object	3.0%	3.1%	6.1%		100.0%			Dangerous goods	0.3%	0.2%	0.50%	Light Damage	61.6%	17%	78.2%	3.14E-05	1.64E-04	68
Truck Collision	Collision with non-fixed object	66.3%	3.0%	69.3%	Other non-fixed/moving object	3.0%	3.1%	6.1%		100.0%			Conventional shipment	99.7%	0.2%	99.98%	Demolished	2.1%	2%	3.8%	4.15E-04	1.59E-03	40
Truck Collision	Collision with non-fixed object	66.3%	3.0%	69.3%	Other non-fixed/moving object	3.0%	3.1%	6.1%		100.0%			Conventional shipment	99.7%	0.2%	99.98%	Severe/Moderate Damage	36.3%	17%	53.7%	7.17E-03	2.25E-02	20
Truck Collision	Collision with non-fixed object	66.3%	3.0%	69.3%	Other non-fixed/moving object	3.0%	3.1%	6.1%		100.0%			Conventional shipment	99.7%	0.2%	99.98%	Light Damage	61.6%	17%	78.2%	1.22E-02	3.28E-02	16
Truck Collision	Collision with non-fixed object	66.3%	3.0%	69.3%	Animal-wild	6.3%	4.2%	10.5%		100.0%			Dangerous goods	0.3%	0.2%	0.50%	Demolished	1.2%	2%	2.7%	1.24E-06	9.69E-06	94
Truck Collision	Collision with non-fixed object	66.3%	3.0%	69.3%	Animal-wild	6.3%	4.2%	10.5%		100.0%			Dangerous goods	0.3%	0.2%	0.50%	Severe/Moderate Damage	54.4%	6%	60.4%	5.85E-05	2.19E-04	56
Truck Collision	Collision with non-fixed object	66.3%	3.0%	69.3%	Animal-wild	6.3%	4.2%	10.5%		100.0%			Dangerous goods	0.3%	0.2%	0.50%	Light Damage	44.5%	6%	50.5%	4.78E-05	1.82E-04	59
Truck Collision	Collision with non-fixed object	66.3%	3.0%	69.3%	Animal-wild	6.3%	4.2%	10.5%		100.0%			Conventional shipment	99.7%	0.2%	99.98%	Demolished	1.2%	2%	2.7%	4.81E-04	1.94E-03	38
Truck Collision	Collision with non-fixed object	66.3%	3.0%	69.3%	Animal-wild	6.3%	4.2%	10.5%		100.0%			Conventional shipment	99.7%	0.2%	99.98%	Severe/Moderate Damage	54.4%	6%	60.4%	2.26E-02	4.38E-02	8
Truck Collision	Collision with non-fixed object	66.3%	3.0%	69.3%	Animal-wild	6.3%	4.2%	10.5%		100.0%			Conventional shipment	99.7%	0.2%	99.98%	Light Damage	44.5%	6%	50.5%	1.85E-02	3.66E-02	10
Truck Collision	Collision with fixed object	15.4%	0.9%	16.3%	Bridge	1.0%	0.5%	1.5%	Run-off	4.0%	4.5%	8.5%	Dangerous goods	0.3%	0.2%	0.50%	Demolished	25.0%	41.8%	66.8%	4.15E-08	6.91E-07	112
Truck Collision	Collision with fixed object	15.4%	0.9%	16.3%	Bridge	1.0%	0.5%	1.5%	Run-off	4.0%	4.5%	8.5%	Dangerous goods	0.3%	0.2%	0.50%	Severe/Moderate Damage	58.3%	49.2%	107.5%	9.68E-08	1.11E-06	109
Truck Collision	Collision with fixed object	15.4%	0.9%	16.3%	Bridge	1.0%	0.5%	1.5%	Run-off	4.0%	4.5%	8.5%	Dangerous goods	0.3%	0.2%	0.50%	Light Damage	16.7%	40.8%	57.5%	2.77E-08	5.94E-07	113
Truck Collision	Collision with fixed object	15.4%	0.9%	16.3%	Bridge	1.0%	0.5%	1.5%	Run-off	4.0%	4.5%	8.5%	Conventional shipment	99.7%	0.2%	99.98%	Demolished	25.0%	41.8%	66.8%	1.61E-05	1.38E-04	75
Truck Collision	Collision with fixed object	15.4%	0.9%	16.3%	Bridge	1.0%	0.5%	1.5%	Run-off	4.0%	4.5%	8.5%	Conventional shipment	99.7%	0.2%	99.98%	Severe/Moderate Damage	58.3%	49.2%	107.5%	3.75E-05	2.23E-04	65
Truck Collision	Collision with fixed object	15.4%	0.9%	16.3%	Bridge	1.0%	0.5%	1.5%	Run-off	4.0%	4.5%	8.5%	Conventional shipment	99.7%	0.2%	99.98%	Light Damage	16.7%	40.8%	57.5%	1.07E-05	1.19E-04	77
Truck Collision	Collision with fixed object	15.4%	0.9%	16.3%	Bridge	1.0%	0.5%	1.5%	Not run-off	96.0%	4.5%	100.5%	Dangerous goods	0.3%	0.2%	0.50%	Demolished	8.8%	5.2%	14.0%	3.48E-07	1.70E-06	100
Truck Collision	Collision with fixed object	15.4%	0.9%	16.3%	Bridge	1.0%	0.5%	1.5%	Not run-off	96.0%	4.5%	100.5%	Dangerous goods	0.3%	0.2%	0.50%	Severe/Moderate Damage	35.6%	20.6%	56.3%	1.41E-06	6.85E-06	93
Truck Collision	Collision with fixed object	15.4%	0.9%	16.3%	Bridge	1.0%	0.5%	1.5%	Not run-off	96.0%	4.5%	100.5%	Dangerous goods	0.3%	0.2%	0.50%	Light Damage	55.6%	5.2%	60.7%	2.20E-06	7.39E-06	91
Truck Collision	Collision with fixed object	15.4%	0.9%	16.3%	Bridge	1.0%	0.5%	1.5%	Not run-off	96.0%	4.5%	100.5%	Conventional shipment	99.7%	0.2%	99.98%	Demolished	8.8%	5.2%	14.0%	1.35E-04	3.41E-04	46
Truck Collision	Collision with fixed object	15.4%	0.9%	16.3%	Bridge	1.0%	0.5%	1.5%	Not run-off	96.0%	4.5%	100.5%	Conventional shipment	99.7%	0.2%	99.98%	Severe/Moderate Damage	35.6%	20.6%	56.3%	5.45E-04	1.37E-03	37
Truck Collision	Collision with fixed object	15.4%	0.9%	16.3%	Bridge	1.0%	0.5%	1.5%	Not run-off	96.0%	4.5%	100.5%	Conventional shipment	99.7%	0.2%	99.98%	Light Damage	55.6%	5.2%	60.7%	8.49E-04	1.48E-03	35
Truck Collision	Collision with fixed object	15.4%	0.9%	16.3%	Other fixed road structure	0.2%	0.2%	0.3%		100.0%			Dangerous goods	0.3%	0.2%	0.50%	Demolished	0.0%	0%	0.0%	0.00E+00	0.00E+00	117
Truck Collision	Collision with fixed object	15.4%	0.9%	16.3%	Other fixed road structure	0.2%	0.2%	0.3%		100.0%			Dangerous goods	0.3%	0.2%	0.50%	Severe/Moderate Damage	71.9%	41%	112.9%	5.25E-07	3.12E-06	99
Truck Collision	Collision with fixed object	15.4%	0.9%	16.3%	Other fixed road structure	0.2%	0.2%	0.3%		100.0%			Dangerous goods	0.3%	0.2%	0.50%	Light Damage	28.1%	41%	69.2%	2.06E-07	1.91E-06	103
Truck Collision	Collision with fixed object	15.4%	0.9%	16.3%	Other fixed road structure	0.2%	0.2%	0.3%		100.0%			Conventional shipment	99.7%	0.2%	99.98%	Demolished	0.0%	0%	0.0%	0.00E+00	0.00E+00	117
Truck Collision	Collision with fixed object	15.4%	0.9%	16.3%	Other fixed road structure	0.2%	0.2%	0.3%		100.0%			Conventional shipment	99.7%	0.2%	99.98%	Severe/Moderate Damage	71.9%	41%	112.9%	2.03E-04	6.26E-04	44
Truck Collision	Collision with fixed object	15.4%	0.9%	16.3%	Other fixed road structure	0.2%	0.2%	0.3%		100.0%			Conventional shipment	99.7%	0.2%	99.98%	Light Damage	28.1%	41%	69.2%	7.95E-05	3.83E-04	51
Truck Collision	Collision with fixed object	15.4%	0.9%	16.3%	Other fixed object	58.7%	2.6%	61.4%		100.0%			Dangerous goods	0.3%	0.2%	0.50%	Demolished	15.0%	3%	17.6%	3.49E-05	8.77E-05	66
Truck Collision	Collision with fixed object	15.4%	0.9%	16.3%	Other fixed object	58.7%	2.6%	61.4%		100.0%			Dangerous goods	0.3%	0.2%	0.50%	Severe/Moderate Damage	45.5%	3%	48.9%	1.06E-04	2.44E-04	49
Truck Collision	Collision with fixed object	15.4%	0.9%	16.3%	Other fixed object	58.7%	2.6%	61.4%		100.0%			Dangerous goods	0.3%	0.2%	0.50%	Light Damage	39.6%	4%	43.8%	9.23E-05	2.19E-04	50
Truck Collision	Collision with fixed object	15.4%	0.9%	16.3%	Other fixed object	58.7%	2.6%	61.4%		100.0%			Conventional shipment	99.7%	0.2%	99.98%	Demolished	15.0%	3%	17.6%	1.35E-02	1.76E-02	14
Truck Collision	Collision with fixed object	15.4%	0.9%	16.3%	Other fixed object	58.7%	2.6%	61.4%		100.0%			Conventional shipment	99.7%	0.2%	99.98%	Severe/Moderate Damage	45.5%	3%	48.9%	4.11E-02	4.89E-02	4
Truck Collision	Collision with fixed object	15.4%	0.9%	16.3%	Other fixed object	58.7%	2.6%	61.4%		100.0%			Conventional shipment	99.7%	0.2%	99.98%	Light Damage	39.6%	4%	43.8%	3.57E-02	4.38E-02	5
Truck Collision	Collision with fixed object	15.4%	0.9%	16.3%	Rock face	3.2%	0.7%	3.9%		100.0%			Dangerous goods	0.3%	0.2%	0.50%	Demolished	44.3%	8%	52.4%	5.70E-06	1.66E-05	83
Truck Collision	Collision with fixed object	15.4%	0.9%	16.3%	Rock face	3.2%	0.7%	3.9%		100.0%			Dangerous goods	0.3%	0.2%	0.50%	Severe/Moderate Damage	46.7%	9%	56.0%	6.01E-06	1.77E-05	81
Truck Collision	Collision with fixed object	15.4%	0.9%	16.3%	Rock face	3.2%	0.7%	3.9%		100.0%			Dangerous goods	0.3%	0.2%	0.50%	Light Damage	9.1%	5%	13.9%	1.17E-06	4.39E-06	95
Truck Collision	Collision with fixed object	15.4%	0.9%	16.3%	Rock face	3.2%	0.7%	3.9%		100.0%			Conventional shipment	99.7%	0.2%	99.98%	Demolished	44.3%	8%	52.4%	2.20E-03	3.33E-03	26
Truck Collision	Collision with fixed object	15.4%	0.9%	16.3%	Rock face	3.2%	0.7%	3.9%		100.0%			Conventional shipment	99.7%	0.2%	99.98%	Severe/Moderate Damage	46.7%	9%	56.0%	2.32E-03	3.55E-03	24
Truck Collision	Collision with fixed object	15.4%	0.9%	16.3%	Rock face	3.2%	0.7%	3.9%		100.0%			Conventional shipment	99.7%	0.2%	99.98%	Light Damage	9.1%	5%	13.9%	4.53E-04	8.79E-04	39
Truck Collision	Collision with fixed object	15.4%	0.9%	16.3%	Snow pile	3.4%	1.1%	4.5%		100.0%			Dangerous goods	0.3%	0.2%	0.50%	Demolished	4.2%	4%	8.5%	5.75E-07	3.12E-06	98
Truck Collision	Collision with fixed object	15.4%	0.9%	16.3%	Snow pile	3.4%	1.1%	4.5%		100.0%			Dangerous goods	0.3%	0.2%	0.50%	Severe/Moderate Damage	54.5%	9%	63.5%	7.41E-06	2.33E-05	79
Truck Collision	Collision with fixed object	15.4%	0.9%	16.3%	Snow pile	3.4%	1.1%	4.5%		100.0%			Dangerous goods	0.3%	0.2%	0.50%	Light Damage	41.2%	11%	52.3%	5.60E-06	1.91E-05	84
Truck Collision	Collision with fixed object	15.4%	0.9%	16.3%	Snow pile	3.4%	1.1%	4.5%		100.0%			Conventional shipment	99.7%	0.2%	99.98%	Demolished	4.2%	4%	8.5%	2.22E-04	6.26E-04	43
Truck Collision	Collision with fixed object	15.4%	0.9%	16.3%	Snow pile	3.4%	1.1%	4.5%		100.0%			Conventional shipment	99.7%	0.2%	99.98%	Severe/Moderate Damage	54.5%	9%	63.5%	2.87E-03	4.66E-03	22
Truck Collision	Collision with fixed object	15.4%	0.9%	16.3%	Snow pile	3.4%	1.1%	4.5%		100.0%			Conventional shipment	99.7%	0.2%	99.98%	Light Damage	41.2%	11%	52.3%	2.17E-03	3.83E-03	27
Truck Collision	Collision with fixed object	15.4%	0.9%	16.3%	Water course	0.1%	0.1%	0.2%		100.0%			Dangerous goods	0.3%	0.2%	0.50%	Demolished	21.4%	39%	60.8%	9.85E-08	1.04E-06	108
Truck Collision	Collision with fixed object	15.4%	0.9%	16.3%	Water course	0.1%	0.1%	0.2%		100.0%			Dangerous goods	0.3%	0.2%	0.50%	Severe/Moderate Damage	42.9%	53%	96.3%	1.97E-07	1.65E-06	104
Truck Collision	Collision with fixed object	15.4%	0.9%	16.3%	Water course	0.1%	0.1%	0.2%		100.0%			Dangerous goods	0.3%	0.2%	0.50%	Light Damage	35.7%	48%	83.3%	1.64E-07	1.43E-06	105
Truck Collision	Collision with fixed object	15.4%	0.9%	16.3%	Water course	0.1%	0.1%	0.2%		100.0%			Conventional shipment	99.7%	0.2%	99.98%	Demolished	21.4%	39%	60.8%	3.81E-05	2.09E-04	64
Truck Collision	Collision with fixed object	15.4%	0.9%	16.3%	Water course	0.1%	0.1%	0.2%		100.0%			Conventional shipment	99.7%	0.2%	99.98%	Severe/Moderate Damage	42.9%	53%	96.3%	7.62E-05	3.31E-04	53
Truck Collision	Collision with fixed object	15.4%	0.9%	16.3%	Water course	0.1%	0.1%	0.2%		100.0%			Conventional shipment	99.7%	0.2%	99.98%	Light Damage	35.7%	48%	83.3%	6.35E-05	2.87E-04	55
Truck Collision	Collision with fixed object	15.4%	0.9%	16.3%	Submersion	0.1%	0.1%	0.2%		100.0%			Dangerous goods	0.3%	0.2%	0.50%	Demolished	93.8%	13%	106.3%	2.91E-07	1.87E-06	101
Truck Collision	Collision with fixed object	15.4%	0.9%	16.3%	Submersion	0.1%	0.1%	0.2%		100.0%			Dangerous goods	0.3%	0.2%	0.50%	Severe/Moderate Damage	6.3%	13%	18.8%	1.94E-08	3.29E-07	114
Truck Collision	Collision with fixed object	15.4%	0.9%	16.3%	Submersion	0.1%	0.1%	0.2%		100.0%			Dangerous goods	0.3%	0.2%	0.50%	Light Damage	0.0%	0%	0.0%	0.00E+00	0.00E+00	117
Truck Collision	Collision with fixed object	15.4%	0.9%	16.3%	Submersion	0.1%	0.1%	0.2%		100.0%			Conventional shipment	99.7%	0.2%	99.98%	Demolished	93.8%	13%	106.3%	1.13E-04	3.74E-04	47

Truck Collision	Collision with fixed object	15.4%	0.9%	16.3%	Submersion	0.1%	0.1%	0.2%		100.0%		Conventional shipment	99.7%	0.2%	99.98%	Severe/Moderate Damage	6.3%	13%	18.8%	7.51E-06	6.60E-05	78
Truck Collision	Collision with fixed object	15.4%	0.9%	16.3%	Submersion	0.1%	0.1%	0.2%		100.0%		Conventional shipment	99.7%	0.2%	99.98%	Light Damage	0.0%	0%	0.0%	0.00E+00	0.00E+00	117
Truck Collision	Collision with fixed object	15.4%	0.9%	16.3%	Ditch	33.2%	2.7%	35.9%		100.0%		Dangerous goods	0.3%	0.2%	0.50%	Demolished	17.2%	4%	21.1%	2.27E-05	6.15E-05	71
Truck Collision	Collision with fixed object	15.4%	0.9%	16.3%	Ditch	33.2%	2.7%	35.9%		100.0%		Dangerous goods	0.3%	0.2%	0.50%	Severe/Moderate Damage	58.2%	5%	63.7%	7.69E-05	1.86E-04	52
Truck Collision	Collision with fixed object	15.4%	0.9%	16.3%	Ditch	33.2%	2.7%	35.9%		100.0%		Dangerous goods	0.3%	0.2%	0.50%	Light Damage	24.6%	3%	27.9%	3.25E-05	8.15E-05	67
Truck Collision	Collision with fixed object	15.4%	0.9%	16.3%	Ditch	33.2%	2.7%	35.9%		100.0%		Conventional shipment	99.7%	0.2%	99.98%	Demolished	17.2%	4%	21.1%	8.77E-03	1.23E-02	18
Truck Collision	Collision with fixed object	15.4%	0.9%	16.3%	Ditch	33.2%	2.7%	35.9%		100.0%		Conventional shipment	99.7%	0.2%	99.98%	Severe/Moderate Damage	58.2%	5%	63.7%	2.97E-02	3.72E-02	6
Truck Collision	Collision with fixed object	15.4%	0.9%	16.3%	Ditch	33.2%	2.7%	35.9%		100.0%		Conventional shipment	99.7%	0.2%	99.98%	Light Damage	24.6%	3%	27.9%	1.26E-02	1.63E-02	15
Truck Collision	Non-collision	15.9%	2.0%	17.9%	Fire/Explosion	2.8%	1.1%	3.8%		100.0%		Dangerous goods	0.3%	0.2%	0.50%	Demolished	52.3%	12%	63.9%	5.92E-06	2.18E-05	82
Truck Collision	Non-collision	15.9%	2.0%	17.9%	Fire/Explosion	2.8%	1.1%	3.8%		100.0%		Dangerous goods	0.3%	0.2%	0.50%	Severe/Moderate Damage	33.6%	10%	43.3%	3.81E-06	1.47E-05	89
Truck Collision	Non-collision	15.9%	2.0%	17.9%	Fire/Explosion	2.8%	1.1%	3.8%		100.0%		Dangerous goods	0.3%	0.2%	0.50%	Light Damage	14.1%	8%	22.0%	1.60E-06	7.48E-06	92
Truck Collision	Non-collision	15.9%	2.0%	17.9%	Fire/Explosion	2.8%	1.1%	3.8%		100.0%		Conventional shipment	99.7%	0.2%	99.98%	Demolished	52.3%	12%	63.9%	2.29E-03	4.36E-03	25
Truck Collision	Non-collision	15.9%	2.0%	17.9%	Fire/Explosion	2.8%	1.1%	3.8%		100.0%		Conventional shipment	99.7%	0.2%	99.98%	Severe/Moderate Damage	33.6%	10%	43.3%	1.47E-03	2.95E-03	32
Truck Collision	Non-collision	15.9%	2.0%	17.9%	Fire/Explosion	2.8%	1.1%	3.8%		100.0%		Conventional shipment	99.7%	0.2%	99.98%	Light Damage	14.1%	8%	22.0%	6.18E-04	1.50E-03	36
Truck Collision	Non-collision	15.9%	2.0%	17.9%	Load spill	2.8%	0.8%	3.6%		100.0%		Dangerous goods	0.3%	0.2%	0.50%	Demolished	19.4%	7%	26.2%	2.22E-06	8.40E-06	90
Truck Collision	Non-collision	15.9%	2.0%	17.9%	Load spill	2.8%	0.8%	3.6%		100.0%		Dangerous goods	0.3%	0.2%	0.50%	Severe/Moderate Damage	42.0%	7%	48.9%	4.79E-06	1.56E-05	85
Truck Collision	Non-collision	15.9%	2.0%	17.9%	Load spill	2.8%	0.8%	3.6%		100.0%		Dangerous goods	0.3%	0.2%	0.50%	Light Damage	38.6%	8%	46.2%	4.41E-06	1.48E-05	86
Truck Collision	Non-collision	15.9%	2.0%	17.9%	Load spill	2.8%	0.8%	3.6%		100.0%		Conventional shipment	99.7%	0.2%	99.98%	Demolished	19.4%	7%	26.2%	8.58E-04	1.68E-03	34
Truck Collision	Non-collision	15.9%	2.0%	17.9%	Load spill	2.8%	0.8%	3.6%		100.0%		Conventional shipment	99.7%	0.2%	99.98%	Severe/Moderate Damage	42.0%	7%	48.9%	1.85E-03	3.13E-03	28
Truck Collision	Non-collision	15.9%	2.0%	17.9%	Load spill	2.8%	0.8%	3.6%		100.0%		Conventional shipment	99.7%	0.2%	99.98%	Light Damage	38.6%	8%	46.2%	1.71E-03	2.96E-03	29
Truck Collision	Non-collision	15.9%	2.0%	17.9%	Other non-collision	66.4%	2.6%	69.0%		100.0%		Dangerous goods	0.3%	0.2%	0.50%	Demolished	16.7%	4%	20.2%	4.53E-05	1.24E-04	60
Truck Collision	Non-collision	15.9%	2.0%	17.9%	Other non-collision	66.4%	2.6%	69.0%		100.0%		Dangerous goods	0.3%	0.2%	0.50%	Severe/Moderate Damage	56.1%	4%	59.7%	1.53E-04	3.67E-04	45
Truck Collision	Non-collision	15.9%	2.0%	17.9%	Other non-collision	66.4%	2.6%	69.0%		100.0%		Dangerous goods	0.3%	0.2%	0.50%	Light Damage	27.2%	2%	29.3%	7.41E-05	1.80E-04	54
Truck Collision	Non-collision	15.9%	2.0%	17.9%	Other non-collision	66.4%	2.6%	69.0%		100.0%		Conventional shipment	99.7%	0.2%	99.98%	Demolished	16.7%	4%	20.2%	1.75E-02	2.49E-02	11
Truck Collision	Non-collision	15.9%	2.0%	17.9%	Other non-collision	66.4%	2.6%	69.0%		100.0%		Conventional shipment	99.7%	0.2%	99.98%	Severe/Moderate Damage	56.1%	4%	59.7%	5.91E-02	7.35E-02	3
Truck Collision	Non-collision	15.9%	2.0%	17.9%	Other non-collision	66.4%	2.6%	69.0%		100.0%		Conventional shipment	99.7%	0.2%	99.98%	Light Damage	27.2%	2%	29.3%	2.87E-02	3.60E-02	7
Truck Collision	Non-collision	15.9%	2.0%	17.9%	Rollover	12.8%	2.2%	15.0%		100.0%		Dangerous goods	0.3%	0.2%	0.50%	Demolished	36.1%	4%	40.5%	1.89E-05	5.41E-05	73
Truck Collision	Non-collision	15.9%	2.0%	17.9%	Rollover	12.8%	2.2%	15.0%		100.0%		Dangerous goods	0.3%	0.2%	0.50%	Severe/Moderate Damage	56.4%	7%	63.2%	2.95E-05	8.43E-05	69
Truck Collision	Non-collision	15.9%	2.0%	17.9%	Rollover	12.8%	2.2%	15.0%		100.0%		Dangerous goods	0.3%	0.2%	0.50%	Light Damage	7.5%	3%	10.4%	3.91E-06	1.39E-05	88
Truck Collision	Non-collision	15.9%	2.0%	17.9%	Rollover	12.8%	2.2%	15.0%		100.0%		Conventional shipment	99.7%	0.2%	99.98%	Demolished	36.1%	4%	40.5%	7.32E-03	1.08E-02	19
Truck Collision	Non-collision	15.9%	2.0%	17.9%	Rollover	12.8%	2.2%	15.0%		100.0%		Conventional shipment	99.7%	0.2%	99.98%	Severe/Moderate Damage	56.4%	7%	63.2%	1.14E-02	1.69E-02	17
Truck Collision	Non-collision	15.9%	2.0%	17.9%	Rollover	12.8%	2.2%	15.0%		100.0%		Conventional shipment	99.7%	0.2%	99.98%	Light Damage	7.5%	3%	10.4%	1.51E-03	2.78E-03	31
Truck Collision	Non-collision	15.9%	2.0%	17.9%	Jack knifing	15.2%	3.3%	18.6%		100.0%		Dangerous goods	0.3%	0.2%	0.50%	Demolished	11.2%	3%	13.8%	7.00E-06	2.28E-05	80
Truck Collision	Non-collision	15.9%	2.0%	17.9%	Jack knifing	15.2%	3.3%	18.6%		100.0%		Dangerous goods	0.3%	0.2%	0.50%	Severe/Moderate Damage	65.5%	6%	71.3%	4.09E-05	1.18E-04	62
Truck Collision	Non-collision	15.9%	2.0%	17.9%	Jack knifing	15.2%	3.3%	18.6%		100.0%		Dangerous goods	0.3%	0.2%	0.50%	Light Damage	23.3%	5%	27.8%	1.45E-05	4.60E-05	76
Truck Collision	Non-collision	15.9%	2.0%	17.9%	Jack knifing	15.2%	3.3%	18.6%		100.0%		Conventional shipment	99.7%	0.2%	99.98%	Demolished	11.2%	3%	13.8%	2.71E-03	4.56E-03	23
Truck Collision	Non-collision	15.9%	2.0%	17.9%	Jack knifing	15.2%	3.3%	18.6%		100.0%		Conventional shipment	99.7%	0.2%	99.98%	Severe/Moderate Damage	65.5%	6%	71.3%	1.58E-02	2.37E-02	13
Truck Collision	Non-collision	15.9%	2.0%	17.9%	Jack knifing	15.2%	3.3%	18.6%		100.0%		Conventional shipment	99.7%	0.2%	99.98%	Light Damage	23.3%	5%	27.8%	5.62E-03	9.22E-03	21
Truck Collision	Other Event	2.4%	2.0%	4.4%		100.0%				100.0%		Dangerous goods	0.3%	0.2%	0.50%	Demolished	1.3%	1%	2.3%	8.23E-07	4.92E-06	97
Truck Collision	Other Event	2.4%	2.0%	4.4%		100.0%				100.0%		Dangerous goods	0.3%	0.2%	0.50%	Severe/Moderate Damage	6.8%	5%	11.9%	4.20E-06	2.59E-05	87
Truck Collision	Other Event	2.4%	2.0%	4.4%		100.0%				100.0%		Dangerous goods	0.3%	0.2%	0.50%	Light Damage	91.9%	6%	97.5%	5.69E-05	2.13E-04	57
Truck Collision	Other Event	2.4%	2.0%	4.4%		100.0%				100.0%		Conventional shipment	99.7%	0.2%	99.98%	Demolished	1.3%	1%	2.3%	3.18E-04	9.86E-04	42
Truck Collision	Other Event	2.4%	2.0%	4.4%		100.0%				100.0%		Conventional shipment	99.7%	0.2%	99.98%	Severe/Moderate Damage	6.8%	5%	11.9%	1.62E-03	5.18E-03	30
Truck Collision	Other Event	2.4%	2.0%	4.4%		100.0%				100.0%		Conventional shipment	99.7%	0.2%	99.98%	Light Damage	91.9%	6%	97.5%	2.20E-02	4.26E-02	9

Appendix B

Conditional Probabilities for Incidents Involving Trains

Collision	Derailment Scenario	Average probability (%)	Std. Dev.	Upper Bound Probability	Collision Scenario	Average probability (%)	Std. Dev.	Upper Bound Probability	Type of Shipment	Average probability (%)	Std. Dev.	Upper Bound Probability	Breach of Dangerous Goods	Average probability (%)	Std. Dev.	Upper Bound Probability	Conditional Probability	Upper Bound of Conditional Probability	Ranking
Train Collision	Remains on rail	36.6%	1.5%	38.1%	Other trains	15.0%	2.1%	17.1%	Dangerous goods	12.5%	1.7%	14.2%	Breach of materials	0.0%	0.0%	0.0%	0.00E+00	0.00E+00	27
Train Collision	Remains on rail	36.6%	1.5%	38.1%	Other trains	15.0%	2.1%	17.1%	Dangerous goods	12.5%	1.7%	14.2%	No breach	100.0%	0.0%	100.0%	6.86E-03	9.21E-03	13
Train Collision	Remains on rail	36.6%	1.5%	38.1%	Other trains	15.0%	2.1%	17.1%	Conventional shipment	87.5%	1.7%	89.2%		100.0%	0.0%	100.0%	4.81E-02	5.80E-02	6
Train Collision	Remains on rail	36.6%	1.5%	38.1%	Life form	19.4%	3.5%	22.9%	Dangerous goods	12.5%	1.7%	14.2%	Breach of materials	0.0%	0.0%	0.0%	0.00E+00	0.00E+00	27
Train Collision	Remains on rail	36.6%	1.5%	38.1%	Life form	19.4%	3.5%	22.9%	Dangerous goods	12.5%	1.7%	14.2%	No breach	100.0%	0.0%	100.0%	8.90E-03	1.24E-02	12
Train Collision	Remains on rail	36.6%	1.5%	38.1%	Life form	19.4%	3.5%	22.9%	Conventional shipment	87.5%	1.7%	89.2%		100.0%	0.0%	100.0%	6.23E-02	7.78E-02	4
Train Collision	Remains on rail	36.6%	1.5%	38.1%	Other objects	57.1%	4.4%	61.4%	Dangerous goods	12.5%	1.7%	14.2%	Breach of materials	1.2%	2.0%	3.1%	3.02E-04	1.05E-03	19
Train Collision	Remains on rail	36.6%	1.5%	38.1%	Other objects	57.1%	4.4%	61.4%	Dangerous goods	12.5%	1.7%	14.2%	No breach	98.8%	2.0%	100.8%	2.59E-02	3.35E-02	9
Train Collision	Remains on rail	36.6%	1.5%	38.1%	Other objects	57.1%	4.4%	61.4%	Conventional shipment	87.5%	1.7%	89.2%		100.0%	0.0%	100.0%	1.83E-01	2.09E-01	2
Train Collision	Remains on rail	36.6%	1.5%	38.1%	Fire/Explosion	8.5%	4.9%	13.4%	Dangerous goods	12.5%	1.7%	14.2%	Breach of materials	0.3%	1.0%	1.3%	1.22E-05	9.43E-05	23
Train Collision	Remains on rail	36.6%	1.5%	38.1%	Fire/Explosion	8.5%	4.9%	13.4%	Dangerous goods	12.5%	1.7%	14.2%	No breach	99.7%	1.0%	100.7%	3.88E-03	7.30E-03	15
Train Collision	Remains on rail	36.6%	1.5%	38.1%	Fire/Explosion	8.5%	4.9%	13.4%	Conventional shipment	87.5%	1.7%	89.2%		100.0%	0.0%	100.0%	2.72E-02	4.56E-02	8
Train Collision	Derailment	63.4%	1.5%	64.9%	Other trains	6.0%	0.8%	6.7%	Dangerous goods	12.5%	1.7%	14.2%	Breach of materials	0.1%	0.3%	0.5%	6.88E-06	2.80E-05	25
Train Collision	Derailment	63.4%	1.5%	64.9%	Other trains	6.0%	0.8%	6.7%	Dangerous goods	12.5%	1.7%	14.2%	No breach	99.9%	0.3%	100.2%	4.73E-03	6.19E-03	14
Train Collision	Derailment	63.4%	1.5%	64.9%	Other trains	6.0%	0.8%	6.7%	Conventional shipment	87.5%	1.7%	89.2%		100.0%	0.0%	100.0%	3.31E-02	3.89E-02	7
Train Collision	Derailment	63.4%	1.5%	64.9%	Life form	<0.1% (0.04%)	0.1%	0.1%	Dangerous goods	12.5%	1.7%	14.2%	Breach of materials	0.0%	0.0%	0.0%	0.00E+00	0.00E+00	27
Train Collision	Derailment	63.4%	1.5%	64.9%	Life form	<0.1% (0.04%)	0.1%	0.1%	Dangerous goods	12.5%	1.7%	14.2%	No breach	100.0%	0.0%	100.0%	3.30E-05	1.00E-04	22
Train Collision	Derailment	63.4%	1.5%	64.9%	Life form	<0.1% (0.04%)	0.1%	0.1%	Conventional shipment	87.5%	1.7%	89.2%		100.0%	0.0%	100.0%	2.31E-04	6.29E-04	20
Train Collision	Derailment	63.4%	1.5%	64.9%	Other objects	3.4%	0.6%	4.0%	Dangerous goods	12.5%	1.7%	14.2%	Breach of materials	0.2%	0.4%	0.5%	4.68E-06	2.01E-05	26
Train Collision	Derailment	63.4%	1.5%	64.9%	Other objects	3.4%	0.6%	4.0%	Dangerous goods	12.5%	1.7%	14.2%	No breach	99.8%	0.4%	100.2%	2.68E-03	3.69E-03	16
Train Collision	Derailment	63.4%	1.5%	64.9%	Other objects	3.4%	0.6%	4.0%	Conventional shipment	87.5%	1.7%	89.2%		100.0%	0.0%	100.0%	1.88E-02	2.31E-02	10
Train Collision	Derailment	63.4%	1.5%	64.9%	Fire/Explosion	Less than 0.1% (0.013%)	Less than 0.1% (0.041%)	Less than 0.1% (0.054%)	Dangerous goods	12.5%	1.7%	14.2%	Breach of materials	0.0%	0.0%	0.0%	0.00E+00	0.00E+00	27
Train Collision	Derailment	63.4%	1.5%	64.9%	Fire/Explosion	Less than 0.1% (0.013%)	Less than 0.1% (0.041%)	Less than 0.1% (0.054%)	Dangerous goods	12.5%	1.7%	14.2%	No breach	100.0%	0.0%	100.0%	1.04E-05	5.02E-05	24
Train Collision	Derailment	63.4%	1.5%	64.9%	Fire/Explosion	Less than 0.1% (0.013%)	Less than 0.1% (0.041%)	Less than 0.1% (0.054%)	Conventional shipment	87.5%	1.7%	89.2%		100.0%	0.0%	100.0%	7.27E-05	3.15E-04	21
Train Collision	Derailment	63.4%	1.5%	64.9%	Main-track train derailment	13.0%	2.3%	15.3%	Dangerous goods	12.5%	1.7%	14.2%	Breach of materials	2.9%	3.2%	6.1%	3.03E-04	8.68E-04	18
Train Collision	Derailment	63.4%	1.5%	64.9%	Main-track train derailment	13.0%	2.3%	15.3%	Dangerous goods	12.5%	1.7%	14.2%	No breach	97.1%	3.2%	100.3%	1.00E-02	1.42E-02	11
Train Collision	Derailment	63.4%	1.5%	64.9%	Main-track train derailment	13.0%	2.3%	15.3%	Conventional shipment	87.5%	1.7%	89.2%		100.0%	0.0%	100.0%	7.22E-02	8.87E-02	3
Train Collision	Derailment	63.4%	1.5%	64.9%	Non-main-track train derailment	77.6%	2.5%	80.0%	Dangerous goods	12.5%	1.7%	14.2%	Breach of materials	0.6%	0.7%	1.3%	3.47E-04	9.23E-04	17
Train Collision	Derailment	63.4%	1.5%	64.9%	Non-main-track train derailment	77.6%	2.5%	80.0%	Dangerous goods	12.5%	1.7%	14.2%	No breach	99.4%	0.7%	100.1%	6.11E-02	7.38E-02	5
Train Collision	Derailment	63.4%	1.5%	64.9%	Non-main-track train derailment	77.6%	2.5%	80.0%	Conventional shipment	87.5%	1.7%	89.2%		100.0%	0.0%	100.0%	4.30E-01	4.63E-01	1