Analysis of Canadian Train Derailments from 2001 to 2014

by

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A thesis submitted in partial fulfillment of the requirements for the degree of

Master of Science

in

Geotechnical Engineering

Department of Civil and Environmental Engineering

University of Alberta

ABSTRACT

Rail transportation is a vital component of Canada’s economy, with great distances separating urban centres. Disruptions to rail service can have costly implications, not only in terms of monetary loss, but also to the environment, the public and railroad employees. Derailments account for a large number of these disruptions, and are caused by a number of factors.

This study investigates long term trends in the number of derailments on Canadian railways from 2001 to 2014, with a focus on main track rail. The total number of derailments are considered, as well as just those that involved dangerous goods cars. To reflect changes in rail traffic volumes over the study period, these trends are normalized against gross tonne-km of goods transported. Another area of focus of this research was to determine the leading causes of derailments, and to assess both frequency and severity for these causes. It was expected that a number of causes would show some degree of seasonality, with subgrade issues more common in the summer and mechanical issues more common in the winter. Spatial trends were developed based on the physiographic regions of Canada to assess the effects of physical geography on the safe operation of railways. Four of the leading derailment causes were selected for this analysis.

This analysis accomplished by analyzing data from two primary sources. Derailment data was obtained from the Railway Occurrence Database System, a database of Canadian rail incidents maintained by the Transportation Safety Board of Canada (TSB). An abbreviated version is publicly available on-line, but a more extensive database was provided for this study by the TSB. This database contains information on all types of rail incidents that are self-reported by the railway operators. Rail traffic data was obtained from publicly available tables on the Statistics Canada website.

A decreasing trend in main track derailments, as well as the subset of derailments with dangerous goods cars involved, was observed from 2001 to 2014. During this time period, it was found that the cause associated with the greatest number of derailments was the “rail, joint bar and rail anchoring” incident cause, followed by “track geometry,” “environmental conditions” and “wheels.” These four causes were included in the seasonal and spatial analyses, and it was observed that derailments due to rail and wheel breaks were more common in the winter, while derailments attributed to subgrade and track geometry issues were more common in the summer. Spatially, a higher number of derailments occurred in the Cordillera, Interior Plains and Canadian Shield regions, while comparatively few occurred in the St. Lawrence Lowlands and Appalachian regions. Decreasing or relatively consistent trends were observed in each region.

ACKNOWLEDGEMENTS

I would like to acknowledge the guidance and advice of my graduate supervisors, Dr. Michael Hendry and Dr. Derek Martin, in the development of this thesis. Their supervision and assistance proved invaluable throughout the entire process. I would also like to acknowledge the TSB for providing the data for this thesis.

My family was a constant source of support throughout this degree. I would like to thank my parents, Bryan and Sherry, for their encouragement. My wife, Fran, was an endless supply of love and motivation in the completion of this degree.

Finally, I would like to acknowledge the financial support of the Canadian Rail Research Laboratory and the Natural Sciences and Engineering Research Council of Canada, without which this research would not have been possible.

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CHAPTER 1 : INTRODUCTION

1.1 Canadian Rail Network

Canada has the third largest railway network in the world (Transportation Safety Board of Canada [TSB] 2016a), at approximately 48,000 route kilometres of track (Transport Canada [TC] 2016a) (Figure 1-1). With the fourth largest volume of goods in the world transported by this network (TSB 2016a), the transportation of goods by rail is an integral component of Canada's economy. There are several rail operators in Canada, with the largest being Canadian National Railway (CN) and Canadian Pacific Railway (CP).

Figure 1-1. Canadian rail network.

Given the extensive nature of the rail network in Canada, it is vulnerable to a number of factors that contribute to risk in terms of society, environment and rail infrastructure itself.

Some of the most significant natural factors include geography, topography and climate. Canadian rail lines pass over highly varied terrain with large stretches of soft glacio-lacustrine clays and very soft peat/muskeg subgrades, particularly in the prairie regions. The mountainous regions in both western and eastern Canada also pose challenges in terms of rock fall and landslide hazards and extreme winter conditions leading to the buildup of ice and snow on the track. Much of the rail network experiences extreme cold temperatures in the winter, high temperatures and extreme rainfall events during the summer months, and drastic changes between seasons.

Some industry factors that contribute to risk levels include recent advancements in train technology that allow for longer and longer trains, and a higher demand for the transportation of goods across Canada. These two factors are leading to increased stresses being imposed on rail infrastructure.

As a result of these challenging operating conditions, Canadian rail operators frequently experience interruptions to rail service that have implications for the cost of transportation and the safety of railway personnel, the public, and the environment. Derailments account for a considerable proportion of these interruptions, which in turn have a significant impact on the public's perception of rail transportation in Canada, particularly when dangerous goods are involved.

As society is becoming less tolerant to such incidents, and with increased media attention being focused on derailments such as at Lac-Mégantic, Quebec, there has been increasing impetus on operators to implement ever-stricter safety measures. The Lac-Mégantic case received widespread media attention due to the leak and ignition of dangerous goods and because the derailment occurred in a populated area. This combination resulted in one of the most catastrophic rail disasters in recent history. The results of these and similar derailments have led to a willingness for operators to focus of safety improvements in Canadian rail transportation.

When any type of incident occurs on Canadian railways, they are reported to the Transportation Safety Board of Canada (TSB) by the rail operator. These can include crossing incidents, fire, explosions, derailments, collisions, trespassers and runaway rolling stock. The TSB collects this information and compiles it in the Railway Occurrence Database System (RODS). This data is analyzed at a high level by the TSB to direct opportunities for the advancement of transportation safety in Canada. A more detailed analysis is expected to provide more insight into the causes of derailments, leading to potential areas of improvement in terms of safety.

1.2 Summary of Recent Derailments in Canada

There have been several derailments that have occurred recently in Canada that have received a significant amount of media attention and are driving the development of new regulations. The case studies described briefly below emphasize the importance of analyzing derailment statistics in order to reduce the potential for similar incidents to occur in the future. The Lac Mégantic incident in particular is among the most devastating rail disasters in Canadian history (Maclean's 2013).

1.2.1 Derailment at Lac Mégantic, Quebec

The Lac Mégantic derailment occurred in July of 2013, when a Montreal, Maine & Atlantic freight train began to roll after being left unattended for the evening. As detailed in the investigation report (TSB 2013a):

- the train travelled for about 7.2 miles and reached a speed of 105 kilometres per hour (km/h) as it approached Lac Mégantic's town centre;
- sixty-three tank cars derailed, spilling approximately 6 million litres of petroleum crude oil;
- the oil ignited, causing fires and explosions;
- 40 buildings and 53 vehicles were destroyed;

- approximately 2,000 people were evacuated;
- fatal injuries were suffered by forty-seven people;
- the spill also resulted in environmental contamination of the town centre and a nearby river and lake.

The aftermath of the derailment is shown in Figure 1-2.

Figure 1-2. Downtown Lac Mégantic after derailment and subsequent explosion.
Source: TSB Investigation Report R13D0054

A condensed summary of the investigation report (TSB 2013b) indicated that as a result of this incident the TSB communicated several recommendations to address safety issues, including:

- the securement of unattended trains;
- the classification of dangerous goods, specifically petroleum crude oil;
- rail conditions at Lac Mégantic;
- and, employee training programs of short line railways.

The summary also indicated that Transport Canada (TC) developed several initiatives as well, such as:

- a directive prohibiting the use of single-person crews on trains transporting dangerous goods;
- several sections of the *Canadian Rail Operating Rules* (CROR);
- and, proposing new standards for tank cars.

Rail transportation in the United States also underwent a number of safety improvements as a result of this incident. Recommendations were developed by the National Transportation Safety Board pertaining to the transportation of dangerous goods by rail. Route planning and emergency response planning were among the most significant, along with improvements to the classification of hazardous materials. The U.S. Department of Transportation also issued directives regarding train securement rules and new tank car standards (TSB 2013b).

The determination of the cause of this derailment was a complex process, and one primary cause was not able to be reported. In fact, as many as 18 different factors were identified as having contributed to this incident. This provides an example of the difficulty inherent in assigning causes to rail incidents.

1.2.2 Derailment at Gainford, Alberta

While not as disastrous as the Lac Mégantic incident, the derailment at Gainford, Alberta in October of 2013 highlights another case of rail incidents receiving media attention. The investigation report for this derailment (TSB 2013c) indicated that thirteen dangerous goods cars derailed, including four tank cars carrying petroleum crude oil and nine tank cars carrying liquefied petroleum gas (LPG). After the derailment, two of the LPG cars breached and caught fire, while LPG was released from the safety valve of a third car which subsequently ignited. No injuries were reported, but 106 homes in the area were evacuated (TSB 2013c). Figure 1-3 shows the outcome of the derailment.

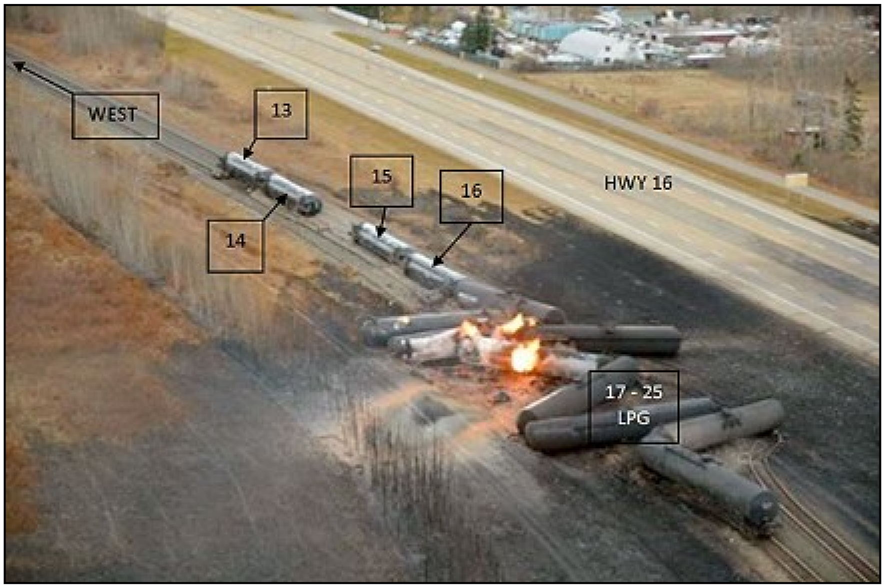


Figure 1-3. Aftermath of derailment at Gainford, Alberta.
Source: TSB Investigation Report R13E0142

The investigation report of this derailment determined that there were numerous transverse defects in the rail, likely due to high traffic density and loading. These defects resulted in one or more rail breaks as the train moved over this section of rail (TSB 2013c), resulting in the derailment.

1.2.3 Derailment near Tellier, Quebec

A third, more recent, derailment occurred in November of 2014. This incident, outlined in a TSB investigation report (TSB 2014), took place near Tellier, Quebec, when an empty ore train collided with rockslide debris on the track. The report stated that environmental conditions were such that the locomotive engineer was able to initiate emergency braking procedures but unable to stop the train before the collision. As a result, the two lead locomotives and the first 9 cars derailed, rolling down the slope adjacent to the track and coming to rest at the bottom of the Moisie River, the locomotive engineer was fatally injured and approximately 1,000 litres of diesel fuel was released and 100 feet of track were destroyed (TSB 2014).

Figure 1-4. Aftermath of derailment near Tellier, Quebec.
Source: TSB Investigation Report R14Q0045

Several safety directives were adopted by the rail operator through this stretch of rail as a direct result of this derailment. These included having a geotechnical specialist conduct rock face inspections, implementing modified procedures during freeze/thaw cycles, improving the training of employees on ground hazards identification, and establishing a database compiling information related to ground hazards (TSB 2014).

1.3 Research Objectives

The overall objective of this research program is to conduct an analysis of derailments in the RODS database from 2001 to 2014. The analysis of the derailment data was conducted to investigate trends in the causes of derailments. These trends are envisioned as input into an improved risk assessment method that is being developed by CN and the University of Alberta.

The purpose of this thesis was to investigate the RODS database for the number of derailments that occurred during the period 2001 to 2014 in order to develop temporal and spatial trends across Canada.

The specific objectives of this thesis were to:

1. Develop temporal trends, focusing on long term trends in total derailments, derailments involving dangerous goods cars, and the frequency and severity of derailments by incident cause.
2. Conduct an analysis of the seasonal changes in the occurrence of the major incident causes to determine the effects of climatic variations.
3. Conduct an analysis of the variation of incident causes by physiographic region of Canada to observe which incident causes were most prevalent in each region, and to observe region-specific trends.

1.4 Thesis Structure

This thesis consists of 7 chapters, including this first introductory chapter and the concluding chapter. Chapter 2 presents a review of literature relevant to the study. The literature review summarizes the major findings of similar studies conducted on Canadian derailments in the 1980's and early 1990's, as well as American derailments from the early 1990's up to 2010.

The purpose of the literature review was to establish context for the information presented in the later chapters of this thesis.

Chapter 3 introduces the sources of the information used in this study. There were two main sources of data: the RODS database, which contains rail incident information, and Statistics Canada, which was used to obtain rail traffic statistics. Limitations of each data set are discussed in this chapter.

Results of the analyses are presented in Chapter 4 through Chapter 6, where Chapter 4 presents long term derailment trends, as well as information on common causes, frequency and severity of derailments. Chapter 5 presents the results of the seasonal and spatial trends of four of the most common incident causes, and Chapter 6 contains findings related to derailments involving dangerous goods cars. The results presented in this chapter pertain to all derailments involving cars carrying dangerous goods, whether there was a release of material or not.

Finally, Chapter 7 concludes the thesis, with a summary of the findings and provides recommendations for future work.

CHAPTER 2 : HISTORIC CANADIAN TRENDS AND RECENT UNITED STATES STATISTICS IN TRAIN DERAILMENTS

2.1 Introduction

The following section presents a review of the literature relevant to the scope of this thesis. It includes a discussion of the results of similar studies using historical Canadian derailment statistics and from more recent data from the United States. This serves to provide a framework for the analyses that were conducted in this study and will contribute to the development of the conclusions presented herein.

Similar research was conducted recently using rail derailment statistics in the United States from 2001 to 2010 (Liu et al. 2012). Derailment factors that affect hazardous materials transportation in the United States were studied using statistics from 1992 to 2001 (Barkan et al. 2003). Both of these studies used data obtained from a database maintained by the Federal Railroad Administration (FRA), a federal agency tasked with ensuring “the safe, reliable and efficient movement of people and goods” (FRA 2016a) in America. Another similar study was carried out using Canadian derailment data from 1980 to 1993 (TSB 1994). This study was concerned with increasing derailment trends reported in the early 1990’s, after a 15% increase in total derailments was observed from 1991 to 1992.

This chapter also provides a review of the effects that climate and physical geography can have on rail operation. Factors such as temperature, precipitation and geohazards are discussed.

2.2 Historical Investigations of Derailment Trends

In the early 1990’s, the TSB initiated a study of main track derailments and their causes after becoming concerned over increasing rail incidents; from 1991 to 1992, there was a 15% increase in derailments on main track. Three major derailments occurred in 1992, one of which resulted in a release of dangerous goods and the 22 day evacuation of Oakville, Manitoba. The House of Commons Standing Committee on Transport requested that the TSB investigate the recent rise in rail incidents. The study, titled *"A Special Study of Main Track Derailments – 1994,"* involved a statistical analysis of main track derailment trends from 1980 to 1993 and an evaluation of some of the more recent incidents. The report also reviewed the safety actions that were recommended during this period, and provided a number of additional actions that could be taken that may further reduce the frequency of derailments in Canada.

The approach adopted for this report was to "review historical trends in derailment rates, severity, consequences, and causes" (TSB 1994). The statistics and trends developed in the report were based primarily on rail incident data reported by the railways to the TSB. After a preliminary analysis of trends, the TSB directed increased attention to main track derailments, with an emphasis on a greater depth to rail incident investigations.

The findings of the report indicated that a considerable reduction in derailments was observed from 1982 to 1988, followed by a relatively stable period from 1988 to 1993 with a slight peak in 1992 (Figure 2-1). Changes to reporting requirements during the study period required an adjustment to the reported incidents in order to accurately reflect derailment information, represented by the dashed line in the figure. These changes included:

- the estimated cost of damages required for a reportable incident was $750 up until November 1987, and subsequently increased to $7,350 in January 1988. This value remained unchanged until superseded by the TSB Regulations in 1992;
- in 1991, a number of dangerous goods were added to the list for the purpose of reportable incidents, which would have resulted in a greater number of derailments reported subsequent to the changes;

- and, in July 1992, new reporting regulations issued by the TSB removed the monetary threshold to damages and implemented a new requirement of any damage that would affect the safe operation of rolling stock.

In general, the changes served to reduce the derailments reported after November 1987, increase them slightly after 1991, and then to further increase them as the TSB Regulations were implemented after July 1992.

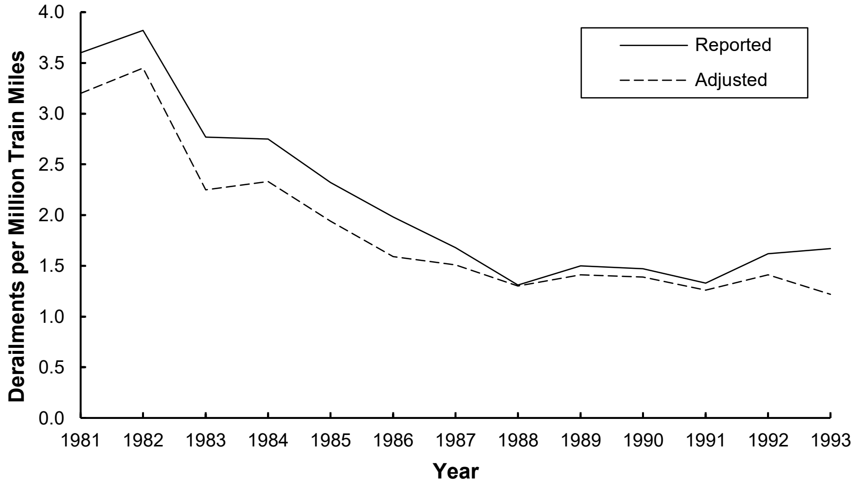


Figure 2-1. Historical derailment trends, 1980 to 1993. (after TSB 1994)

The reduction in the mid 1980's represented a major improvement in derailment statistics. Noted in the report was the fact that the investigation report for a derailment that occurred near Mississauga in 1979 was submitted in January of 1981, the findings of which may have made a contribution to this trend. A number of factors were thought to have contributed to the improvement in safety statistics during this period. The report cited improvements in the installation and repair of continuous welded rail, improvements in metallurgy, the automation of track geometry measurements, and advancements in rail defect detection technology. The reason for the leveling off subsequent to 1988 was not fully understood, and was again assumed to be the result of a numerous factors working in combination.

The TSB report considered derailment severity in terms of the number of cars derailed per derailment and the speed at which the derailment initiated. Where the greater the number of cars derailed was deemed to be a higher severity incident and derailments that occurred at higher speed were also deemed to be of higher severity. The results of the severity analyses are shown below in Figure 2-2 and Figure 2-3.

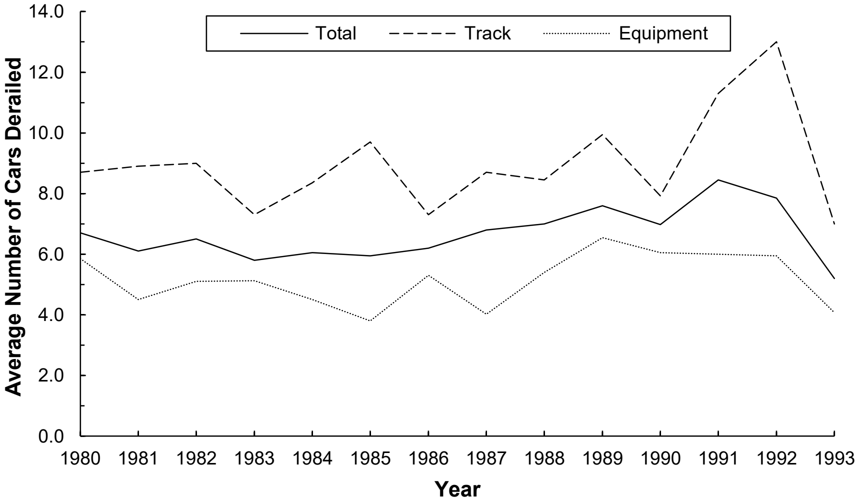


Figure 2-2. Number of cars derailed per derailment, 1980 – 1993. (after TSB 1994)

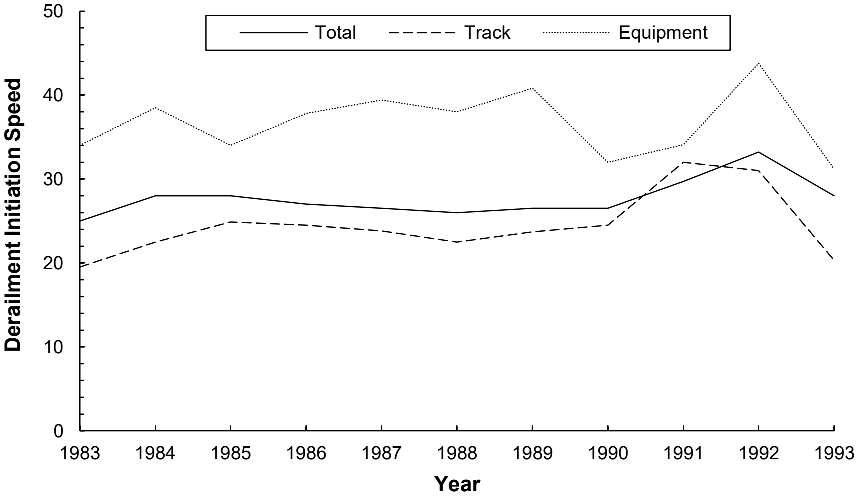


Figure 2-3. Average derailment initiation speed (mph), 1983 – 1993. (after TSB 1994)

The following findings regarding derailment severity were reported:

- there was a relatively constant number of cars derailed per derailment, with a gradual increase beginning in the mid 1980's;
- a significant increase was observed for track-related derailments after 1990;
- and, track-related derailments accounted for the greatest severity.

The TSB report considered two metrics for the consequences of main track derailments during the period 1980 to 1993: injuries (including fatalities) and the post-derailment release of dangerous goods. The results of the consequence analysis are presented below in Figure 2-4 and Figure 2-5.

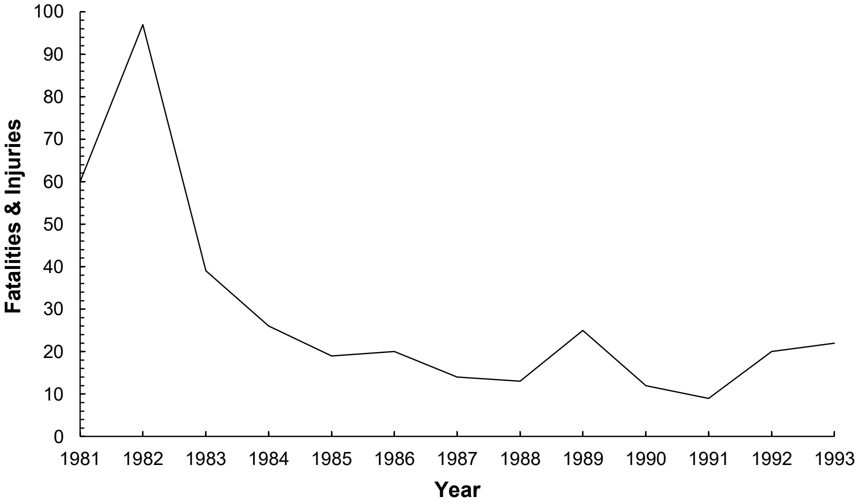


Figure 2-4. Fatalities and injuries resulting from main track derailments, 1981 – 1993. (after TSB 1994)

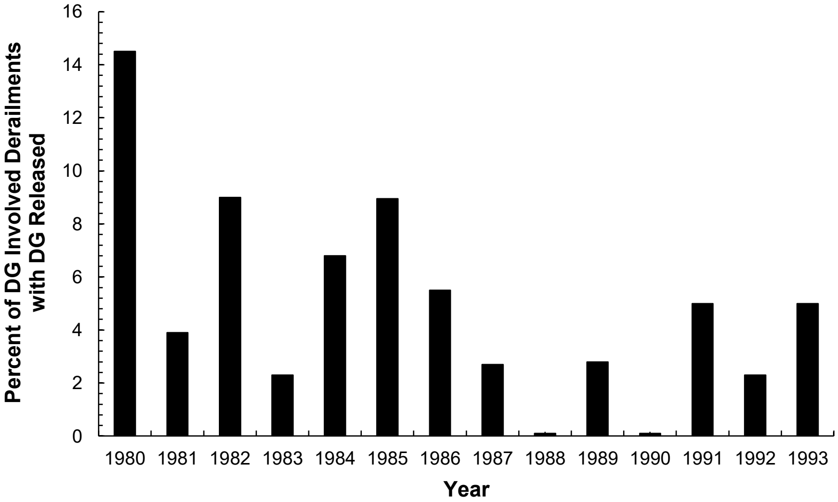


Figure 2-5. Post-derailment release of dangerous goods, 1980 – 1993. (after TSB 1994)

The report presented the following findings regarding consequences of main track derailments:

- there was a substantial reduction in fatalities and injuries from 1982 to 1984, followed by a relatively stable period;
- no fatal injuries to passengers or members of the public had occurred since 1983;
- two employees were fatally injured during the study period;
- only one serious injury to a member of the public had occurred; and,
- although an increasing amount of dangerous goods was being transported by rail, the proportion of derailments involving dangerous goods cars which resulted in a release decreased from about 15% to less than 5%.

Regarding the causes of main track derailments from 1980 to 1993, track, equipment and operations-related safety issues were among the most common. Track-related issues consisted of broken rail and inadequate track geometry maintenance. Broken rail lead to the greatest number of serious consequence derailments (TSB 1994). Equipment-related issues were primarily related to wheels and roller bearings. Operations-related issues were associated mainly with human errors, particularly involving the handling of switches.

2.3 American Derailment Statistics

The Federal Railway Administration (FRA) was enacted through the Department of Transportation Act of 1966, and is one of ten departments in the U.S. Department of Transportation that is interested with intermodal transportation. One of the primary purposes of the FRA is to collect and analyze data reported by railways and to produce statistics related to rail safety. These statistics are generally presented at a highly aggregated level.

Rail incidents in the United States have declined substantially over the last 35 years. As reported by the Association of American Railroads (AAR) (2015a), the incident rate in 2014 was the lowest ever experienced on American rails at just over 2 per million train miles, and represented a decrease of 79% from 1980, 50% from 1990 and 43% from 2000 (Figure 2-6). The AAR report also indicated that injuries to railroad employees have decreased by 83% since 1980, 76% since 1990 and 46% since 2000.

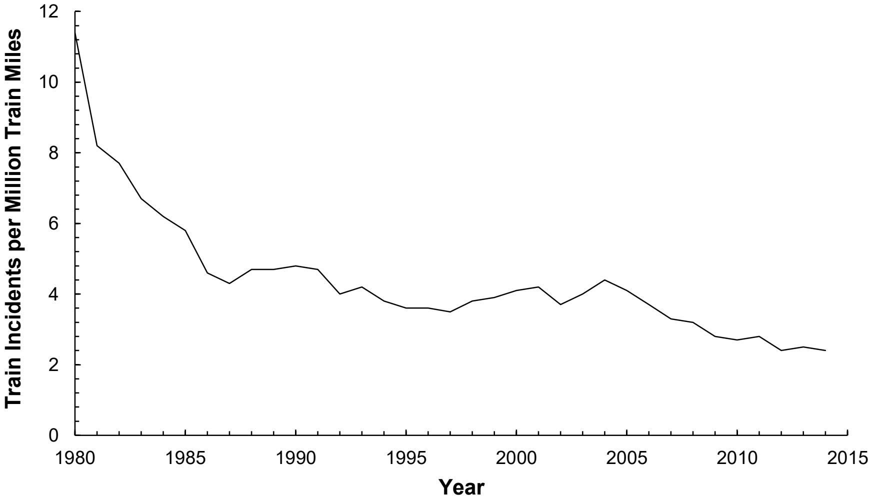


Figure 2-6. Historical American rail incident trends, 1980-2014. (after AAR 2015a)

Another function of the FRA is to oversee rail incidents and to investigate and determine the causes of serious incidents. According to U.S. government regulations issued by the FRA (Railroad Accidents/Incidents: Reports Classification, and Investigation 2015):

> It is the policy of the FRA to investigate rail transportation accidents/incidents which result in the death of a railroad employee or the injury of five or more persons. Other accidents/incidents are investigated when it appears that an investigation would substantially serve to promote railroad safety. (p. 437)

Information reported by railroads is entered into one (or more) of three databases depending on the characteristics of the incident. This data is analyzed by the FRA to produce high level statistical trends of rail incidents. Several studies have been conducted using this data in finer detail to make further contributions to enhance the safety of rail transportation in America. This type of analysis is intended to advance the safety of rail operations in a cost-effective manner.

Liu et al. (2012) used this data to provide insight into the frequency of rail incidents by incident cause and the number of cars derailed per derailment. The approach adopted in this study was a statistical analysis to examine the effects of incident cause, track type and derailment speed, considering derailments during the period 2001 to 2010. Track types in the database were classified as main, yard, siding and industry.

Using FRA data, Liu et al. (2012) showed that derailments accounted for the majority of incidents for each of the track types, with approximately 72% of all incident types falling within this category. With an average of 6.8 cars derailed per derailment, derailments also had the greatest severity (Liu et al. 2012). The results also indicated that by frequency and severity, broken rail or welds was the leading cause of derailments on all track types (Table 2-1 and Table 2-2). Similarly, for the period 1992 to 2001, broken rail or welds was the leading cause of derailments in terms of frequency and the sixth leading cause in terms of severity (Barkan et al. 2003).

Table 2-1. Top 5 Incident Causes of Freight Train Derailments by Track Type: Number of Derailments, 2001-2010 (after Liu et al. 2012)

Rank	Main Track		Siding		Yard	
	Cause ID	%	Cause ID	%	Cause ID	%
1	Broken rail or welds	15.3	Broken rail or welds	16.5	Broken rail or welds	16.4
2	Track geometry (excluding wide gauge)	7.3	Wide gauge	14.2	Use of switches	13.5
3	Bearing failure (car)	5.9	Turnout defects – switches	9.7	Wide gauge	13.5
4	Broken wheels (car)	5.2	Switching rules	7.7	Turnout defects – switches	11.1
5	Train handling (excluding brakes)	4.6	Track geometry (excluding wide gauge)	7.2	Train handling (excluding brakes)	6.7

Table 2-2. Top 5 Incident Causes of Freight Train Derailments by Track Type: Number of Cars Derailed, 2001-2010 (after Liu et al. 2012)

Rank	Main Track		Siding		Yard	
	Cause ID	%	Cause ID	%	Cause ID	%
1	Broken rail or welds	22.7	Broken rail or welds	23.2	Broken rail or welds	19.3
2	Track geometry (excluding wide gauge)	5.5	Wide gauge	13.8	Wide gauge	18.2
3	Buckled track	5.0	Turnout defects – switches	10.4	Use of switches	10.0
4	Obstructions	4.9	Track geometry (excluding wide gauge)	6.2	Turnout defects – switches	9.8
5	Bearing failure (car)	4.6	Use of switches	4.8	Train handling (excluding brakes)	7.7

Liu et al. (2012) concluded that mechanical failures were more prevalent on main track, and that human related factors played a greater part on siding and yard track. Switch related factors became an issue on siding and yard track, likely due to two reasons (Liu et al. 2012):

- more frequent use of switches on these types of tracks, resulting in a greater likelihood of causing a derailment; and,

- the switches are subject to more wear and tear the more they are used.

A regression analysis was conducted on FRA derailment data from 1999 to 2008 to show the effect of derailment speed on severity (Liu et al. 2011). This study showed that derailments that occurred at higher speeds resulted in a greater number of cars derailed. Liu et al. (2011) also observed that track-related incident causes, broken rails or welds in particular, resulted in a higher severity when compared to equipment-related causes (Figure 2-7).

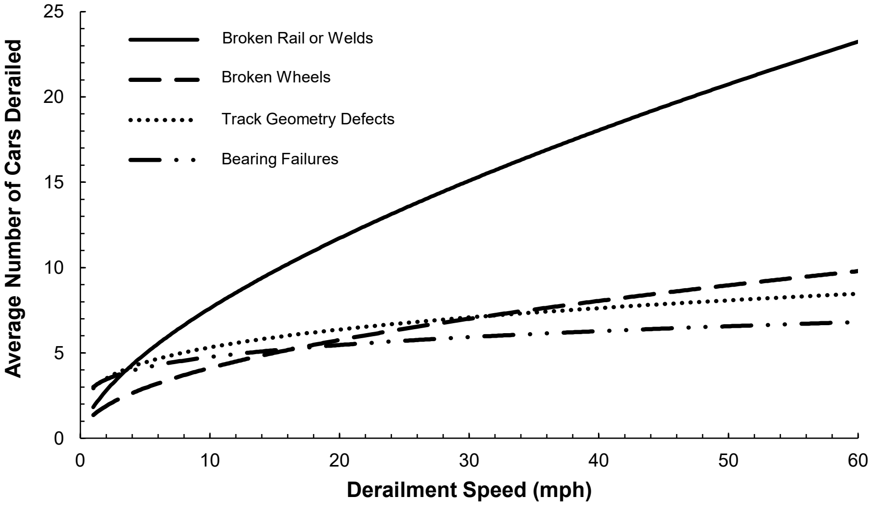
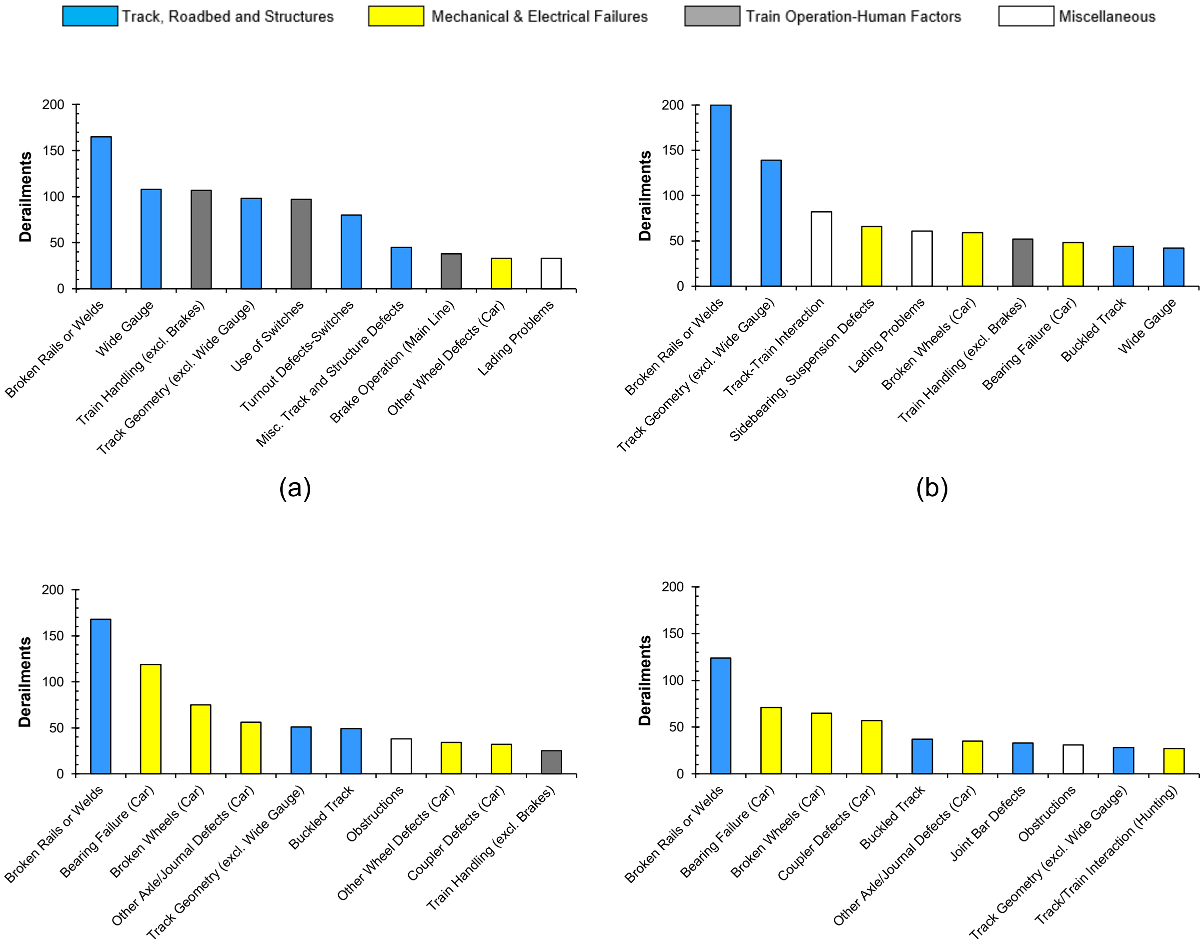


Figure 2-7. Regression analysis for relationship between severity and derailment speed, 1999 to 2008. (after Liu et al. 2011)

Liu et al. (2012) displayed derailment causes by speed broken down by FRA track class speed ratings and concluded that broken rails or welds accounted for the greatest number of derailments for each speed range (Figure 2-8). The relative frequency of the next most common causes was found to vary by derailment speed (Liu et al. 2012):

- below 16 kilometres per hour (km/h) (10 mph), track- and human-related incidents occurred more frequently than equipment-related incidents; and,

- above 40 km/h (25 mph), equipment-related incidents occurred much more frequently.



(a)

(b)

(c)

(d)

Figure 2-8. Frequency of derailments by speed and incident cause on American Class I mainline track, 2001 to 2010: (a) 0 to 16 km/h; (b) 16 to 40 km/h; (c) 40 to 64 km/h; (d) >64 km/h. (after Liu et al. 2012)

When the frequency of a derailment cause is plotted against severity, the relative importance of each cause is evident. This type of plot indicates areas that railways could focus on that may provide the greatest opportunity for rail safety improvements. Figure 2-9 shows results of severity versus frequency obtained by Liu et al. (2012) for the period 2001 to 2010.

Causes that plotted in the upper right quadrant of the graph had higher than average frequency and severity, whereas those plotting in the lower left quadrant had lower than average frequency and severity.

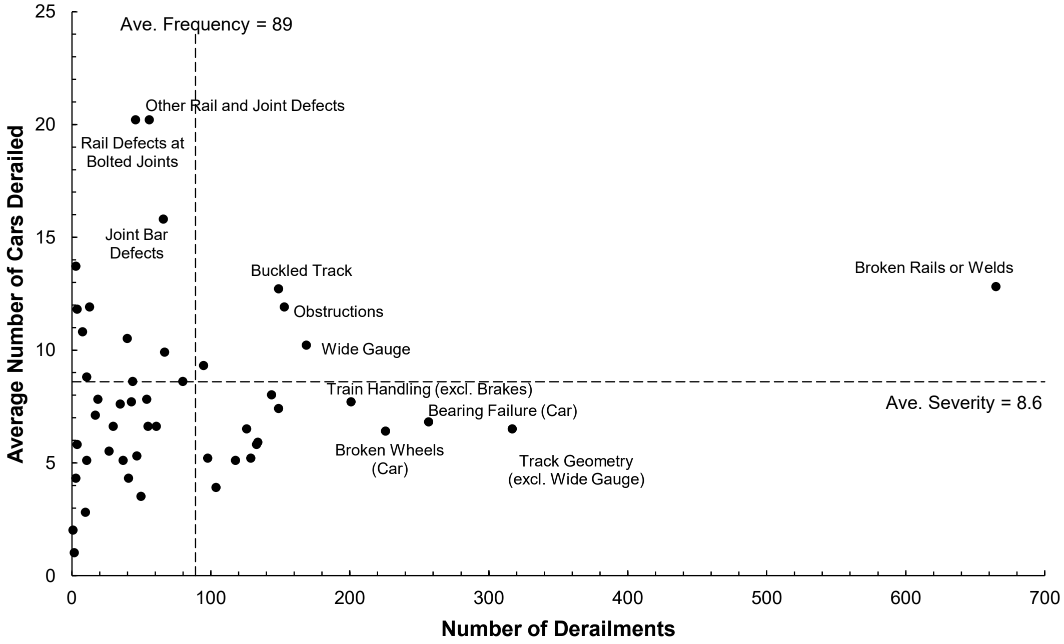


Figure 2-9. Frequency and severity plot of Class I main line freight derailments, 2001-2010. (after Liu et al. 2012)

Five cause groups showed a higher than average frequency and severity. These were:

- broken rails or welds;
- wide gauge;
- buckled track;
- obstructions;
- and, main-line brake operation.

The transportation of hazardous materials in the U.S. has seen a dramatic increase since 2008. Due to technological advances allowing for the economically viable recovery of crude oil and natural gas trapped in shale rock, carloads of crude oil have increased from 9,500 in 2008 to more than 490,000 in 2014 (AAR 2015b) (Figure 2-10). In total, more than two million carloads of hazardous materials are transported by rail in the U.S. (AAR 2015a).

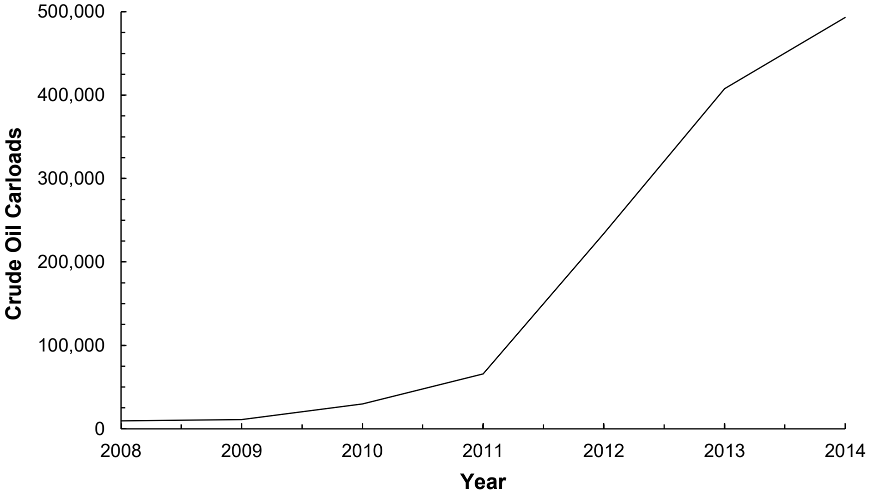


Figure 2-10. Originated crude oil carloads on Class I railroads. (after AAR 2015b)

Despite the considerable amount of hazardous materials transported by rail, more than 99% of all hazardous materials shipments arrived at their destination without a release caused by a train incident (AAR 2015a). The rate of incidents resulting in a release decreased by 94% since 1980, 71% since 1990 and 62% since 2000 (AAR 2016) (Figure 2-11).

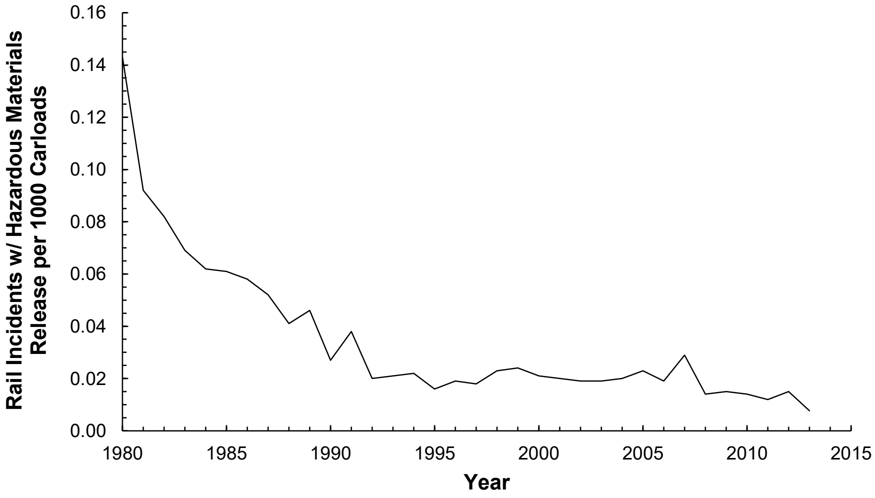


Figure 2-11. Rate of derailments involving release of hazardous materials since 1980. (after AAR 2016)

2.4 Influence of Climate on Rail Operations

Rail operators around the world are faced with challenging climatic conditions that can have a significant role in the safe transport of goods. For instance, climate was estimated to be responsible for up to 20% of unplanned delays in the United Kingdom (UK) (Thornes and Davis 2002). Rosetti (2002) indicated that a variety of extreme weather events can lead to the disruption of rail service. He provided the following examples:

- flash flooding can cause the track subgrade to wash out;
- segments of track can be inundated during seasonal flooding of rivers;
- uneven thermal expansion in warm summer months can warp or buckle the rail steel;
- snow and ice can build up on the track in the winter;
- extreme cold temperatures can cause brittle rail steel increasing the likelihood of breaks;
- and, high wind velocity perpendicular to a train can affect the stability of rolling stock.

Rosetti (2002) conducted an analysis of climate related incidents and incidents that occurred in the United States from 1993 to 2002. Using the FRA database, Rosetti (2002) found the following incident causes were related to climate:

- Roadbed soft or settled
- Washout/rain/slide/flood/snow/ice damage to track
- Other roadbed defects
- Track alignment irregular (buckled/sunkink)
- Snow, ice, mud, gravel, coal, etc. on track
- Extreme weather (tornado, flood, dense fog, extreme wind)
- Other extreme environmental conditions
- Highway user-related due to weather

The incidents and incidents attributed to the above causes by month are reproduced below in Figure 2-12.

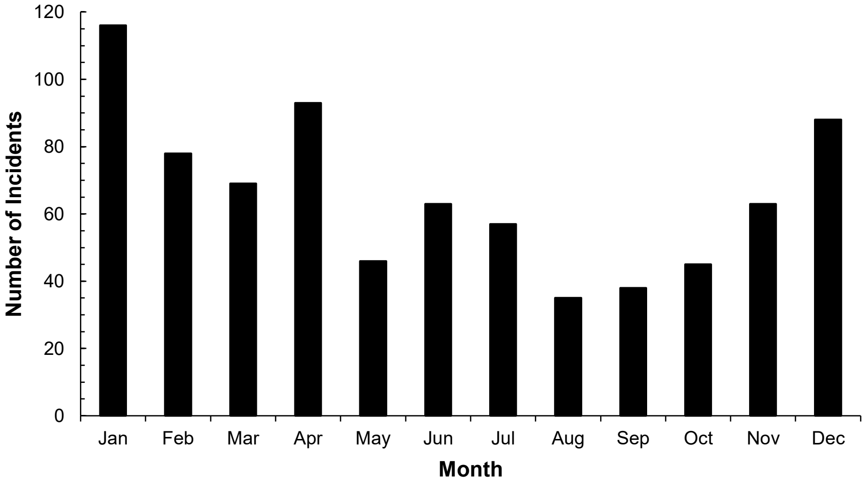


Figure 2-12. Climate-related incidents for US rail, by month, 1993-2002 (after Rosetti 2002)

Using this data, Rosetti (2002) noted that “weather-related incidents reach their peak in the December to January time frame, with a secondary peak in April, likely coinciding with the problems of spring floods, soft roadbeds and the like.” From his 2007 study, Rosetti plotted weather-related incidents by month and included the most frequent cause. This plot is reproduced below in Figure 2-13.

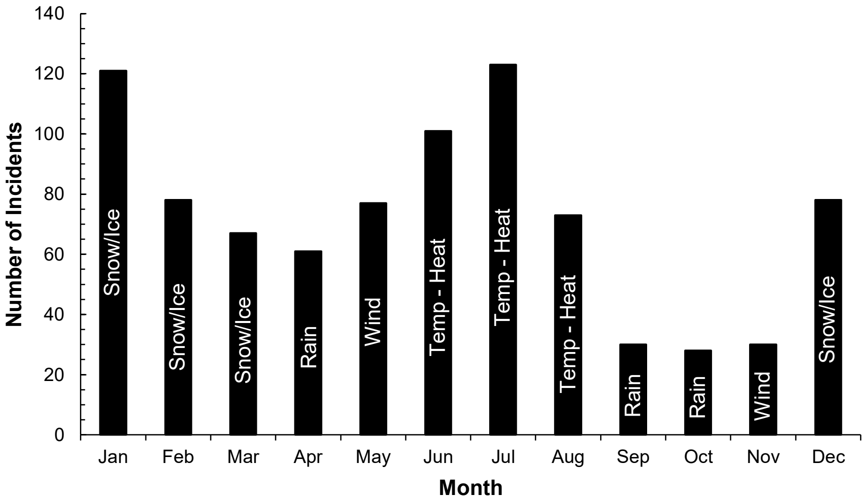


Figure 2-13. Climate-related incidents for US rail, by month and most frequent cause, 1995-2005 (after Rosetti 2007)

The above figure shows two peaks annually in US rail incidents. The first occurred in January and the second occurred in July. Incidents that occurred in the winter months were found to be most frequently caused by snow and ice accumulation on the track, while incidents in the summer months were attributed to high temperatures.

2.4.1 Temperature

A study of US rail incident data contained in the FRAs Rail Accident and Incident Reporting System from 1995 to 2005 revealed that “temperature extremes and temperature variability are the most frequently seen weather related cause of incidents in the database, especially those associated with high heat" (Rosetti 2007).

In the case of rail buckling or sunkinks, Dobney et al. (2009) indicated that rail does not buckle spontaneously, but rather requires an additional input, such as the loading from a passing train. A number of jurisdictions introduce slow orders during periods of high temperature in an attempt to reduce train impact loading (Bruzek et al. 2013). Speed restrictions are imposed when the ambient air temperature rises to 36°C in the UK (Dobney et al. 2009). In terms of severity, trains travelling at high speeds over buckled track have a high potential to derail a large number of rolling stock (Rosetti 2007). Wheels subjected to high thermal loading and fatigue due to rolling contact are also more susceptible to failure (Haidari & Tehrani, 2015).

Several issues have been identified with low temperatures. Extreme cold can result in the transition from ductile to brittle behaviour of steel components (Havers & Morgan, 1972). A high degree of tensile stress can be imposed on continuously welded rail during periods of extreme cold, and has been identified as one of the contributing causes of rail breaks (Kish & Aten, 2012). Other components, such as wheels, rail joints and bolts, couplers, wires and brake lines are also susceptible to failure due to cold temperatures (Changon 2006). The track bed may also be vulnerable to frost heave depending on the track subgrade material.

2.4.2 Precipitation

Precipitation can result in a number of hazards to the rail industry. High waters from flash flooding, river flooding, prolonged periods of heavy rainfall and rapid snowmelt can all have dramatic effects on rail transportation. Problems associated with flooding include roadbed washouts, bridge foundation erosion, submerged track and deposition of debris on the track, while heavy precipitation can lead to mud and rockslides in mountainous regions (Changnon 2006). Rapid snowmelt can have a similar effect by causing saturation and softening of the track roadbed (Rosetti 2007).

Snowfall also has a detrimental effect to the rail network. Common issues include snow drifts, avalanches in mountainous regions and ice buildup on the track. Snow and ice can accumulate on rails, thereby reducing wheel traction (Chagnon 2006). There can also be an accumulation in switches, brake components, flangeways and grade crossings, leading to increased risk of derailments or other types of incidents (Rosetti 2007).

2.4.3 Wind

Wind, while not as significant of a factor as temperature and precipitation, can still have an impact on rail operations. High winds can develop along exposed sections of track in the prairie regions and along the front ranges of mountains, such as the foothills in Alberta; gusts of up to 170 km/h have been recorded at Lethbridge, Alberta in the southern plains (McGinn 2010). Such gusts can lead to instability of rolling stock. Rollovers and derailments can occur, with lightly loaded or empty hopper cars being particularly susceptible (Rosetti 2007).

2.5 Effect of Physical Geography on Railways

There are a number of hazards faced by Canadian railways that are the result of geology and topography. The differences in physical geography across Canada, resulting from different bedrock conditions and glacial processes have led to a variety of hazards related to physical geography (i.e. geohazards), some of which are specific to certain regions (Fulton 1989). The terrain across Canada varies widely from mountainous areas in the Cordillera, relatively flat topography throughout the prairies and large expanses with surficial organic soils, muskeg and sensitive clay in eastern Canada. Common geohazards that can have an effect on the railways include flooding, erosion, landslides and other mass movement processes, and soft surficial soils.

In mountainous regions, such as those found in British Columbia, high relief, steep slopes, seismic activity and climatic conditions make wasting processes one of main geological hazards in Cordillera (Jackson 1989b). Ongoing maintenance of railway routes through these regions is required to minimize impacts of these hazards to the public and delays to the transportation of goods (Hungr et al. 1999). Specific geological hazards and associated consequences include (Evans & Gardner 1989):

- Snow avalanches, which have imposed considerable limitations on the location, operation and maintenance of railway and other transportation routes;
- Debris flows and flash floods have been known to cause damage to transportation routes and other infrastructure in certain areas of the Cordillera, most notably in the Coast Mountains;
- Widespread rock slope instability. Volcanoes in the southern Coast Mountains have been particularly susceptible to rock avalanches in the past. Small scale rock falls are a constant problem in the vicinity of cliffs and cut slopes along transportation routes.

The prairie provinces in Canada, including Alberta, Saskatchewan and Manitoba, see relatively few geological hazards due to low relief and little seismic activity (Jackson 1989b). The topography and geology of the region are such that some areas are susceptible to landslides and flooding, particularly in the Lake Agassiz Basin in Manitoba (Jackson 1989b), while other areas are prone to collapse features associated with soluble subsurface rock (Scott 1989). The most common locations for slope instabilities are along river banks, with frequent failures along the Peace, North and South Saskatchewan Rivers, as well as along the slopes of proglacial meltwater channels (Scott 1989). Flooding in general is not typically a problem in most areas of the prairies; however, the Lake Agassiz Basin has seen floods that have had a substantial impact in terms of loss of life and monetary damages (Scott 1989).

Geological hazards in central and eastern Canada are the result of Quaternary and pre-Quaternary events and tectonic action, with the most frequent geohazards being landslides and flooding (Jackson 1989b). Slope stability is a complex issue in this region. Loading from glacier ice caused a depression of the crust, resulting in the development of a temporary sea and several lakes that lead to the deposition of soft, fine sediments, and subsequent slope failures in these sediments (Jackson 1989b). Sensitive clays caused by the leaching of salt from marine clays are located in the St. Lawrence and adjacent tributary valleys and are a main contributory factor to landslides in this part of Canada (Locat & Chagnon 1989). Failures in sensitive soils can be catastrophic if the slide scarp retrogresses, and can cause significant damage to linear infrastructure (Quinn 2007). Peat, muskeg and thick deposits of organic soil, particularly in poorly drained areas of southern Ontario (Dyke et al. 1989), are also a risk to rail alignments in terms of soft track beds.

2.6 Conclusion

The purpose of this chapter was to present a brief outline of some of the derailment statistics that have been developed for Canadian and American railways, and to present the effects of the Canadian climate and physical geography on railways.

A review of available literature pertaining to these issues was conducted. Specifically, a number of papers on American derailment statistics and trends have recently been published that will allow for comparisons with some of the trends presented below. Historical Canadian trends were developed in a 1994 TSB report. Data from these studies indicated that rail incidents have been declining in recent years, and a number of incident causes are common between the two jurisdictions. These sources provided the basis for the analyses conducted for this thesis.

Climatic influences on railways include temperature, precipitation and wind. Both cold and hot temperatures can induce high stresses in rail, potentially leading to buckled rail in summer months and increased brittleness and rail breaks in winter months. Precipitation can result in flooding leading to roadbed washouts, submerged track, and debris flows and other mass wasting processes. High wind velocities can result in instability of rolling stock, particularly empty cars.

The varied physical geography across Canada and the associated geohazards pose a risk to the rail industry. Landslides, rock falls, flooding and avalanches are common problems to linear infrastructure, and have implications for safety and the cost of operating and maintaining rail lines across the country.

CHAPTER 3 : CANADA'S DERAILMENT DATABASE

3.1 Introduction

This chapter provides a discussion regarding the sources of data used for this study. Canadian derailment data was provided by the TSB, while statistics pertaining to rail traffic and dangerous goods were obtained from Statistics Canada. Several limitations were present in the data, and will be discussed in detail below.

3.2 Transportation Safety Board of Canada

The Transportation Safety Board of Canada is an independent agency within the federal government of Canada created by the Canadian Transportation Accident Investigation and Safety Board Act in 1989 (Act: S.C. 1989, c. 3). It consists of five board members and over 200 employees across Canada. There are investigators in eight regional offices with the head office located in Gatineau, Quebec.

One of the main purposes of the TSB is to investigate all manner of transportation incidents in Canada, as well as across the globe through international collaboration. The TSB is tasked with conducting investigations into selected incidents, identifying safety deficiencies, making recommendations based on any identified deficiencies, and reporting any findings to government and the public.

3.2.1 Incident Reporting

Rail incidents in Canada are self-reported by rail operators based on criteria set out in *Transportation Safety Board Regulations* (Canadian Transportation Accident Investigation and Safety Board Act 2014). The TSB keeps a record of these incidents and works with the government and the transportation industry to provide guidance pertaining to potential areas of improvement in terms of safety performance.

According to the *Transportation Safety Board Regulations*, a rail incident must be reported when:

- there is a fatality or serious injury;
- any rolling stock is involved in a collision or derailment, is damaged, or causes damage to track infrastructure;
- there is a risk of collision;
- any rules or regulations of the Railway Safety Act are contravened;
- there is unplanned and uncontrolled movement of rolling stock;
- there is an accidental release of dangerous goods; and,
- there are other miscellaneous signals or switch deficiencies.

It should be noted that there is no requirement for a monetary threshold in the *Regulations*, and hasn't been since 1992 (TSB 1994). This differs from the TSB's counterpart in the United States, the FRA, which has similar requirements as listed above, but also includes a monetary threshold. For example, in 2014 the reporting threshold for this type of incident was $10,500 (Railroad Accidents/Incidents: Reports Classification, and Investigation 2015).

Also according to the *Transportation Safety Board Regulations*, the train operator, track operator, or any member of the crew that has knowledge pertaining to an incident is able to make a report to the TSB. Any information that is available at the time of the incident is required to be reported as soon as possible. The remainder of the information must be reported by the end of the next calendar month. Information that must be reported includes:

- the incident date;
- the location of each incident in terms of province, nearest city or town, subdivision and milepost;
- incident type;

- track type and class;
- whether or not a derailment took place, and the number of cars derailed;
- a brief summary of the incident; and,
- the primary cause of the incident, if one is able to be determined.

3.2.2 Investigation Process

According to a TSB publication titled "*Investigation Process*" (TSB 2016b), they have the capacity to investigate each incident as it sees fit. Due to the high number of incidents reported each year, however, only a small percentage of these can feasibly be investigated. Although an individual incident may not warrant an investigation, a group of incidents exhibiting similar primary causes can be investigated to provide valuable information.

Some of the factors that affect the probability of an investigation occurring are:

- the frequency of similar incidents in the past;
- the amount of existing infrastructure that may exhibit similar defects;
- if the investigation will provide new information on an existing safety issue;
- the impact on the environment;
- and, if there are potential political implications and public perception of an incident.

An investigation will always take place after a major transportation disaster or if there is potential that it will advance transportation safety and reduce risk to the public and the environment. There may also exist a certain amount of public expectation that an investigation be carried out. An investigation is typically a three part process comprised of a field component, followed by examination and analysis, and finally reporting (TSB 2016b).

The field component consists of an examination of the site by an investigation team, including any equipment or vehicles involved. Interviews are conducted with witnesses, employees and government personnel.

In the next stage, the information collected in the field is examined and analyzed. Vehicle components may be tested in a laboratory setting, and company or government records may be examined. Simulations may be carried out to determine and reconstruct the sequence of events. Any safety deficiencies are identified during this stage.

Once the analysis is complete, the findings are reported to the public after a review process by the board and any independent reviewers the board feels may contribute to completeness and accuracy. Once the reviewers' comments have been incorporated, the report is finalized and released to the public on the TSB website as well as any other media that may be appropriate.

3.2.3 Railway Occurrence Database System

The Railway Occurrence Database System was provided by the TSB in the format of a series of tables in a Microsoft Access Database file. The file contained detailed information on derailments since the early 1980's. In more recent years, as reporting requirements evolved and became more stringent, increasingly more detailed data was recorded. The type of data provided in the database included a record of rail incidents, environmental conditions such as weather and visibility at the time of the incident, the type of dangerous goods cargo being carried (if any), type of rail, information on mechanical components of the rolling stock and rail infrastructure (ie. frogs, switches, fasteners), and track geometry information at the incident location, among others.

All of the incidents in the RODS database were self-reported by the individual rail operators, and each one is assigned a unique eight character ID code. The format of the ID code is

RXXYYYYY, where the R indicates that the incident was a rail incident, XX represents the year in which the incident took place, and YYYYY is a sequential report number.

The research presented in this thesis primarily made use of the record of incidents while referencing several other tables within the database. This record included the incident ID number, the date, time and location (province, nearest town, and subdivision) of the incident, track class, incident type, number of trains involved, incident type, activity type, whether or not there was a fire, explosion or evacuation, total rolling stock involved, number of dangerous goods cars involved, if a release of dangerous goods took place, whether or not there were any injuries, a brief summary, and the primary cause of the incident.

The most common types of incidents consisted of derailments, collisions and crossing incidents. Each incident type had the potential to result in derailed rolling stock. For the purposes of this study each incident that resulted in at least one derailed car was considered a derailment.

The incident causes listed in the RODS Database were organized into three levels. The highest level consisted of five main cause groups, as follows:

- Track, Roadbed and Structures;
- Mechanical and Electrical Failures;
- Train Operation - Human Factors;
- Signal and Communication;
- and, Miscellaneous.

Within each of these main groups, there were two sublevels that allowed for a very specific primary cause to be reported in the RODS database. The database contained a list of approximately 400 such causes. For example, a primary cause of “track alignment irregular” falls under the “track geometry” sublevel, which in turn is found within the “track, roadbed and structures” major cause group.

3.3 Statistics Canada

A number of rail traffic statistics used in the analysis of train derailments were obtained from Statistics Canada. Information regarding track tonnage, carloading, and dangerous goods transportation was acquired from several tables within the CANSIM database. This information was used to normalize a number of the derailment statistics in order to show the effects of increasing rail traffic during the study period.

CANSIM is a database maintained and updated regularly by Statistics Canada. A large range of data is available through these tables, and is publicly available for downloading at Statistics Canada’s website. Each of the tables in CANSIM is assigned a seven digit ID number. All transportation-related CANSIM tables begin in the 400 range, with rail transportation statistics in the 404 and 409 categories. For example, the ID number for the table reporting operating statistics by mainline company is 404-0014. The statistics presented in the tables can be manipulated to a certain degree. In most cases, rail traffic statistics can be presented for different time periods, and can be broken down by month in some cases.

3.4 Potential Biases and Errors in the Data

Although the RODS database and the CANSIM tables provided a vast quantity of information, there were some limitations. This section details any potential biases in the data, and should be noted when viewing the results of this research.

The most notable limitation of the RODS database was that a large amount of incidents were not reported with a primary cause. For example, of the 2,348 main track derailments in the

RODS database from 2001 to 2014, less than half had primary cause codes attributed to them. This is potentially due to the difficulty inherent in determining the primary cause of an incident.

Additionally, the distribution of derailments that were reported with an incident cause varied throughout the study period (Figure 3-1). From 2001 to 2005, less than 30% of derailments were reported with a cause. Beginning in 2006 this number began to rise, leveling off between 80 and 90%. This presented some difficulty in conducting the analyses, and will be discussed further in the appropriate sections below.

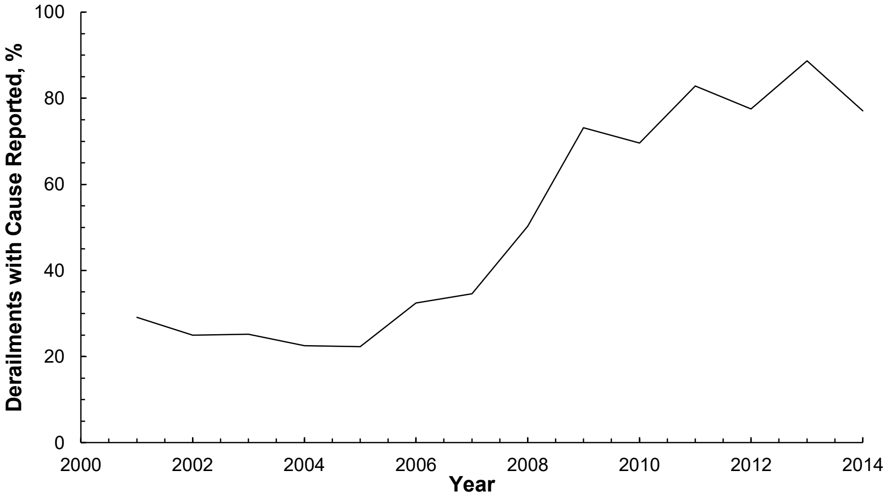


Figure 3-1. Percentage of main track derailments with cause reported, 2001-2014.

Another limitation of the RODS database is that incidents are self-reported by each individual operator, which in some instances can result in missing or incomplete data. However very unlikely, it is also possible that some operators may decide not to report some incidents, or smaller operators may not have the resources or capability to conduct an appropriate level of investigation to provide all the information required, such as the primary cause of an incident.

Additionally, as it is impractical for the TSB to investigate each incident, it is anticipated that much of the information reported was not verified by the TSB.

A third limitation is that policies of the individual operators may change over time. This would have the effect of varying the quantity and quality of information reported from year to year. An operator may have implemented more stringent policies at some point during the study period, resulting in improved reporting practices. Improved reporting could provide more detail on primary incident causes, for example, that wasn't available in the earlier years of the study period.

Finally, the RODS database is a live document, undergoing updates as information becomes available during the investigation process. As such, historical information may change over time, with older incidents less likely to be altered (TSB 2015).

A limitation of the data obtained from Statistics Canada is that insufficient information related to rail traffic was available. For example, normalizing the number of derailments by gross tonne-km provided a valuable depiction of derailment statistics in relation to the amount of rail traffic. However, this metric was not able to be separated by month. Hence, not all of the derailment data was able to be normalized by the same metric, namely by gross tonne-km. For example, the seasonal analysis conducted relied on tonnes of goods transported instead of gross tonne-km. Similarly, dangerous goods traffic was only available by tonne.

The effects of these limitations are difficult to quantify, but should be kept in mind when considering the results of this study.

CHAPTER 4 : CANADIAN DERAILMENT TRENDS AND INCIDENT CAUSES FROM 2001 TO 2014

4.1 Introduction

This chapter presents the results of an analysis of long term derailment trends from 2001 to 2014. Included in this discussion is a high level overview of derailments on all track types, followed by a more detailed analysis of derailments that occurred on main track. The causes of derailments were examined to determine which factors lead to the greatest number of derailments. The severity and frequency of main track derailments were assessed to identify high risk causes. The speed at which derailments initiated was also investigated in order to determine its effect on the frequency and severity of derailments. A number of the analyses were conducted based on those conducted for similar studies on past Canadian derailment data and more recent American derailment data.

Trends were normalized by rail traffic to capture the effect of an increasing amount of goods being carried by rail during the study period. In most cases, gross tonne-km were used to normalize the data. This was determined to best represent the amount of traffic on the rail network in Canada, as this encompasses the total weight of the trailing tonnage, including both loaded and empty cars, and how far it was transported. This data was not available in all cases, and in these instances track tonnage was used.

Even though a large portion of train derailments occurred on non-main and yard tracks, this study was mainly concerned with main track derailments. Trains moving on main track typically travel at higher speeds and have greater mass, resulting in the generation of considerable forces and a higher risk of damage to track infrastructure, harm to the environment, and a greater threat to public safety in the event of a derailment.

Finally, a discussion on the transportation of dangerous goods (DG) in Canada is provided, with a particular emphasis on the consequences of train derailments with DG cars involved.

Although incidents like the Lac Mégantic derailment described above in Section 1.2.1 have a relatively low likelihood of occurring, the consequences can be catastrophic. These types of incidents garner a large amount of media attention, and can have an impact on the people and communities, environmental and political implications, in addition to economic impacts to railway operators.

4.2 Derailments by Track Type

In the RODS database, all incidents can be referenced to three categories of track:

- main track;
- non-main track;
- and, yard track.

Main track refers to any uninterrupted, continuous section of rail, such as main-line track. Non-main track is any discontinuous section of track, such as a siding, and has a requirement to operate at a reduced speed. Yard track corresponds to a system of non-main track used for switching, train composition, and loading or unloading. The official definition of each track type is provided in TC's *Canadian Rail Operating Rules* (TC 2015) as shown in Table 4-1. Each of these track types has different operational characteristics and thus exhibit different derailment frequency and severity by incident type.

Table 4-1. Transport Canada definition of track types (TC 2015)

Track Type	Canadian Rail Operating Rules Definition
Main	"A track of a subdivision extending through and between stations governed by one or more methods of control upon which movements, track units and track work must be authorized"
Non-Main	"Any track(s) other than those listed in time table columns as having CTC, OCS, ABS or Cautionary Limits applicable and unless otherwise provided include a requirement to operate at REDUCED speed"
Yard	"A system of non-main tracks, utilized to switch equipment and for other purposes over which movements may operate subject to prescribed signals, rules and special instructions"

Derailment information contained within the RODS database was assessed to illustrate a variety of metrics for each track type, including the number of derailments, the total number of cars derailed and the average number of cars derailed per derailment (Table 4-2). This information provides a broad overview of derailment statistics by track type and incident type.

Table 4-2. Derailment frequency, severity and total cars derailed by incident type and track type, 2001-2014

Track Type	Incident Type					
	Derailment	Collision	Crossing	Other[1]	Incident Type not Indicated	Total
			Number of Derailments			
Main	2,102	54	83	29	80	*2,348*
Non-main	3,057	62	10	17	180	*3,326*
Yard	6,490	600	4	27	137	*7,258*
Other	35	1	0	0	7	*43*
Total	*11,684*	*717*	*97*	*73*	*404*	*12,975*
			Total Number of Cars Derailed			
Main Track	11,321	254	533	76	138	*12,322*
Non-main	5,839	150	11	18	260	*6,278*
Yard	13,634	1,407	4	37	203	*15,285*
Other	67	1	0	0	7	*75*
Total	*30,861*	*1,812*	*548*	*131*	*608*	*33,960*
			Average Number of Cars Derailed per Derailment			
Main Track	5.4	4.7	6.4	2.6	1.7	*5.2*
Non-main	1.9	2.4	1.1	1.1	1.4	*1.9*
Yard	2.1	2.3	1.0	1.4	1.5	*2.1*
Other	1.9	1.0	0.0	N/A	1.0	*1.7*
Total	*2.6*	*2.5*	*5.6*	*1.8*	*1.5*	*2.6*

1. Other incident types include fire, explosion, runaway rolling stock, and trespasser.

Of the almost 13,000 rail incidents in the RODS database that resulted in derailed rolling stock between 2001 and 2014, the “derailment” incident type was found to be most frequent by a wide margin, followed by “collisions” and “crossing” incidents. “Derailments” made up 90% of all incident types, while “collisions” and “crossing” incidents made up 5.5% and 0.7%, respectively. The remaining incident types accounted for 0.6%. No incident type was indicated for 3.2% of incidents.

Of the nearly 34,000 cars that were reported to have derailed between 2001 and 2014, 91% resulted from the “derailment” incident type, while “collisions” and “crossing” incidents accounted for 5.3% and 1.6%, respectively. The remaining incident types accounted for 0.4% of the total number of cars derailed, while approximately 2% were reported with no incident type.

The severity of an incident, defined in this study as the number of cars derailed per derailment, was found to vary with track type and incident type. It was observed that for all incident types, the severity was greatest on main track, while incidents on non-main and yard track were nearly equal in severity for all incident types. The greatest severity corresponded to derailments that occurred as a result of “crossing” incidents on main track, with an average of 6.4 cars derailed per derailment. An overall average of 2.6 cars derailed per derailment was determined for all incident types on all track types.

4.3 Long Term Trends in Derailments and Rail Traffic

Long term derailment trends were developed based on the similar studies on Canadian and American data described in Chapter 2 (i.e. TSB 1994, AAR 2015a). Information was obtained from the RODS database for rail classified as main track. The total number of incidents that resulted in derailed rolling stock that occurred during each year of the study period, regardless of incident type or cause, was used in the development of the trends presented in this section. This allowed for an examination of the combined effectiveness of the various safety improvements that were implemented by rail operators, either at the direction of regulators or self-imposed, without limiting the data to only those incidents that were reported with incident causes.

During the study period the amount of rail traffic increased significantly, placing an increasing stress on the Canadian rail network. (Figure 4-1). From 2001 to 2014, the total gross tonne-km as reported in the CANSIM tables from Statistics Canada grew from approximately 586 billion to 781 billion, an increase of approximately 33%. There was also an increase in the average quantity of goods being carried per rail car, as shown in Figure 4-2. This figure indicates an increase in the average quantity of non-intermodal goods per car from 78.9 tonnes in 2001 to 82.0 tonnes in 2014, an increase of about 4%. Both of these factors have contributed to considerable demand on rail infrastructure.

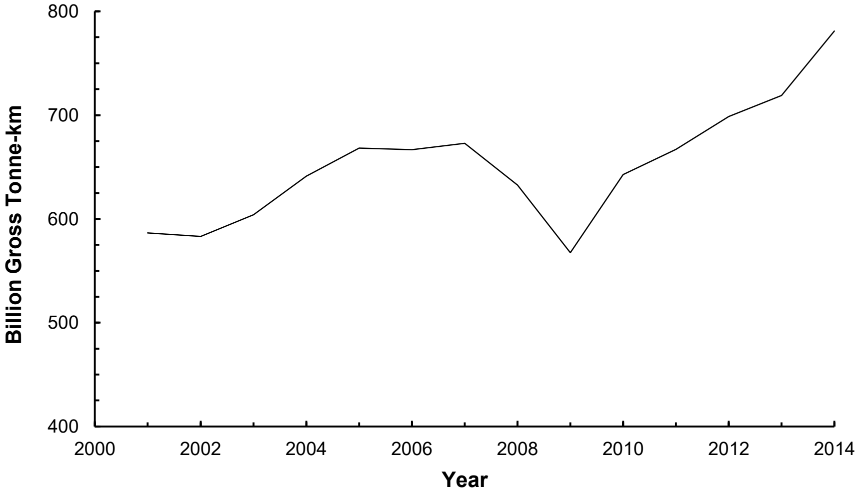


Figure 4-1. Increase in rail traffic, billion gross tonne-km, 2001- 2014.

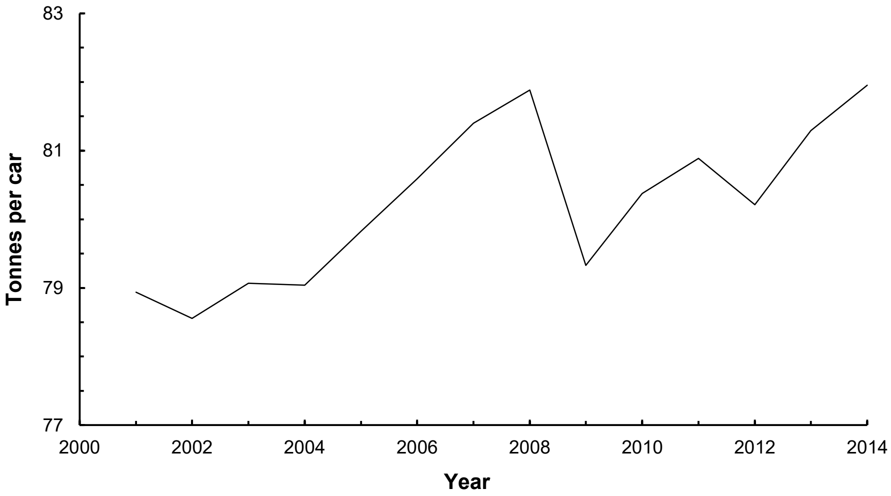


Figure 4-2. Average quantity of goods carried per rail car, tonnes, 2001-2014.

The total number of derailments in 2001 was 223, while in 2014 the number of derailments was 135. This represents a 40% decrease in total main track derailments. A peak of 251 derailments was observed in 2005. Such statistics do not convey the complete picture however, as the amount of rail traffic has increased significantly since 2001 (Figure 4-1). To capture both the derailment statistics and the increase in rail traffic, the trend data was normalized to gross tonne-km (Figure 4-3).

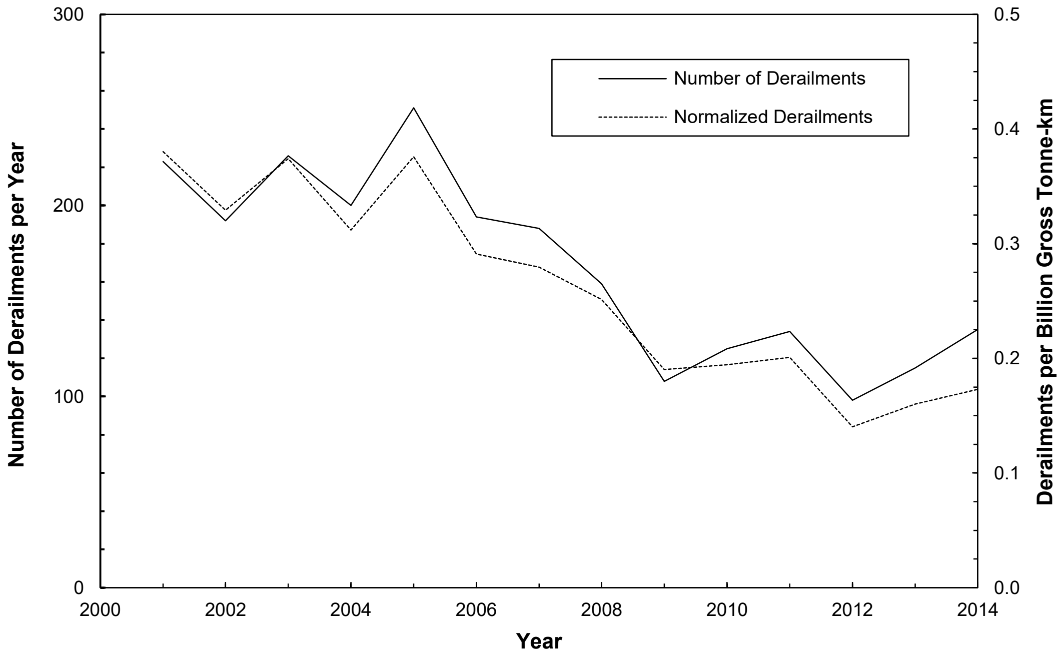


Figure 4-3. Total main track derailments and derailments normalized by billion gross tonne-kilometres, 2001-2014.

Figure 4-3 shows a decreasing trend in both the total number of derailments and the number of derailments normalized to rail traffic during the study period. The number of derailments per billion gross tonne-km that occurred on main track decreased from 0.38 in 2001 to 0.17 in 2014, a reduction of approximately 55%. The reasons for the plateaus and decreasing trends observed in Canadian derailment data is likely due to a combination of factors, including the implementation of long-train technology and distributed power beginning in the early 2000's. This was not an instantaneous solution as sidings had to be lengthened to allow for the extra train length. The decreasing trend may be the result of enough of these infrastructure upgrades being completed that the technology began to have an effect on reducing derailments.

Derailment statistics in the US are typically normalized by train-miles to account for changes in rail traffic. To allow for a direct comparison between the two countries, the total number of derailments were normalized by the same metric. The results are shown in Figure 4-4 below. Of interest in this figure is a similar plateau from 2001 to 2005, followed by a decreasing trend. A steeper trend is seen in the Canadian data, followed by another plateau beginning in 2009. This second plateau is not observed in the US data.

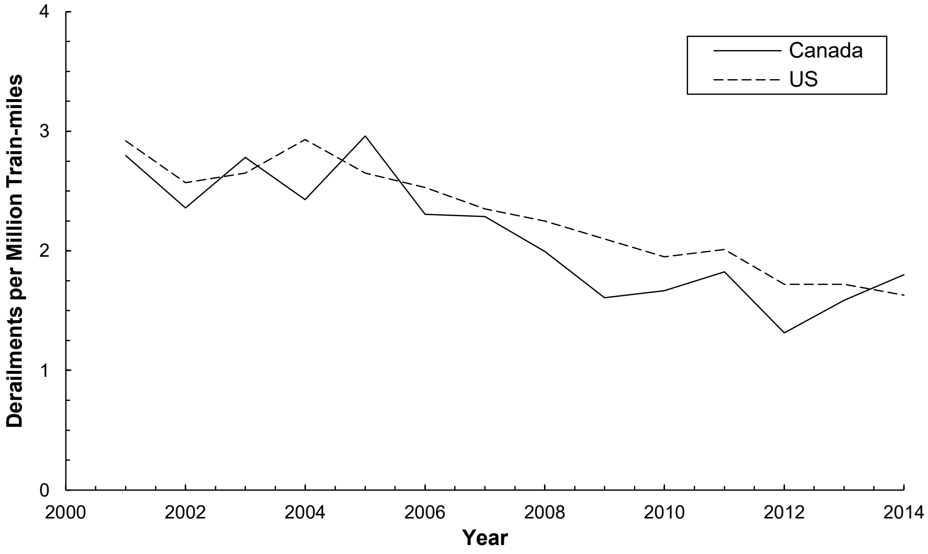


Figure 4-4. Comparison of Canadian and US derailments, normalized by train-miles, 2001-2014 (US data after FRA, 2016b)

Figure 4-5 shows the distribution of derailments attributed to Class I railways compared to all other (short line and regional) railways. This plot is normalized by gross tonne-km to reflect changes in rail traffic from 2001 to 2014.

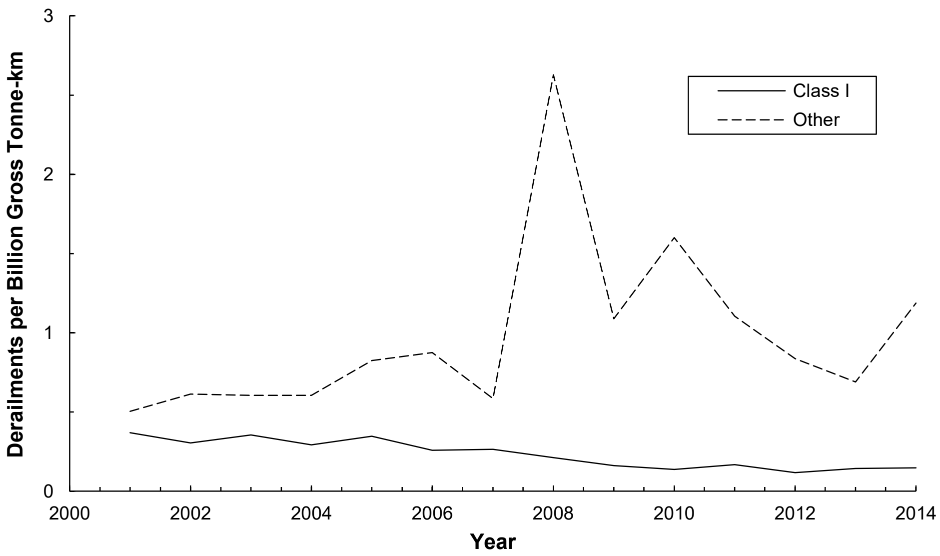


Figure 4-5. Distribution of main track derailments by railway class, 2001-2014

It is evident from this figure that derailments by Class I railways occurred at a lower rate compared to other railways, and that the number of derailments showed a decreasing trend. A peak in short line and regional railways was observed in 2008, as well as an overall increasing trend in the number of normalized derailments.

It would be difficult to attribute any improvements in derailment statistics to individual causes over the study period and it is not the purpose of this thesis to do so. However, any reduction in derailments is likely the result of a number of different factors working in conjunction. Some of the contributing factors may include (P. Miller, personal communication, October 30, 2015):

- the development and gradual implementation of long train technology, resulting in maximum train lengths increasing up to 150 cars (approximately 4 km);
- an increase in the density of wayside detectors, combined with improvements in detector technology and processes;
- distributed power;

- improved technology and increased use of rail flaw detection, and track geometry inspections;
- and, economic variability leading to cutbacks in operations and maintenance.

4.4 Derailment Causes

As mentioned above, the incident causes listed in the RODS Database were categorized into three levels, with approximately two hundred specific primary causes within the third sublevel for main track derailments. However, this level of causes was poorly populated and the categories often did not provide statistically significant sample sizes. Only the highest two levels of causes were investigated in order to provide meaningful statistics.

4.4.1 Main Cause Groups

Figure 4-6 displays the variation of main track derailments over the study period separated by main cause group. From Figure 4-6, it appears that the number of derailments increased during the study period, when total number of derailments decreased, as shown in Section 4.3. This is due to the number of derailments reported with an incident cause increased throughout the study period (Section 3.4). Less than 40% of derailments were reported with an incident cause in the earlier years of the study period, whereas this number rose to above 80% in the later years (Figure 3-1).

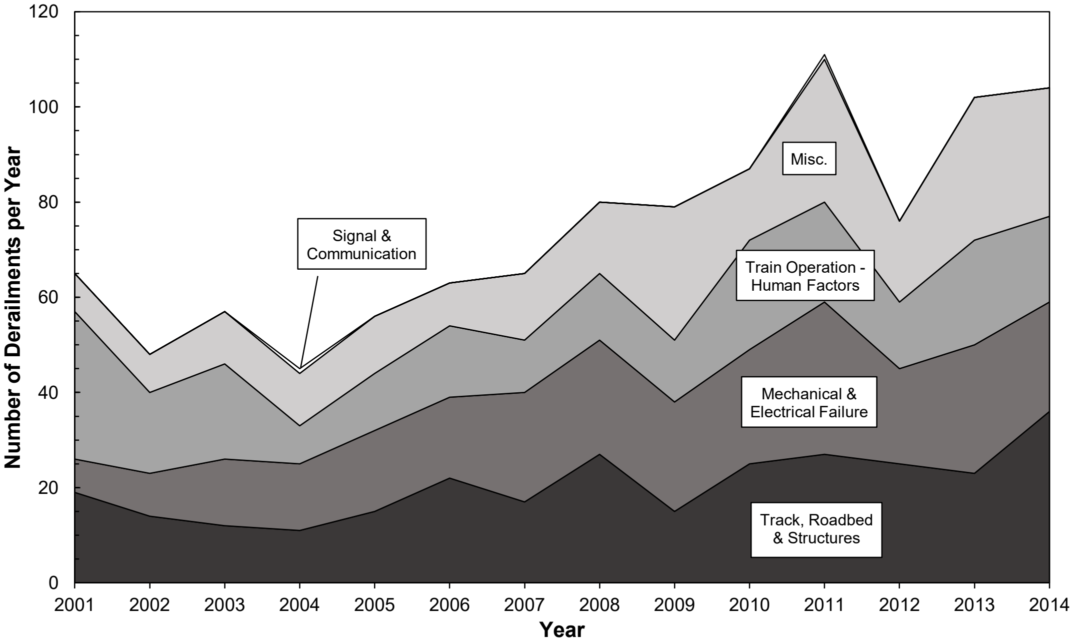


Figure 4-6. Variation of main track derailments by main cause group, 2001-2014.

The “track, roadbed & structures” and “mechanical & electrical failures” groups comprised an approximately equal number of derailments, and these groups combined accounted for more than half of all main track derailments (Figure 4-7). “Train operation - human factors” and “miscellaneous” also made up an approximately equal number of derailments, and accounted for just under half of all main track derailments. “Signal & communication” accounted for a negligible amount of derailments and derailed rolling stock.

Figure 4-7 also indicates the percentage of cars derailed by main cause group. The “track, roadbed and structures” group made up the greatest percentage of derailed rolling stock. “Miscellaneous” and “mechanical and electrical failures” accounted for just over 20% each, while “signal and communication” made up a negligible amount (0.2%).

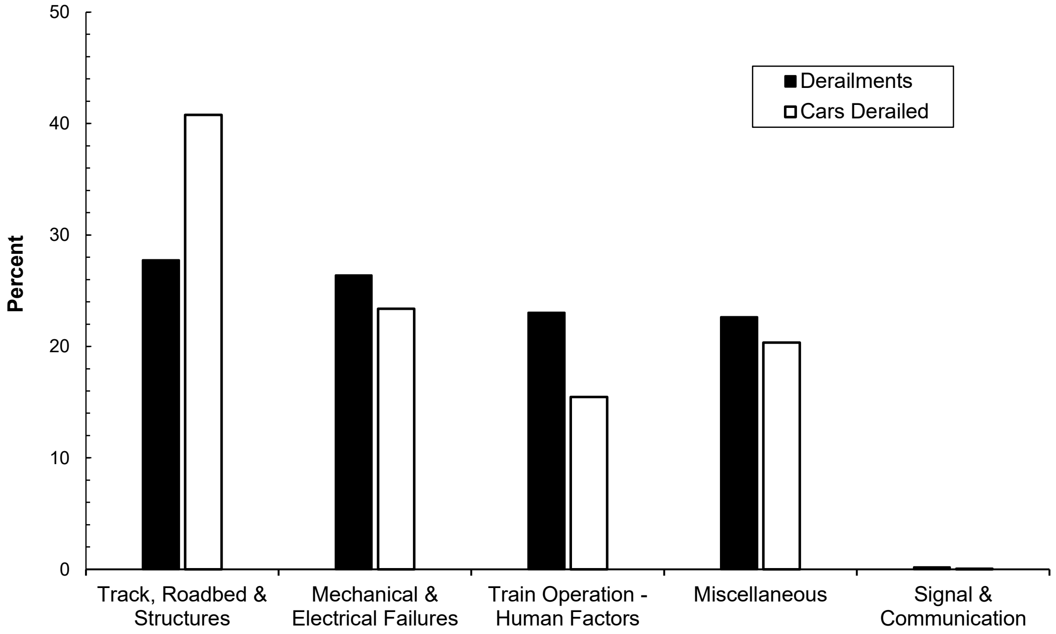


Figure 4-7. Distribution of derailments and derailed rolling stock on main track by major cause group, 2001-2014.

4.4.2 Detailed Cause Groups

A ranking of incident causes within the first sublevel revealed the top ten causes for each of the three track types. These causes were similar to those presented for American derailment data by Liu et al. (2012). The results are presented in Table 4-3 and Table 4-4, and graphically in Figure 4-8.

Table 4-3. Top 10 incident causes of train derailments by track type: number of derailments, 2001-2014

Rank	Main Track		Non-main Track		Yard	
	Cause ID	%	Cause ID	%	Cause ID	%
1	Rail, joint bar and rail anchoring	10.8	Track Geometry	17.9	General switching rules	20.7
2	Track geometry	9.7	General switching rules	17.6	Switches, use of	15.1
3	Environmental conditions	6.9	Environmental conditions	12.3	Track geometry	9.8
4	Wheels	6.8	Frogs, switches and track appliances	9.1	Frogs, switches and track appliances	9.3
5	Train handling / train make-up	6.6	Switches, use of	8.5	Other miscellaneous	6.4
6	Other miscellaneous	6.2	Other miscellaneous	7.0	Train handling / train make-up	5.4
7	Axles and journal bearings	5.3	Rail, joint bar and rail anchoring	5.6	Rail, joint bar and rail anchoring	5.0
8	General switching rules	5.0	Train handling / train make-up	3.5	Environmental conditions	4.2
9	Switches, use of	4.8	Brakes, use of	2.5	Unusual operating situations	3.9
10	Brakes	3.9	Miscellaneous human factors	2.4	Miscellaneous human factors	2.8

Table 4-4. Top 10 incident causes of train derailments by track type: number of cars derailed, 2001-2014

Rank	Main Track		Non-main Track		Yard	
	Cause ID	%	Cause ID	%	Cause ID	%
1	Rail, joint bar and rail anchoring	25.9	Track geometry	20.9	General switching rules	18.5
2	Track geometry	9.9	General switching rules	13.8	Switches, use of	14.2
3	Wheels	9.9	Rail, joint bar and rail anchoring	10.1	Track geometry	12.0
4	Train handling / train make-up	6.8	Environmental conditions	9.9	Frogs, switches and track appliances	8.0
5	Other miscellaneous	6.2	Switches, use of	9.1	Train handling / train make-up	7.8
6	Highway-rail grade crossing incidents	5.0	Frogs, switches and track appliances	8.2	Rail, joint bar and rail anchoring	7.7
7	Environmental conditions	4.2	Other miscellaneous	7.0	Other miscellaneous	5.4
8	Axles and journal bearings	3.8	Train handling / train make-up	5.0	Unusual operating situations	4.0
9	Roadbed	3.6	Roadbed	2.1	Environmental conditions	3.3
10	Coupler and draft system	3.5	Miscellaneous human factors	1.9	Brakes	2.7

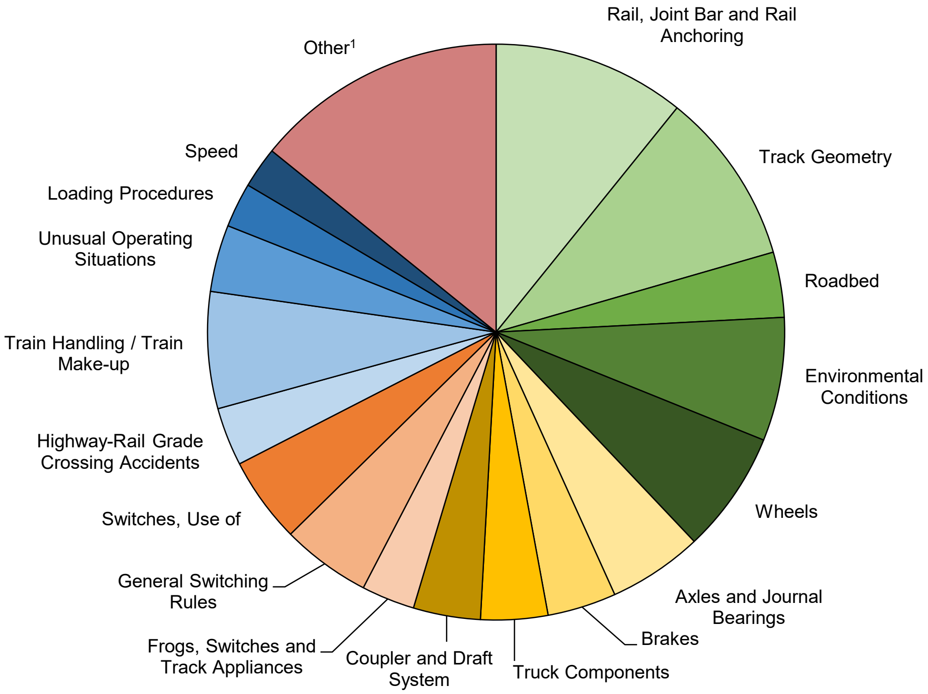


Figure 4-8. Distribution of derailment causes by frequency, 2001-2014.

1. Twelve additional causes in the "Other" category

The rankings show that on all track types, the "track geometry" cause was a major contributing factor to the total number of derailments and the number of cars derailed. Another finding was that "rail, joint bar and rail anchoring" was the number one cause in terms of the number of derailments and total cars derailed on main track. Incident causes associated with switches and other track appliances were major factors on non-main and yard track. "Environmental conditions" was another cause that recurred in each list.

4.5 Frequency-Severity Analysis

Consideration was given to the frequency and severity of main track derailments. Severity provides an assessment of the magnitude of a derailment. Two metrics can be analyzed to gain insight into the severity of derailments: first, the number of cars derailed can provide a measure as to the severity, with multi-car derailments being more severe than single car derailments, as noted by Liu et al. (2012); second, the speed at which a derailment initiates can have an impact on severity, as described by both TSB (1994) and Liu et al. (2012). In general, derailments that occur at higher speeds have higher energy and can result in greater damage.

Figure 4-9 shows the distribution of the average number of cars derailed per derailment throughout the study period. This plot indicates a slightly upward trend in the severity of derailments from 2001 to 2014, with increasing spread in the data toward the later years of the study.

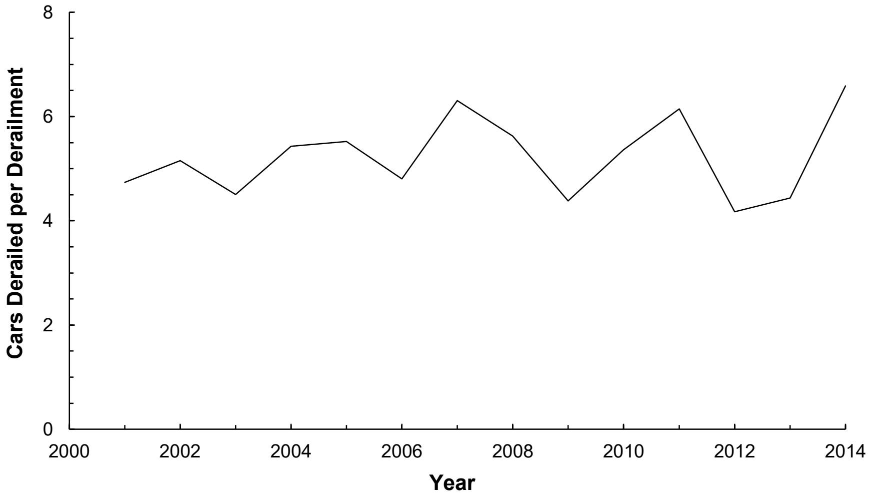


Figure 4-9. Average number of cars derailed per derailment on main track, 2001-2014.

The variation in the number of derailments with one car versus multi-car derailments is shown in Figure 4-10. This plot indicates a general decreasing trend in all four cases. The most dramatic reduction occurred in incidents with only one car derailed beginning in 2005, while the smallest decrease was observed in derailments with more than ten derailed cars.

There was however a small increase in the number of derailments with 2 or more cars derailed from 2013 to 2014.

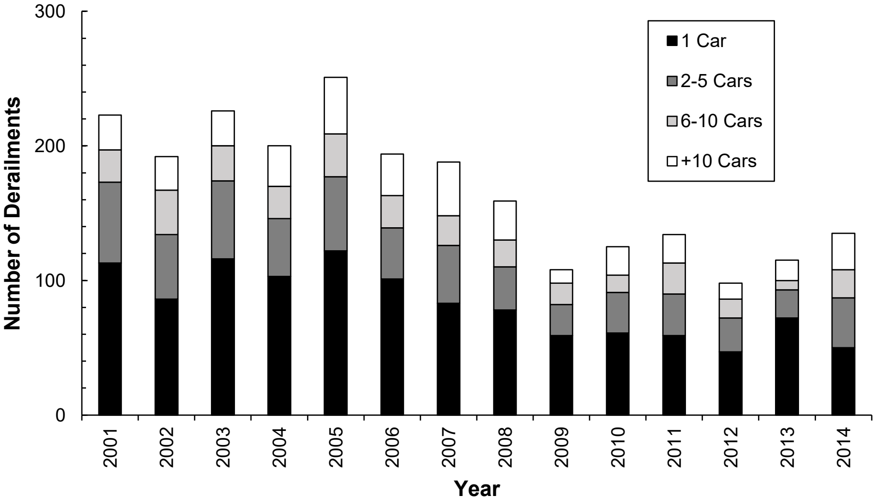


Figure 4-10. Derailment severity by number of cars derailed per incident, 2001-2014.

4.5.1 Derailment Severity by Incident Cause

An analysis of derailment frequency and severity on main track was conducted based on the various incident causes contained in the RODS database (Table 4-5). Liu et al. (2012) presented a similar table for American derailment data from 2001 to 2010. The number of cars derailed per derailment is an important metric as the more cars that are derailed the higher the potential consequences may be to rail infrastructure, the environment and public safety.

Table 4-5. Main track derailment frequency and severity by incident cause, 2001-2014

Cause ID	Description	Derailments		Cars Derailed		Average Number of Cars Derailed per Derailment
		Number	%	Number	%	
8	Rail, Joint Bar and Rail Anchoring	112	10.8	1,320	25.9	11.8
7	Track Geometry	101	9.7	505	9.9	5.0
32	Environmental Conditions	72	6.9	213	4.2	3.0
17	Wheels	71	6.8	503	9.9	7.1
26	Train Handling/Train Make-up	68	6.6	349	6.8	5.1
36	Other Miscellaneous	64	6.2	317	6.2	5.0
16	Axles and Journal Bearings	55	5.3	196	3.8	3.6
24	General Switching Rules	52	5.0	82	1.6	1.6
28	Switches, Use of	50	4.8	116	2.3	2.3
11	Brakes	40	3.9	129	2.5	3.2
14	Coupler and Draft System	39	3.8	178	3.5	4.6
15	Truck Components	39	3.8	111	2.2	2.8
35	Unusual Operating Situations	39	3.8	162	3.2	4.2
6	Roadbed	38	3.7	182	3.6	4.8
34	Highway-Rail Grade Crossing Incidents	34	3.3	256	5.0	7.5
9	Frogs, Switches and Track Appliances	31	3.0	63	1.2	2.0
30	Miscellaneous	28	2.7	33	0.6	1.2
33	Loading Procedures	26	2.5	90	1.8	3.5
27	Speed	24	2.3	147	2.9	6.1
13	Body	14	1.3	32	0.6	2.3
20	General Mechanical and Electrical	8	0.8	19	0.4	2.4
10	Other Way and Structure	6	0.6	11	0.2	1.8
18	Locomotives	6	0.6	11	0.2	1.8
25	Main Track Authority	6	0.6	15	0.3	2.5
21	Brakes, Use of	4	0.4	27	0.5	6.8
31	Loading Procedures	4	0.4	5	0.1	1.3
23	Flagging, Fixed, Hand and Radio Signals	3	0.3	15	0.3	5.0
19	Doors	2	0.2	14	0.3	7.0
37	Signal and Communication	2	0.2	3	0.1	1.5
	TOTALS	1,038		5,104		4.9

Table 4-5 indicates that by both frequency and severity “rail, joint bar and rail anchoring” and “track geometry” were among the most common incident causes during the period 2001 to 2014. When combined, these two causes accounted for about 20% of derailments, and 36% of all cars derailed. The “rail, joint bar and rail anchoring” incident cause accounted for the greatest severity, at 11.8 cars derailed per derailment. The overall average severity for main track derailments was 4.9 cars derailed per derailment. Liu et al. (2012) came to the same conclusion that rail breaks and track geometry were the leading causes of main-line derailments on American railways.

The frequency and severity of derailments were plotted against one another (Figure 4-11) in order to visualize the incident causes that pose the greatest risk to the rail industry. This plot was based on a similar to one developed by Liu et al. (2012) for American main-line derailment data. The plot is divided into four sections based on the average derailment frequency and severity for all incident types. Incident causes that plotted within the upper right quadrant posed the greatest risk due to higher than average frequency and severity. Incident causes that plotted within the lower left quadrant had lower than average frequency and severity. Some of the notable incident causes are labeled.

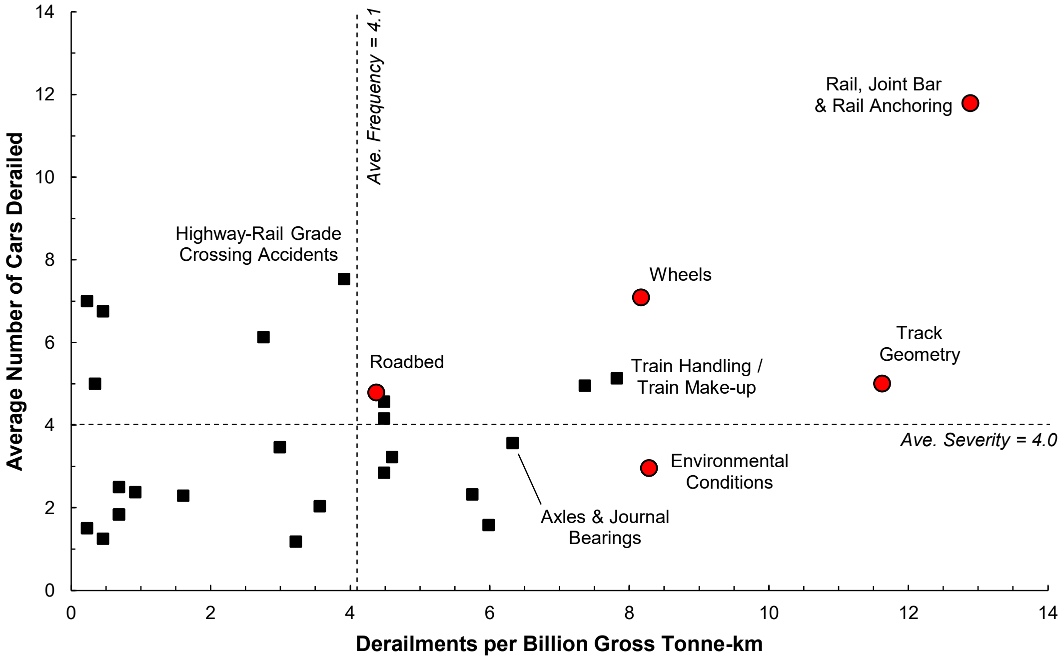


Figure 4-11. Derailment frequency v. severity plot on main track, 2001-2014.

Five incident causes plotted within the upper right portion of the graph, while an additional three causes plotted in close proximity to the intersection of the average frequency and severity delineations. The five highest risk causes were:

- rail, joint bar and rail anchoring;
- track geometry;
- wheels;
- train handling/train make-up;
- and, other miscellaneous.

These five incident causes combined for 40% of derailments and 59% of all derailed rolling stock on main track rail. The other miscellaneous category may sometimes be used as a placeholder for ongoing investigations. It is likely that some of the derailments in this category could be reassigned to other categories.

Four other causes that are of interest due to a relatively high severity are:

- highway-rail grade crossing incidents;
- doors;
- brakes, use of;
- and, speed.

These incident causes accounted for 6% of derailments and 9% of derailed rolling stock on main track rail.

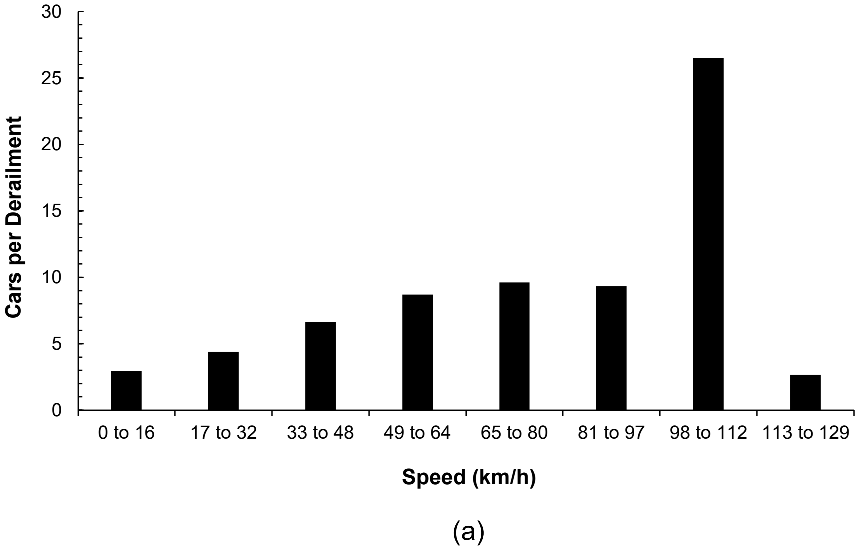
An additional four causes that are of interest due to a relatively high frequency of occurrence are:

- environmental conditions;
- axles and journal bearings;
- general switching rules;
- and, switches, use of.

These incident causes accounted for 22% of derailments and 12% of derailed rolling stock on main track rail.

4.5.2 Effects of Derailment Initiation Speed

Aside from incident cause and track type, another factor that can have an effect on the severity of a derailment is the speed at which a derailment initiates. It can generally be assumed that, in most cases, trains travelling at greater speed result in more cars derailed per derailment. This was the case for main track derailments from 2001 to 2014, as shown in Figure 4-12a.



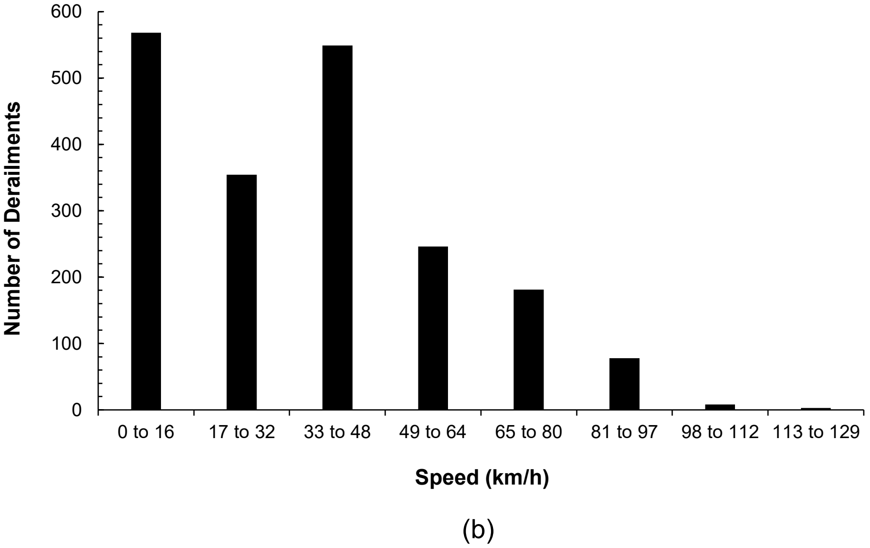


Figure 4-12. Distribution of main track derailments by speed, 2001-2014: (a) severity; and, (b) frequency.

This figure shows a strong relationship between the number of cars derailed per derailment and the speed at which the derailment occurred up to the 65 to 80 km/h range. Below this speed range, higher derailment speeds resulted in greater severity. Above this speed the relationship deviated, with a spike in the 98 to 112 km/h range and a drop in the 113 to 129 km/h range. However, there was a significant decrease in the number of derailments that occurred above speeds of 80 km/h, and very few at speeds greater than 97 km/h (Figure 4-12b). This may account for the deviation from the relationship at higher speeds, as the limited amount of data was more likely to be influenced by extreme outliers. It is noted that the maximum allowable speed for freight trains and passenger trains on Class 5 track is 129 km/h and 153 km/h, respectively.

Figure 4-13 shows the average derailment initiation speed for each year of the study period. It was observed that the average speed at which derailments initiated showed a decreasing trend from 2001 to 2014. Recent derailments were observed to be occurring at a lower average speed when compared to data from the 1994 TSB study. From 1983 to 1993, speeds of between 40 km/h and 50 km/h were common, with a peak of approximately 53 km/h (Figure 2-3 above). Between 2001 and 2014, derailment initiation speeds ranged from 30 km/h to 40 km/h, with a peak of 45 km/h.

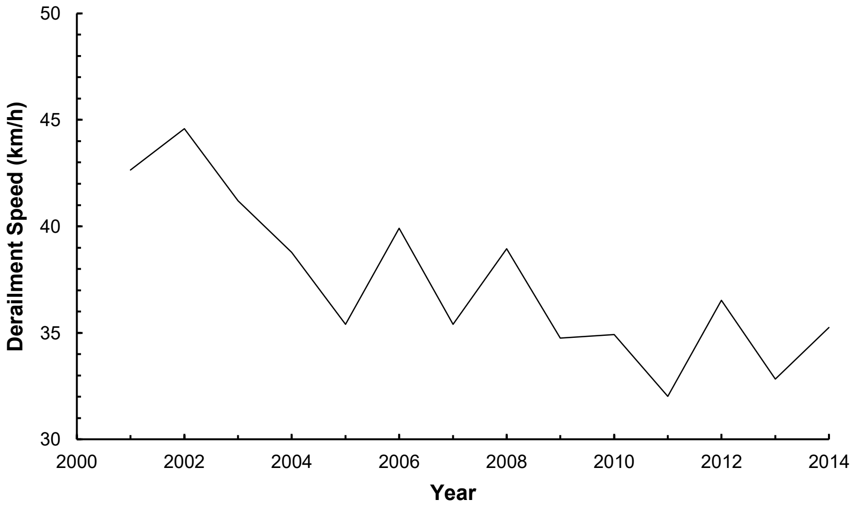
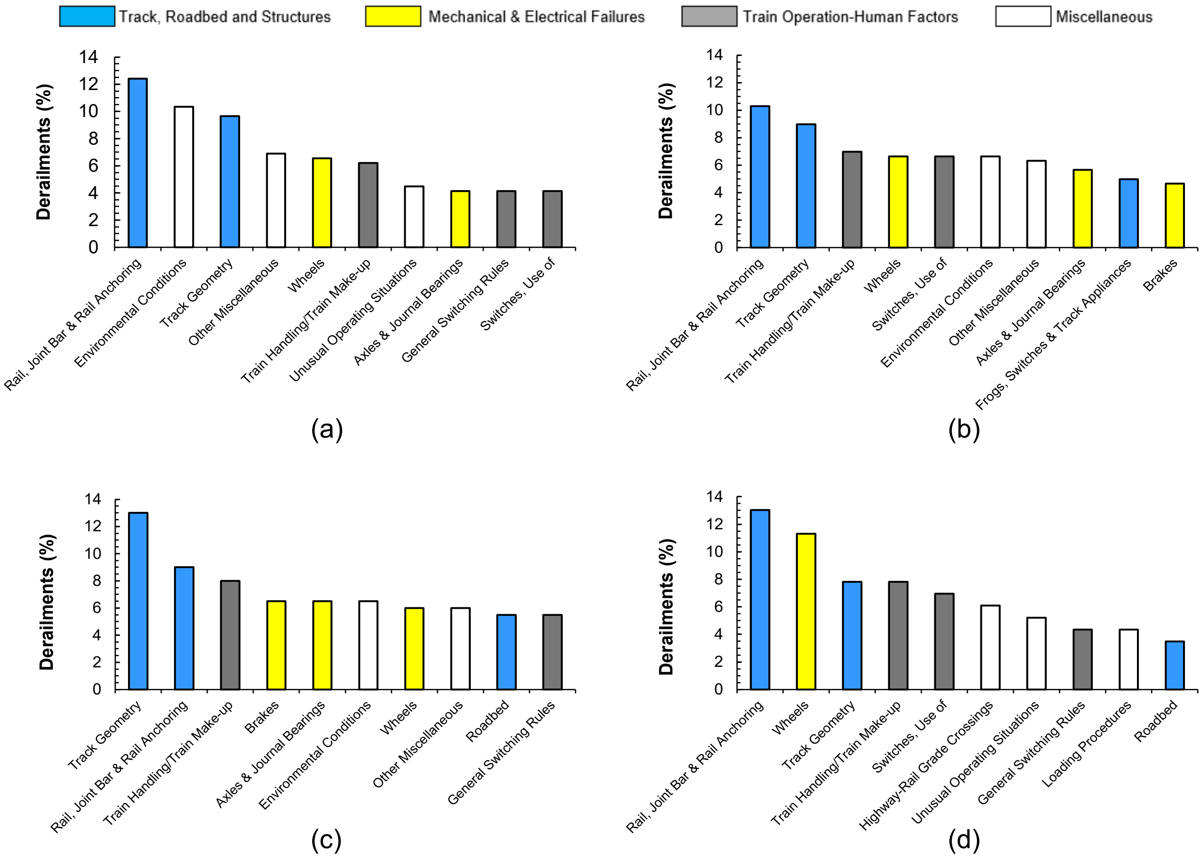


Figure 4-13. Average derailment initiation speed, 2001-2014.

A significant reduction in derailment speed was evident from 2001 to 2005, followed by a slightly downward trend with a cyclical pattern between 2005 and 2010. During 2010 to 2014, the average derailment speed appeared to have leveled off at 33 to 35 km/h, but the cyclical pattern remained. This represents a reduction of 24% from a peak of 45 km/h in 2002.

When analyzed by incident causes, four speed ranges were selected based on FRA track class speeds to allow for comparison between Canadian data and the American data discussed above in Section 2.3. The top ten derailment causes were determined for each speed range (Figure 4-14).



(a) (b) (c) (d)

Figure 4-14. Distribution of derailments by incident cause and speed on main track rail, 2001-2014: (a) 0 to 16 km/h; (b) 16 to 40 km/h; (c) 40 to 64 km/h; and, (d) > 64 km/h.

The following findings were apparent from these plots:

- the “rail, joint bar and rail anchoring” incident cause resulted in the most derailments in three of the speed ranges, and the second most in the fourth;
- the “environmental conditions” incident cause was common at low speeds;
- the “track geometry” incident cause was among top three in all speed ranges;
- Mechanical and electrical failures resulted in a greater number of derailments at higher speeds,
- Incident causes associated with track, roadbed and structures resulted in a greater number of derailments at lower speeds.

4.6 Derailments Involving Dangerous Goods

Information from the RODS database was investigated for derailments involving DG cars. To capture the effect of DG traffic carried by rail, this data was normalized by the tonnage of DG using data obtained from the CANSIM tables. Finally, the number of derailments resulting in a release of DG was assessed as a measure of the severity of this type of incident.

4.6.1 Transportation of Dangerous Goods in Canada

Transportation of dangerous goods is a critical component of Canada’s economy, with an increasing number of dangerous goods transported by rail in Canada every year. According to the Canadian Association of Petroleum Producers (2014), more than 200,000 barrels per day of petroleum crude oil was being transported by rail in Canada in 2014, and is forecast to grow to about 720,000 barrels per day by 2016. As such, the development of regulations and research dedicated to enhance the safe transport of dangerous goods is becoming increasingly important, especially considering some recent high consequence derailments.

The safe transportation of dangerous goods in Canada was enacted under the *Transportation of Dangerous Goods Act, 1992* (Act: S.C. 1992, c.34). The *Transportation of Dangerous Good Regulations* (a consolidated version is available from http://www.tc.gc.ca), which have been adopted by all provinces and territories, establishes safety requirements for the transportation of dangerous goods. An extensive list of controlled products is provided in both federal and provincial legislation.

Transport Canada provides a central point for the promotion of safe transportation of dangerous goods across the country. The Transportation of Dangerous Goods Directorate within TC, which works closely with other government agencies, is a key body for the development of regulations, as well as providing information and guidance to industry, government and the public. There are several branches that act under the Directorate, including the Regulatory Affairs Branch, the Research, Evaluation and Systems Branch, and the Compliance and Response Branch.

The Regulatory Affairs Branch is tasked with overseeing the *Transportation of Dangerous Goods Act* and the *Transportation of Dangerous Goods Regulations*. This branch has various responsibilities, including establishing requirements for the classification, labeling and marking of containers, transportation documentation, and safety marking for vehicles transporting dangerous goods (TC 2016b).

The Research, Evaluation and Systems Branch uses risk management techniques to provide recommendations and execute decisions and directives in an attempt to minimize the impact of incidents associated with dangerous goods transportation, with specific focus of people, property and the environment. The techniques used by this branch reduce some uncertainty by estimating the likelihood and severity of incidents involving dangerous goods. The Research Division and Evaluation Division work with other Branches in the Directorate to advise senior management with regards to risk policy. They direct research and development activities and review and update risk management methods to advance safety initiatives in a cost-effective way. The Systems Division manages the Dangerous Goods Information System and the Transport Dangerous Goods website.

Remedial Measures Specialists work with industry to review emergency response plans that have been registered with the Directorate. They are able to conduct investigations to verify that the plans can be implemented effectively in the event of an emergency. Emergency response plans require an assessment that includes an analysis of any scenario that would result in the release of dangerous goods.

In the event of an emergency, the Canadian Transport Emergency Centre (CANUTEC) provides an advisory and regulatory information service, offering assistance to emergency responders. CANUTEC worked jointly with the United States Department of Transportation and the Secretariat of Communications and Transportation of Mexico to develop the 2008

Emergency Response Guide, which contains information on recommended immediate on-site response to a dangerous goods incident.

4.6.2 Long Term Dangerous Goods Derailment Trends

This section focuses on main track incidents resulting in the derailment of one or more cars containing dangerous goods. Two long term trends were developed in this analysis. The first considered all main track derailments that involved DG cars. The second trend was a subset of the first, and only took into account derailments on main track that resulted in a release of DG. These analyses follow those from similar studies from the TSB (1994) and AAR (2016). The results presented are not directly comparable as the data has been normalized against different metrics, however the overall trends are evident.

Main track derailments that involved DG cars exhibited a similar, although less drastic, reduction during the study period when compared to all main track derailments. However, there was a dramatic increase in the transportation of dangerous goods, particularly since 2010 (Figure 4-15). This figure indicates a growth of just over 60%, from 20.6 to 33.5 million tonnes of DG. From 2009 to 2014, there was a 50% increase from 22.5 million tonnes to 33.5 million tonnes. Much of this growth can be attributed to increased oil production and transportation in western Canada during this time period.

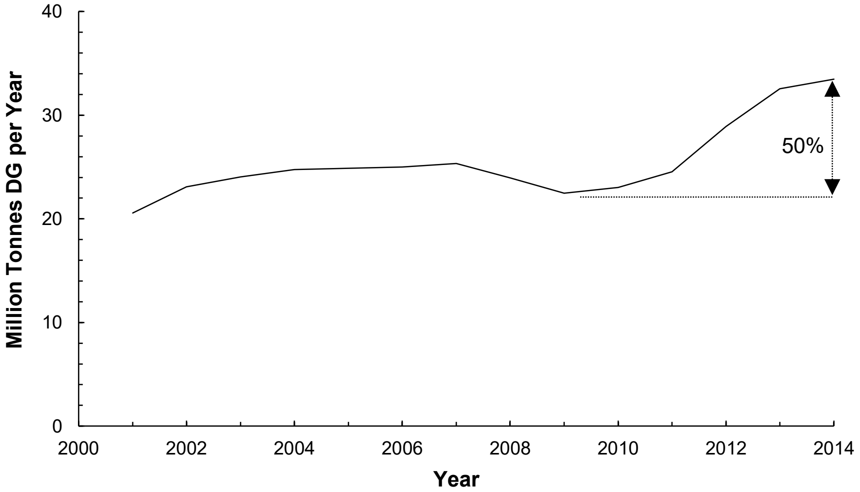


Figure 4-15. Transportation of dangerous goods, million tonnes, 2001-2014.

The number of derailments with DG cars involved was found to be highly variable during the study period (Figure 4-16). In general, however, a slightly downward trend was observed despite the total number of derailments increasing from 22 in 2001 to 30 in 2014. A high of 45 was reported in 2004, while a low of 9 was reported in 2012. A cyclical pattern was apparent where a spike in the number of derailments involving DG cars occurred every 3 to 4 years. The data presented in Figure 4-16 indicates that the latter years of the study period corresponds to one of these peaks. It is unclear what the cause of this cyclical pattern is, and is likely a combination of many different factors.

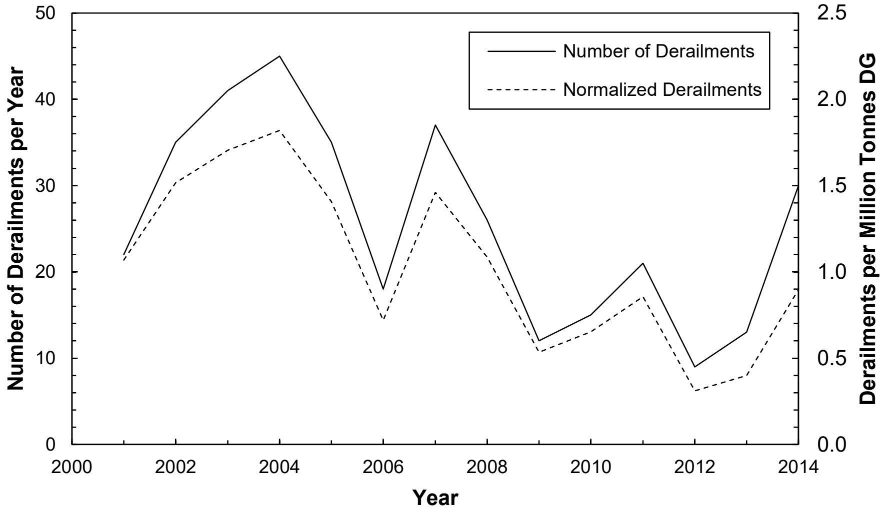


Figure 4-16. Main track derailments with dangerous goods cars involved, 2001-2014.

When normalized to the amount of dangerous goods being transported, the decreasing trend became more apparent. There was a decrease from 1.07 derailments per million tonnes of DG in 2001 to 0.90 derailments per million tonnes of DG in 2014, an overall reduction of 16%. The cyclical pattern was again observed in the normalized derailment data. One possible explanation for the cyclical pattern is

When analyzed by track class (ie; Class 1 through Class 5 railways), it became evident that the majority of derailments occurred on Class 5 track, with a maximum operating speed of 130 km/h (80 mph) for freight trains. No derailments involving DG cars occurred on Class 1 track, where the maximum allowable speed is 16 km/h (10 mph). The cyclical pattern was apparent on rail of all track classes (Figure 4-17). These derailments were not normalized to rail traffic, as this data was not available through the CANSIM tables.

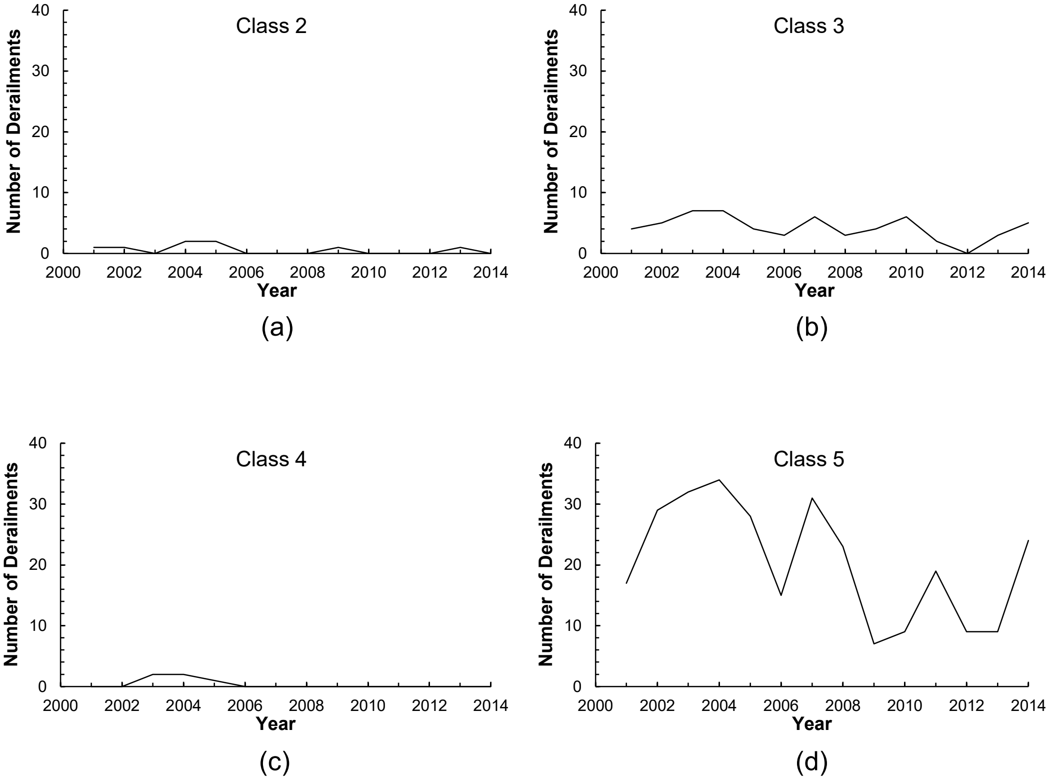


Figure 4-17. Distribution of derailments involving DG cars by track class, 2001-2014; (a) Class 2; (b) Class 3; (c) Class 4; (d) Class 5.

The results were further analyzed by mainline (CN and CP) and regional (all others) operators. The majority of derailments involving DG cars occurred were attributed to CN operated trains, and the fewest occurred on regional operators (Figure 4-18). The cyclical trend was apparent for both CN and CP, and to a lesser degree for regional operators. The number of derailments were not able to be normalized to the amount of DG transported by each operator, as this information was not available through CANSIM.

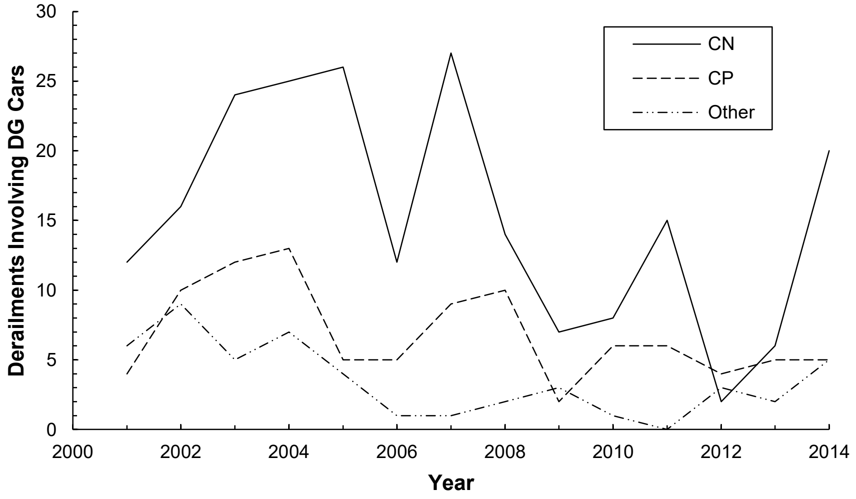


Figure 4-18. Distribution of derailments involving DG cars by operator, 2001-2014.

The results presented above show all derailments that involved DG cars. Of particular interest is the number of derailments that resulted in a release. Generally a very small fraction of main track derailments with DG cars involved actually resulted in a release. Figure 4-19a shows the total number of main track derailments that resulted in the release of DG, and Figure 4-19b shows the number of derailments with a release normalized to the amount of DG transported by rail.

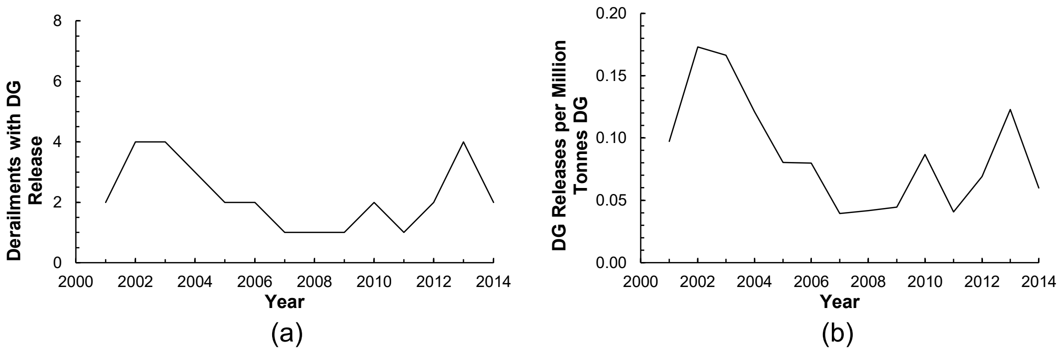


Figure 4-19. Derailments with dangerous goods cars involved with DG release, 2001-2014: (a) total DG releases; and, (b) normalized by DG goods transported.

The above figures indicate that the total number of derailments that occurred was relatively consistent during the study period, with a high of 4 in 2002, 2003 and 2013, and an average of approximately 2 throughout the rest of the study period.

When normalized to the amount of DG traffic, a decreasing trend emerged, with a 40% reduction in the number of derailments that resulted in the release of DG per million tonnes of DG carried from 0.10 to 0.06. This was especially noticeable in the earlier years of the study period, followed by a period where DG releases leveled off from 2007 to 2011. A small spike in derailments with DG released can be observed in the latter years of the study period.

4.7 Conclusion

The purpose of this chapter was to present the results of an investigation into derailment trends from 2001 to 2014, with a focus on main track rail. This was achieved by examining the RODS database for total numbers of derailments and normalizing to rail traffic data obtained from CANSIM tables.

A high level analysis indicated that “derailments” was the leading incident type on all three types of rail considered. Derailments accounted for 90% of all incidents and 91% of all derailed rolling stock.

It was found that the total number of derailments decreased by 40% from 2001 to 2014. The most drastic reduction occurred from about 2003 to 2009, followed by a period of relative stability with a slight increase in 2014. During this time, the amount of rail traffic by gross tonne-km increased by 33%. When the total number of main track derailments was normalized to rail traffic, there was an overall reduction of 55%. The normalized data did not display the upturn in 2014 that was evident in the total derailments, but was relatively more stable in nature.

When analyzed by track class, it was evident that Class I railways have improved in the number of derailments normalized to rail traffic; a steady decreasing trend was observed. Short line and regional railways however showed an increasing trend in normalized derailments, with a peak in 2008.

An analysis of severity and frequency of main track derailments was conducted. It was shown that the average severity, or number of cars derailed per derailment, displayed a slightly upward trend from 2001 to 2014, with a cyclical pattern more apparent towards the end of the study period. Five incident causes were found to have been high in frequency and severity, and accounted for 40% of main track derailments. These were:

- “Rail, joint bar and rail anchoring;”
- “Track geometry;”
- “Wheels;”
- “Train handling/train make-up;”
- And, “other miscellaneous.”

The speed at which a derailment initiated was found to have an effect on severity. The average derailment initiation speed was found to have decreased from 2001 to 2014. The analysis showed that higher speeds resulted in a greater number of cars derailed, with a strong relationship observed for derailment speeds up to 80 km/h. Insufficient data was available at higher speeds to comment on trends above 80 km/h. Mechanical and electrical failures resulted in a greater number of derailments at higher speeds, while the incident causes within the track, roadbed and structures category lead to more derailments at lower speeds.

Information from this type of study has been used in Canada and other jurisdictions to direct research initiatives to further reduce the number and severity of derailments. For example, the study conducted on Canadian data from the 1980’s and 1990’s found that a similar plateau had been reached in the number of derailments after a period of steady decreases. A number of areas were identified that could potentially lead to further reductions in derailments. These included items such as improving the identification of internal rail defects, the replacement of straight-plate wheels and revising the spacing of hot box detectors. American derailment data has recently been used to identify new ways to manage and reduce risk to the rail industry, such as upgrading track quality (Liu et al. 2011), and identifying the leading causes for each track type (Liu et al. 2012).

Long term trends were presented for the number of rail incidents between 2001 and 2014 that resulted in the derailment of one or more DG cars, as well as the number of derailments resulting in a release of DG. This was accomplished by analyzing information contained in the RODS database and developing trends for both the total number of derailments involving DG cars and normalizing this data to DG traffic obtained from CANSIM tables.

The number of derailments that involved DG cars was relatively small when compared to the total derailments that occurred on main track rail, and was found to be highly variable with a cyclical pattern clearly observed. A peak in the number of derailments took place every 3 to 4 years, with an upturn in the data evident in the final two years of the study period. In general, a slightly downward trend was apparent in the number of derailments with DG cars involved.

It was observed that the amount of dangerous goods carried by rail increased by 60% during the study period. The majority of this increase began in 2010, and was most likely due to a rise in oil production in western Canada. When the total derailments with DG cars were normalized to DG traffic, a more pronounced downward trend was observed, with a 16% reduction in derailments from 2001 to 2014.

When derailments resulting in a DG release were considered, it was found that there was a decreasing trend up until 2007, followed by a period of relative stability, and a slight upturn in the data beginning in 2012. This may be related to the cyclical nature of derailments with DG cars involved. A peak of 4 derailments resulted in a DG release in the years 2002, 2003 and 2013. A low of 1 DG release occurred in the years 2007, 2008, 2009 and 2011. An average of 2.2 derailments per year resulted in a DG release for the study period. When normalized to the amount of DG carried by rail, a peak of 0.17 and a low of 0.04 releases per million tonnes. An overall decrease in DG release derailments of 40% was observed from 2001 to 2014.

Data from this type of analysis can be used to further enhance safety standards for the transportation of dangerous goods. Recent results from similar studies in the U.S. have focused on identifying the leading causes that lead to releases of hazardous materials and the preventative measures that may reduce these types of derailments. Because of the low number of these types of incidents, derailment data may be used as input for a risk-based approach as a predictive method to reducing releases (Barkan et al. 2003).

CHAPTER 5 : SEASONAL AND SPATIAL ANALYSES ON CANADIAN MAIN TRACK DERAILMENTS FROM 2001 TO 2014

5.1 Introduction

This chapter presents the results of the temporal and spatial analyses conducted on Canadian main track derailment data from 2001 to 2014. This analysis was intended to provide insight into the effects that climate and physical geography have had on risk to Canadian railways between 2001 and 2014, with an emphasis on specific incident causes. Some causes are expected to display seasonal variation, such as steel components having a higher likelihood of failure during cold temperatures due to an increase in brittleness (Havers & Morgan, 1972). Some incident causes may exhibit trends related to physical geography, such as weak subgrades over muskeg or glacio-lacustrine soils, and routes through areas prone to landslide and avalanche activity.

Included in this chapter is a brief description of climatic conditions how they relate to derailments. Climate data was obtained from Environment Canada using Canadian climate normals for the most recent thirty year period (1981 to 2010). Temperature and precipitation data is presented for this period. A general description is also provided for each of the five physiographic regions that are traversed by Canadian railways. The boundaries of these regions were delineated using data from Natural Resources Canada (NRC). The Government of Canada provides this information, as well as maps and other publications that can be used without restriction, through the Geogratis website maintained by the NRC (www.geogratis.gc.ca).

The seasonal analysis was conducted by examining derailment information contained in the RODS database by month. The spatial analysis was conducted using data from the RODS database; however, the physical location of each incident in the database was only provided in terms of province, subdivision and milepost. The incidents were assigned physiographic regions based on the information obtained from NRC. The analysis was conducted for all derailments regardless of incident cause, and then again for the four causes that were most sensitive to seasonal variation. These will be described in more detail in the following sections.

Rail traffic information was obtained from CANSIM tables. The seasonal trends presented in the following sections were normalized to tonnes of goods carried, as the gross tonne-km were not able to be sorted by month. The spatial trends by region were not normalized as this information was not available in the CANSIM tables. However, the track tonnage was available by province, which provided an approximation of the amount of traffic that can be expected within each region.

As it is difficult to determine the start and end of each season across the entire country, the seasons were arbitrarily defined to simplify the analysis. Two distinctions were made, with colder "winter" temperatures defined from November to May, and warmer "summer" temperatures from May to November. Each incident cause is described in detail in the following sections.

5.1.1 Canadian Climate

The climate in Canada varies greatly from coast to coast and presents multiple challenges to the rail industry. In particular, cold weather and precipitation play a large role in risk to the railways. In the winter months, particularly in the prairie region, the temperature can regularly reach -30^{o}C or colder (McGinn 2010). Figure 5-1 shows that the rail alignment experiences considerable periods of the year with temperatures below freezing. Conversely, average temperatures in the summer months across Canada are in the range of 20^{o}C to 26^{o}C (Environment Canada 2010). In the prairies, a maximum recorded temperature of 45^{o}C was has been observed (McGinn 2010). Precipitation and snowmelt runoff can also pose a serious risk to the rail industry. The east and west coasts of Canada can typically see annual average rainfall in the order of 2 m or more (Figure 5-2), in the range of 1 m in southern Ontario and Quebec and typically less than 500 mm in the prairies.

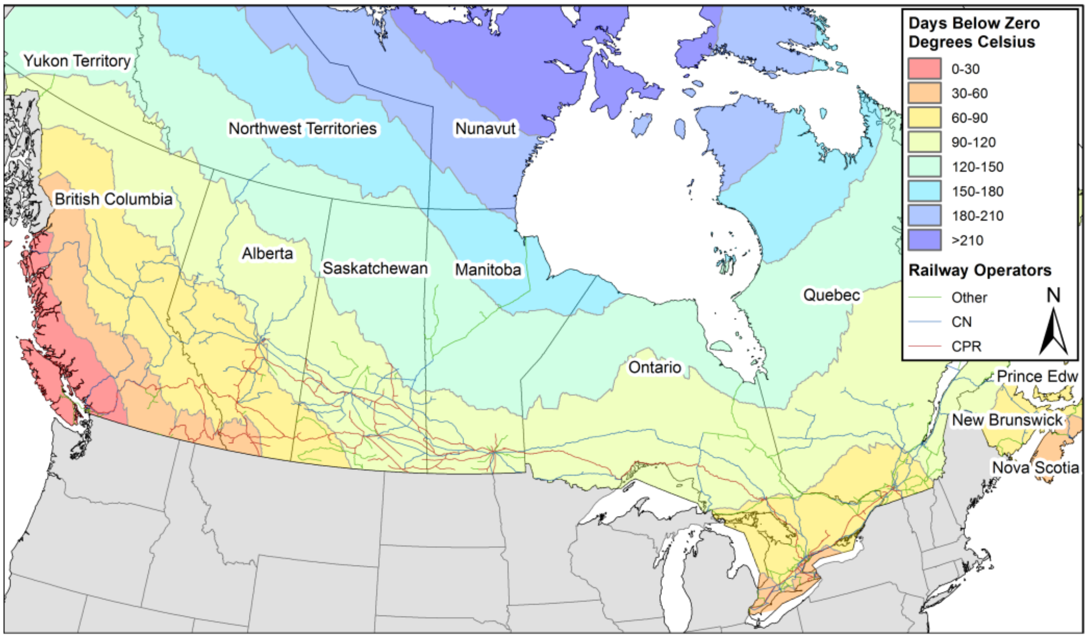


Figure 5-1. Number of days below zero degrees Celsius, 1981-2010.
(Source: Environment Canada)

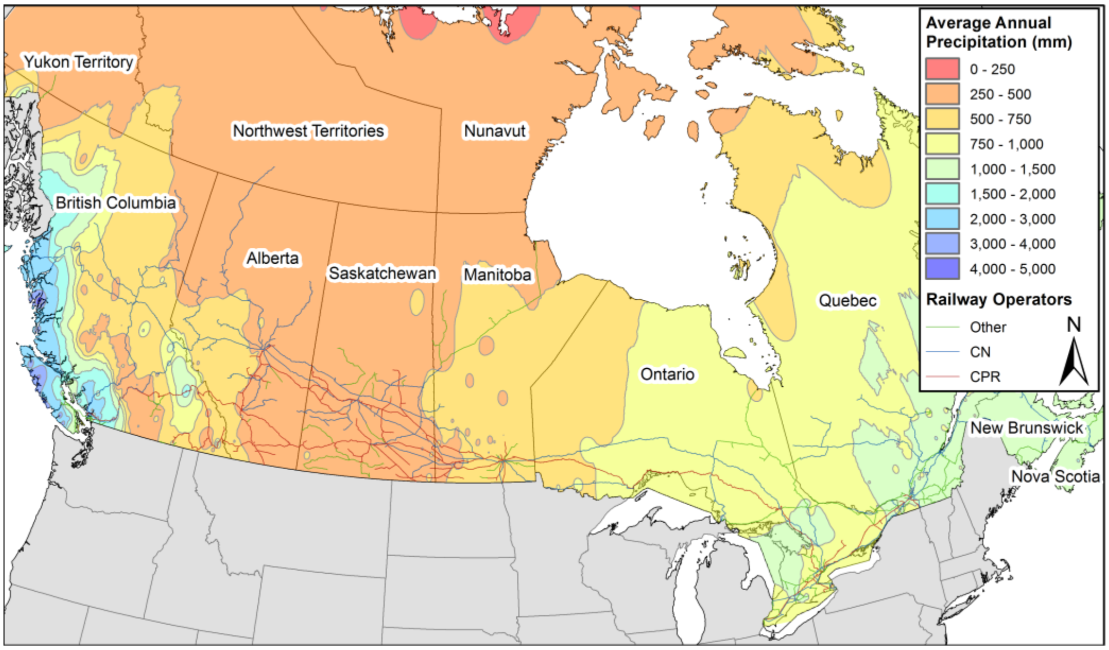


Figure 5-2. Average annual precipitation (mm), 1981-2010.
(Source: Environment Canada)

As discussed above in Section 2.4, temperature has a significant impact on rail safety. Extreme cold can induce very high tensile stresses in rail steel (Kish & Aten, 2012) and a transition from ductile to brittle behavior (Havers & Morgan, 1972), leading to increased potential for damage to track infrastructure or failure of mechanical components. When tensile stresses are high enough, rail steel can break under train loading (Rosetti 2007). Temperatures in the summer months can induce high compressive stresses in the rail steel, and can lead to track geometry issues, such as buckled or sunkinked rail (Rosetti 2007).

Three incident causes that were expected to be directly affected by temperature were "rail, joint bar and rail anchoring," "wheels" and "track geometry." All of these are explained in further detail below. It was expected that an increase in derailments would occur in the winter for the "rail, joint bar and rail anchoring" and "wheels" causes based on increased brittleness and tensile stresses due to cold temperatures. Derailments due to "track geometry" were expected to increase in the summer due to compressive stresses causing buckled rail.

The risk posed by precipitation is a complex issue. Much of the prairies of western Canada are underlain by soft clays deposited in glacial lakes (Quigley 1980), which are susceptible to weakening when subjected to increases in moisture content (Li & Selig, 1995). This can include rainfall in the summer months and snowmelt runoff in the spring. As a result, track roadbeds need to be designed carefully to promote surface water drainage away from the rail bed to prevent subgrade softening. Further, climatic fluctuations that produce increased precipitation and temperature swings are more likely to trigger earth, rock and snow slides in mountainous regions (Rosetti 2002). Issues related to precipitation include soft or settled roadbed, washouts, and snow and ice buildup on the track.

The incident causes that were believed to be affected by precipitation were "roadbed" and "environmental conditions," which were combined in this study to form the "ground hazards" cause group. It was anticipated that derailments would increase in the spring and summer for the "roadbed" cause due to subgrade softening during spring melt and rainfall events.

Derailments attributed to “environmental conditions” were expected to increase in the winter due to snow and ice buildup on track.

5.1.2 Physiographic Regions of Canada

Canada’s geography can be categorized into two broad groups: the Shield and the Borderlands (NRC 2010). The Shield is comprised of massive Precambrian rock, and is surrounded by younger rocks contained in the Borderlands. The Borderlands can be divided into four distinct regions: the Cordilleran Region and the Interior Plains to the west of the Shield, and the St. Lawrence Lowlands and the Appalachian Region to the southeast (NRC 2010). The regions are shown in Figure 5-3.

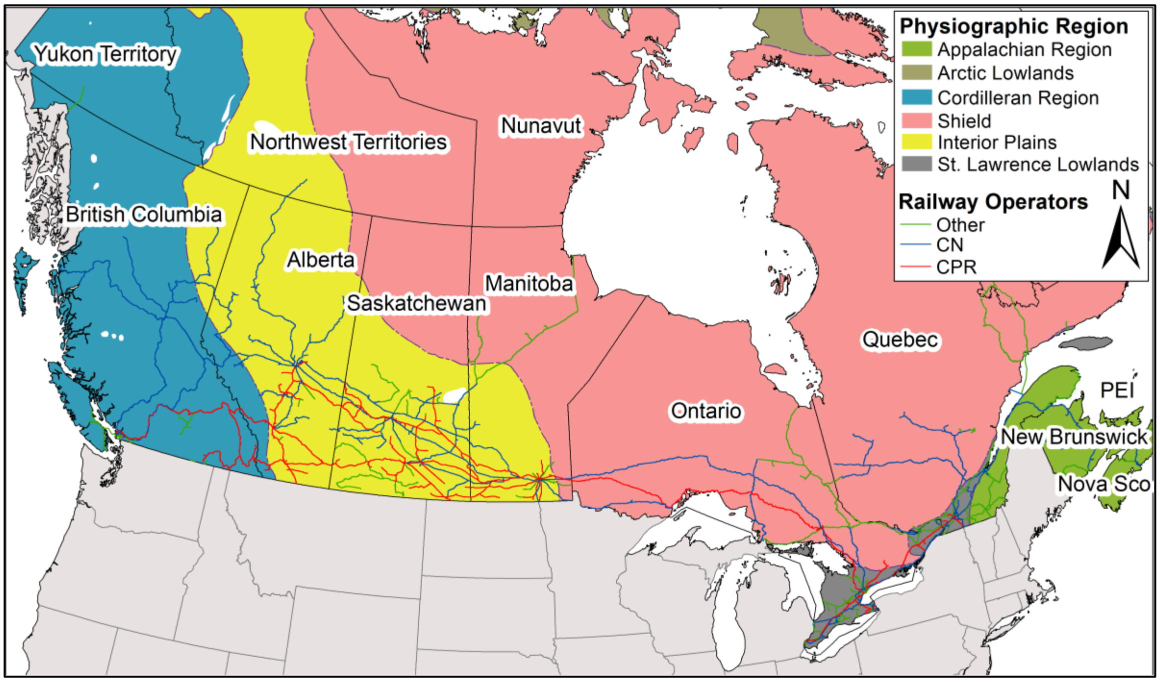


Figure 5-3. Physiographic regions of Canada.
(Source: Natural Resources Canada)

The Cordilleran region encompasses the majority of British Columbia and the Yukon, and is bordered by the Rocky Mountains to the east. The geography of this region comprises mountain ranges, valleys, basins, plains and plateaus (Clague 1989b). Glaciation features such as striations, drumlins and eskers are commonly found on plateaus, while valleys may contain thick deposits of glacio-lacustrine clay and silt or glacio-fluvial sands and gravels (Acton et al. 2012). The irregular nature of the topography presents challenges to the rail industry in terms of route selection due to the mountainous terrain and natural hazards from avalanches, landslides and rock falls, which occur frequently in this region (Clague 1989b, Evans & Gardner, 1989). Aside from economic losses due to blocked traffic, there is typically a very large cost in clearing the resulting obstructions (Clague 1989a).

The majority of Alberta, southern Saskatchewan and southwest Manitoba make up the Interior Plains. This region is generally flat due to the low relief of the sedimentary bedrock (Fulton 1989). The southern portion of the Plains is characterized by semi-arid grassland prairie, the central portion is generally tree covered, and tundra makes up the northern-most segment of the region (NRC 2010). Surficial material in the Interior Plains comprises glacial till and glacio-lacustrine soil deposited as lakes formed at the terminus of glaciers (Fulton 1989). Some of the challenges that must be dealt with by the rail industry in this region include weak subgrades due to the presence of glacio-lacustrine clays (Selig 1995), numerous low-lying wetlands, and meandering rivers that can influence the location of crossings.

The Shield accounts for the largest physiographic region in Canada. It is composed primarily of primarily of crystalline Precambrian rock mantled with glacial till in most areas, and as such its topography has remained relatively stable (Acton 2012). Erosion of this region over several million years has resulted in relatively low topographic relief, while glacial processes have led to numerous shallow lakes, ponds and swamps throughout the region (which are typically occupied by organic soils) creating problems with soft foundations (Dyke et al. 1989).

The St. Lawrence Lowlands region is located to the southeast of the Shield. This region can be characterized by generally flat to undulating plain-like topography (Acton 2012). Surficial deposits are comprised of glacial till, glacio-lacustrine soils and marine deposits (Karrow 1989). Moraines mark the location of temporary pauses in the retreat of glaciers (Acton 2012). Railways through this region must contend with sensitive marine clays and associated landslide activity (Locat & Chagnon 1989) as described above in Section 2.5.

The Appalachian region includes part of southern Quebec and the Maritimes in eastern Canada. This region is dominated by a combination of mountainous uplands and lowlands (NRC 2010). The uplands were formed by regional uplift of stronger rock, while the lowlands were formed through erosion of weaker rock (NRC 2010). There are relatively few geographical hazards associated with this region, however railways are faced with challenges primarily in the form of fine grained soil flow and slumping, particularly where naturally stabilized slopes are altered, and rock falls in fractured bedrock (Grant 1989).

5.2 Seasonal Derailment Trends

The overall temporal trend for main track derailments regardless of incident cause is presented in Figure 5-4. This plot shows two separate increases in the number of derailments, one corresponding to colder temperatures in the winter months, and one in the warmer summer months; peaks were evident in January and July. The incident causes investigated generally displayed this trend, with a peak in either the “winter” or “summer”.

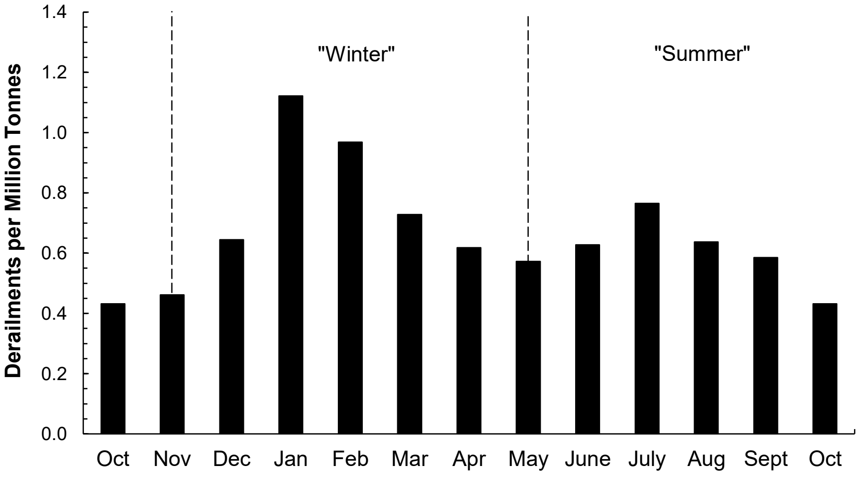


Figure 5-4. Temporal Distribution of main track derailments, 2001-2014.

Monthly trends were developed for select incident causes within the first sublevel of causes, as described above in Section 4.5. Four causes were analyzed based on a perceived sensitivity to climatic conditions, as described in the section above. These were:

- “rail, joint bar and rail anchoring;”
- “track geometry;”
- “wheels;”
- and, “ground hazards,” which includes both the “roadbed” and “environmental conditions” causes.

The results of the analyses are presented in the following sections.

5.2.1 Rail, Joint Bar and Rail Anchoring

The “rail, joint bar and rail anchoring” incident cause includes a number of defects with the rail steel itself. Some examples include broken or worn rail, broken joint bars and broken or missing joint bolts (Figure 5-5). The majority of derailments reported within the “rail, joint bar and rail anchoring" incident cause during the period 2001 to 2014 were attributed to broken rail. There are a number of ways that rail breaks can manifest themselves. Welds can fail, bolt holes can crack, the head and web of the rail can separate, the steel may be subjected to fatigue, there can be horizontal or vertical cracks in the head, and transverse or compound fissures can occur. It was determined that a transverse defect led to the rail break that caused the derailment near Gainford, Alberta described above in Section 1.2.2 (TSB 2013c).

(a) (b)

Figure 5-5. Examples of common rail break type failures: (a) failure initiated at weld; and, (b) transverse defects. (Source: TSB Railway Investigation Reports R99H0010 and R11C0118)

This incident cause was selected for analysis as it was theorized that the majority of rail breaks were caused by increased tensile stresses induced by cold temperatures in winter (Kish & Aten, 2012). Another reason for selecting this cause was that it accounted for the greatest number of derailments that occurred on main track, and therefore required further investigation.

The results of the analysis are shown below in Figure 5-6.

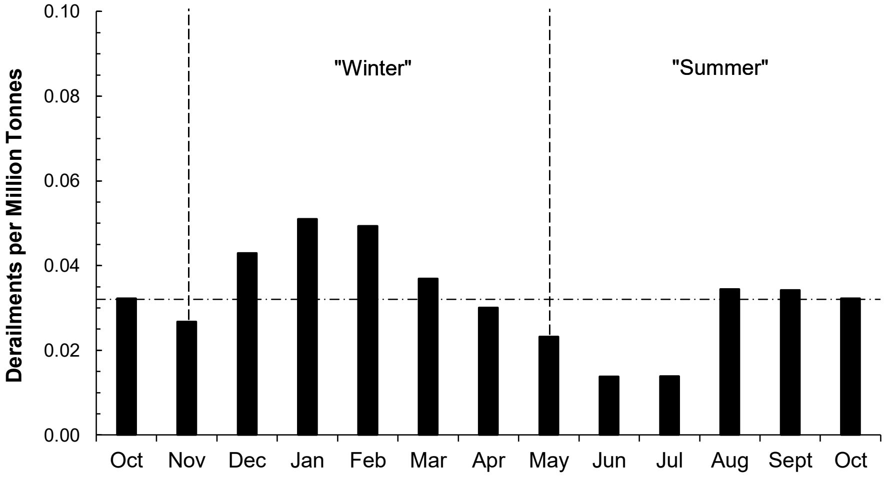


Figure 5-6. Temporal distribution of number of derailments caused by Rail, Joint Bar and Rail Anchoring, 2001-2014.

The results were as expected, with a higher number of derailments taking place in the winter period, reaching a high of 0.05 derailments per million tonnes of goods transported in January and a low in June and July of 0.01. Of note is a slight increase in derailments in August through October was observed, the cause of which is unknown. The average for the study period is also plotted for this incident cause at 0.032 derailments per million tonnes.

5.2.2 Track Geometry

The “track geometry” incident cause encompasses a number of rail alignment defects. These can include irregular cross level, irregular alignment, non-uniform top-of-rail profile, disturbed ballast, improper super-elevation, and wide gage. Some examples of these can be seen below in Figure 5-7. The most common track geometry issue in terms of number of derailments was wide gage due to defective or missing crossties, followed closely by buckled or sunkinked rail. The information in the RODS database indicated that buckled track accounted for 19% of derailments within the “track geometry” incident cause group, while wide gage accounted for 36%.

(a) (b)

Figure 5-7. Examples of common track geometry deficiencies: (a) irregular alignment track alignment (buckled rail); and, (b) disturbed ballast. (Source: TSB Railway Investigation Reports R06T0153 and R10Q0037)

This incident cause was selected for analysis for seasonal trends because it was believed that a greater number of alignment defects would develop during months with increased precipitation, potentially leading to conditions conducive to shifting or movement of the track bed. Another consideration is warmer temperatures in the summer, when the rail steel is subject to thermal expansion, resulting in large compressive stresses in the rail and thus increasing the potential of the rail buckle laterally. The results of the seasonal analysis are shown below in Figure 5-8.

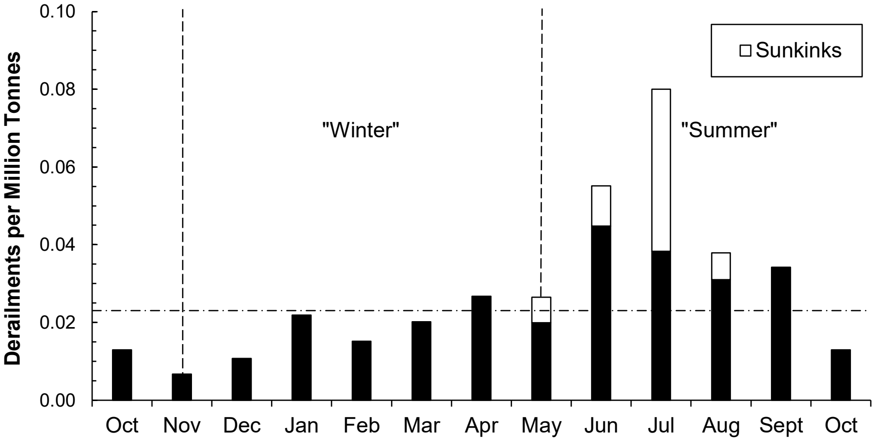


Figure 5-8. Temporal distribution of number of derailments caused by Track Geometry, 2001-2014.

It is evident from the Figure 5-8 that a greater number of track geometry related derailments occurred in the summer compared to the winter, particularly in July when a maximum of 0.08 derailments per million tonnes of goods transported. The increase in the summer months was primarily due to buckled rail, as sunkinks were only observed from May to August, with a peak in July. In fact, sunkinks accounted for 33% of derailments attributed to the "track geometry" incident cause during these months, while the remaining 67% were split between 9 other specific causes. Therefore, this incident cause was a main contributor to the peak in derailments in the summer observed in Figure 5-4. As mentioned above, wide gage accounted for 36% of track geometry related derailments, and these were found to be relatively evenly distributed across all months. Without considering derailments caused by sunkinks, an average of 0.023 derailments per million tonnes was observed.

5.2.3 Wheels

Several wheel related issues fall into the "wheels" incident cause category. These can include broken, damaged or worn flanges, rims and plates, loose wheels and thermal cracks in the flange or tread. Some examples of this incident cause type are shown below in Figure 5-9.

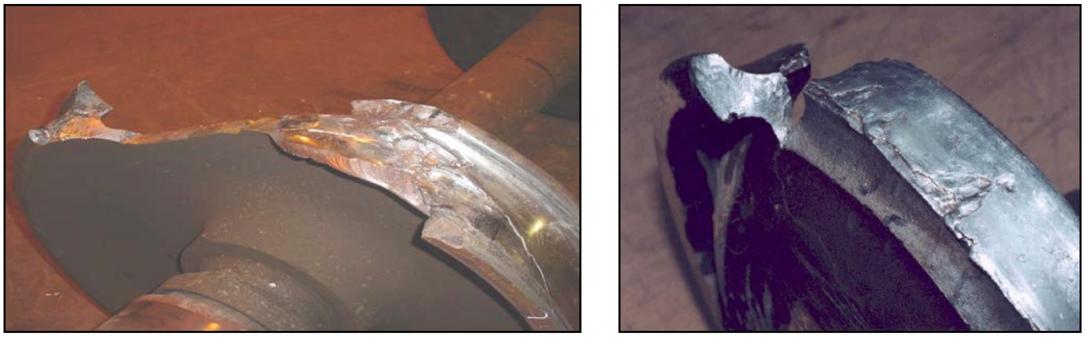


Figure 5-9. Examples of wheel related failures. (Source: TSB Railway Investigation Reports R04T0008 and R04Q0047)

This incident cause was selected for analysis for seasonal trends for two reasons. First, it was assumed that colder temperatures in the winter months would lead to an increased brittleness of steel components (Havers & Morgan, 1972), particularly those subject to a large degree of stress. Second, derailments attributed to this cause accounted for the fourth leading cause of main track derailments in Canada. Wheel failures can also be caused by a combination of high temperatures and fatigue due to both rolling contact loads and high thermal loads during braking (Haidari & Tehrani, 2015).

The results of the analysis are shown below in Figure 5-10.

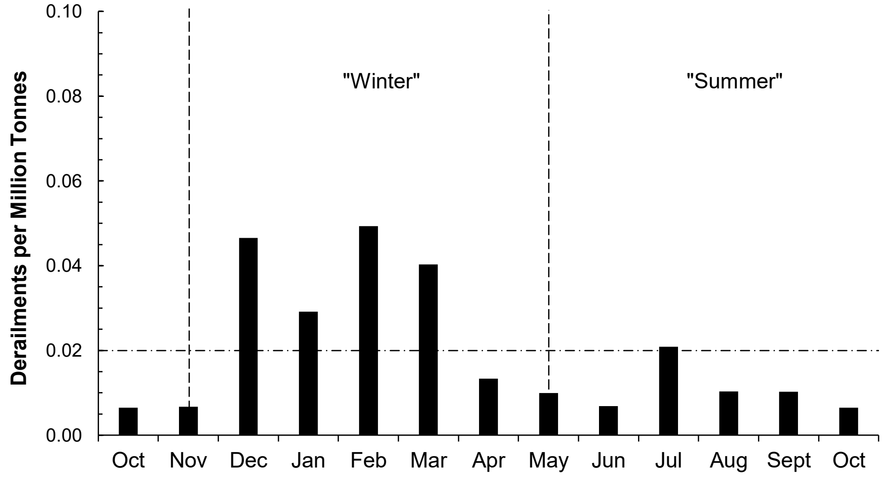


Figure 5-10. Temporal distribution of number of derailments
caused by Wheels, 2001-2014.

The results show that, as expected, a greater proportion of derailments occurred in the winter months, with a maximum of 0.05 derailments per million tonnes in February, and an average of 0.020. Broken, worn or damaged wheel components accounted for 77% of derailments attributed to the “wheels” incident cause. No specific differentiation was noted in the RODS database as to what caused these failures, however, it can be postulated that brittle behaviour due to cold temperatures likely had an effect, and that the smaller peak in July could be due to thermal stresses from both braking operations and high ambient temperatures.

5.2.4 Ground Hazards

The “roadbed” and “environmental conditions” incident causes were combined to form the “ground hazards” cause. This was done to group derailment causes that may be closely related. For example, environmental conditions may lead to situations that adversely affect the track roadbed.

The “roadbed” cause includes soft or settled roadbed as well as damage to the roadbed due to washout, rain, slide, flood or ice. The linear nature of railways sometimes requires the construction of track through less than ideal ground conditions, such as through marsh lands or muskeg. Combined with precipitation events, these ground conditions can easily lead to the softening of the track subgrade. The “environmental conditions” cause includes extreme weather events such as flooding or extreme wind velocity. Flooding can result in ponded water along the track alignment, which in turn increases the potential of the track subgrade softening. Flooding can also result in more serious subgrade washouts. This incident cause also includes debris on the track such as snow, ice, mud, gravel coal or sand. Typical examples these incident causes are shown below in Figure 5-11.

(a) (b)

Figure 5-11. Examples of common ground hazards incidents: (a) subgrade washout; and, (b) debris slide on track. (Source: TSB Railway Investigation Reports R13W0124 and R09V0235)

These incident causes were selected for analysis because of how these types of incidents can be influenced by changing climatic conditions. Results of the analysis are shown below in Figure 5-12.

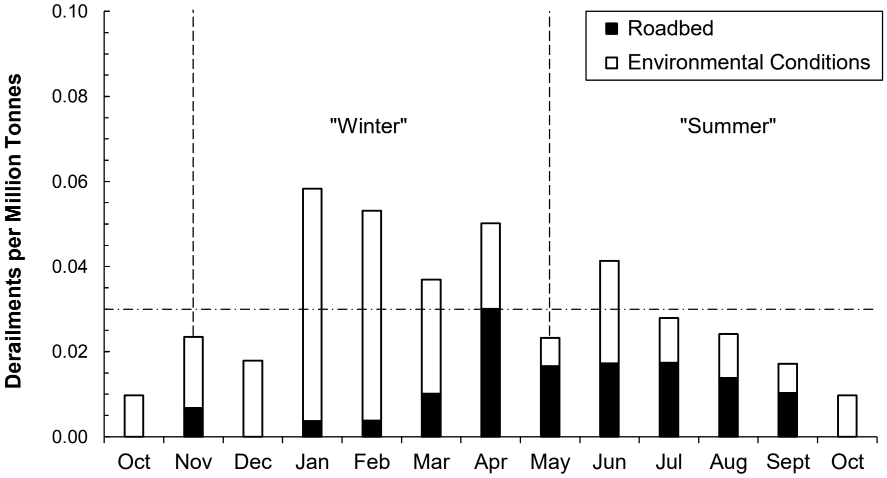


Figure 5-12. Temporal distribution of number of derailments caused by Ground Hazards, 2001-2014.

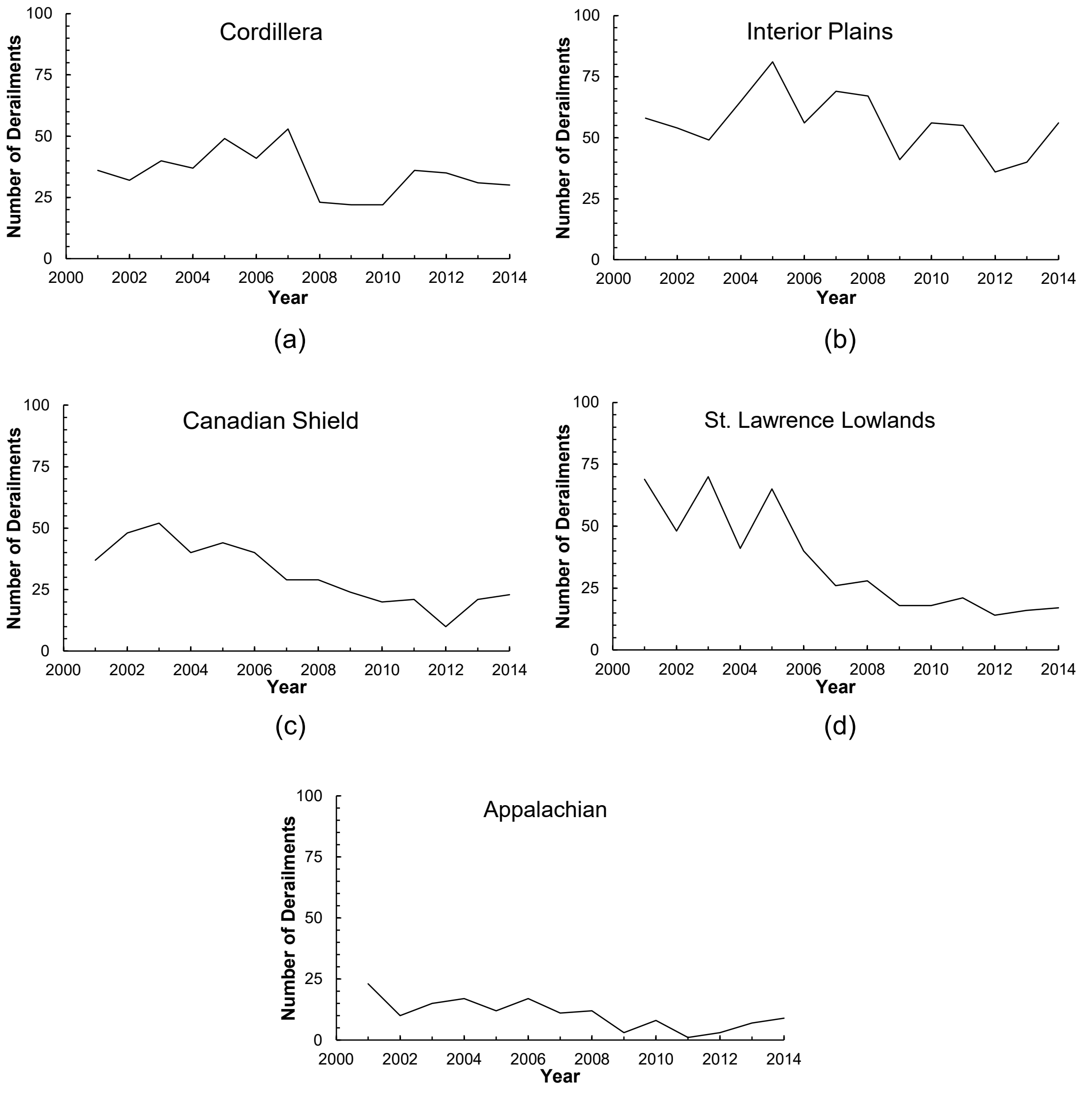
The above plot indicates two trends. First, an increase in derailments occurred during the winter months, beginning in January and decreasing through to April. This trend was due mainly to the "environmental conditions" incident cause, and can more specifically be attributed to snow and ice build-up on the track. There was a relatively consistent number of derailments caused by environmental conditions throughout the remainder of the months. This incident cause was a main contributor to the increase in derailments observed in Figure 5-4.

Secondly, another increase in derailments was observed in the spring due to the "roadbed" incident cause, followed by a slow decline through the summer. This trend in the "roadbed" cause is believed to have been the result of subgrade softening due to spring thaw, combined with an increase in water flowing along the track from snow melt. A relatively low number of derailments was attributed to this cause through the fall and winter months. An average of 0.030 derailments per million tonnes was observed for the "ground hazards" cause.

5.3 Spatial Derailment Trends

5.3.1 Long Term Trends

The following plots in Figure 5-13 show the results of long term derailment trends by physiographic region. The data in these plots is presented in terms of total derailments as regional rail traffic data was not available in the CANSIM tables. Rail traffic is presented below by the provinces that approximate the regions.



(a) (b) (c) (d) (e)

Figure 5-13. Main track derailment trends by physiographic region, 2001-2014; (a) Cordillera; (b) Interior Plains; (c) Canadian Shield; (d) St. Lawrence Lowlands; and, (e) Appalachian.

These plots indicate the variation in the number of derailments across the country. In most regions, a decreasing trend is apparent, particularly in the Canadian Shield and the St. Lawrence Lowlands. These regions reflect the overall trend in derailments in that the majority of the reduction occurred between 2001 and 2007, followed by a relatively stable period. Highs of 52 and 70 derailments were observed in the Shield and the St. Lawrence Lowlands, respectively.

The remainder of the regions had a less pronounced decrease. Derailments in the Cordillera region increased from 2001 to 2007, followed by a sharp decrease and a level to slightly decreasing trend between 2011 and 2014. A high of 53 derailments was observed in 2007.

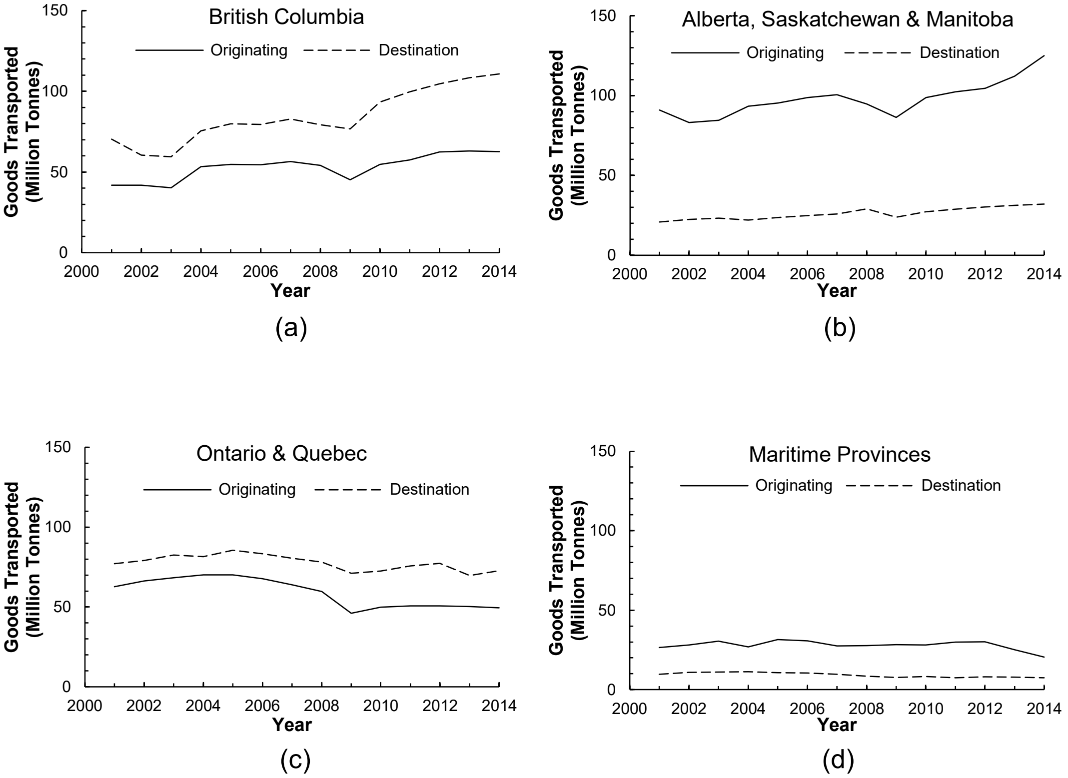
The Interior Plains saw the greatest overall number of derailments during the study period. A cyclical pattern is apparent in the above plot, with a slightly downward trend. An average of 56 derailments was observed during the 14 year study period, including a high of 81 derailments in 2005.

The Appalachian region had the fewest derailments, as the region with the least amount of track. The number of derailments was relatively constant between 2001 and 2008, with an average of approximately 13. There was a decrease in 2009 followed by a levelled off period with an average of approximately 5 derailments per year until 2013. A small upward turn in the data was observed from 2013 to 2014.

Although the amount of rail traffic reported by Statistics Canada was not able to be separated by physiographic region, a crude approximation was determined by considering traffic by province. Figure 5-14 presents rail traffic data for the following provinces:

- Figure 5-14(a): British Columbia, representing the Cordillera region;
- Figure 5-14(b): Alberta, Saskatchewan and Manitoba, representing the Interior Plains;
- Figure 5-14(c): Ontario and Quebec, representing the Canadian Shield;

- and, Figure 5-14(d): the Maritime provinces, representing both the St. Lawrence Lowlands and Appalachian regions.

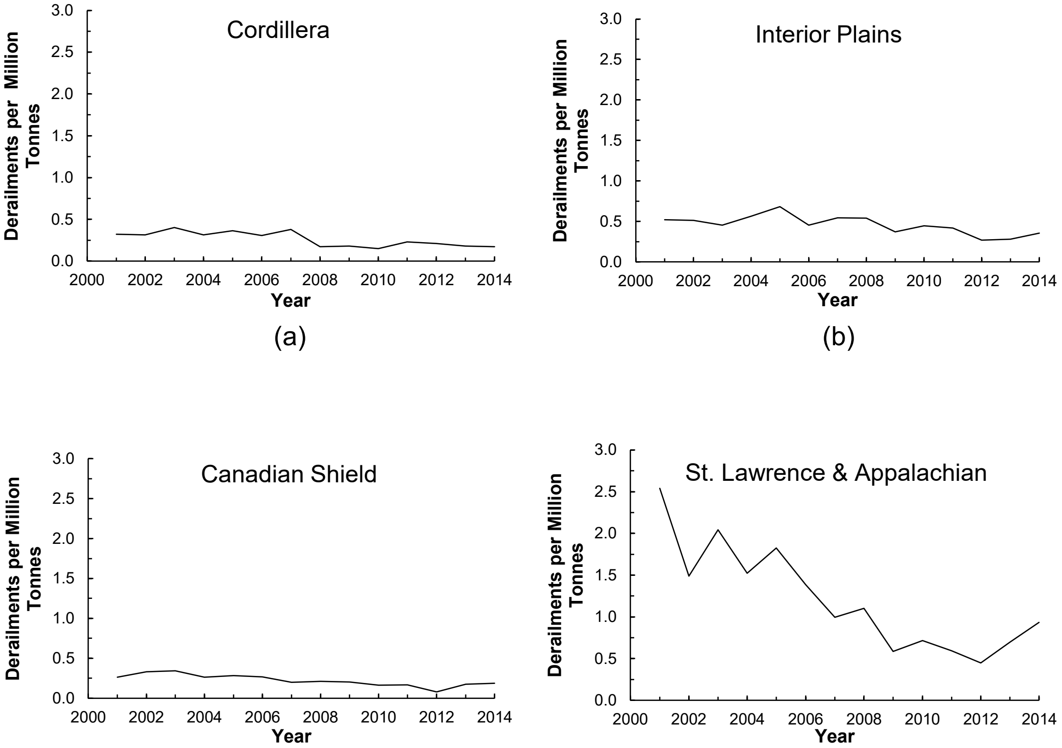


(a) (b)

(c) (d)

Figure 5-14. Goods transported in Canada by approximate physiographic region, 2001-2014; (a) British Columbia; (b) Alberta, Saskatchewan and Manitoba; (c) Ontario and Quebec; (d) Maritime Provinces.

The above plots indicate an increasing trend in the amount of traffic in British Columbia and the prairie provinces, a slight downward trend in Ontario and Quebec and a comparatively low but constant amount of traffic in the Maritimes. This data was used to provide an approximation of normalized derailments by region. The St. Lawrence and Appalachian regions were combined to account for the way rail traffic was presented in the CANSIM tables.



(a) (b)

(c) (d)

Figure 5-15. Normalized derailments by approximate physiographic region, 2001-2014; (a) Cordillera; (b) Interior Plains; (c) Canadian Shield; (d) St. Lawrence and Appalachian.

The normalized derailment plots indicate decreasing trends in each of the regions. Also of note is the high number of derailments in the St. Lawrence and Appalachian regions, likely a result of the comparatively low quantity of rail traffic.

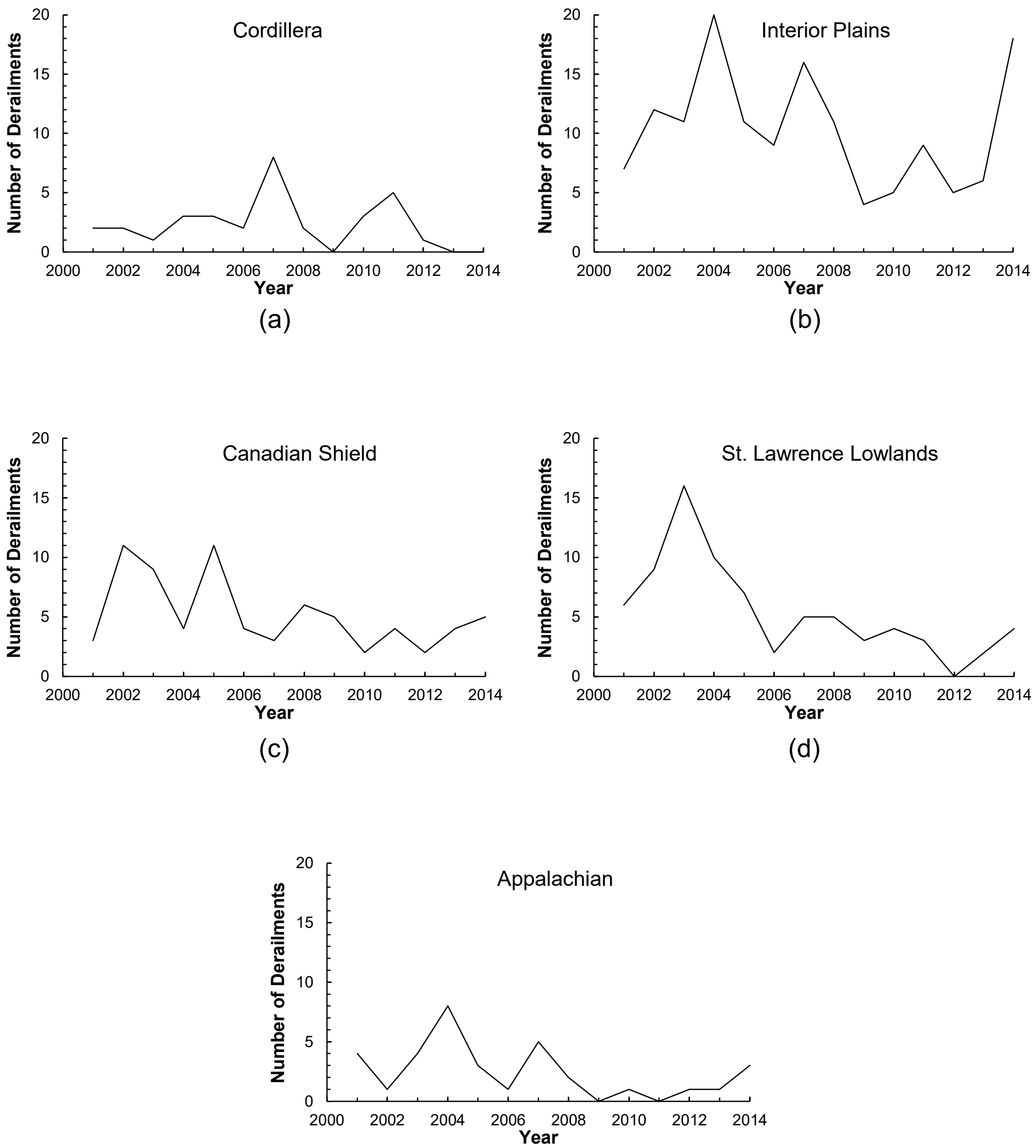
In terms of incident causes by region, Table 5-1 below shows a ranking of the top five for each region, along with the proportion of derailments within the region that were attributed to each cause.

Table 5-1. Ranking of top 5 incident causes by physiographic region by number of derailments, 2001-2014

Rank	Cordillera		Interior Plains		Canadian Shield		St. Lawrence Lowlands		Appalachian	
	Cause	%	Cause	%	Cause	%	Cause	%	Cause	%
1	Environmental Conditions	11.6	Rail, Joint Bar & Rail Anchoring	17.5	Track Geometry	14.6	Track Geometry	9.6	Track Geometry	10.4
2	Rail, Joint Bar & Rail Anchoring	9.2	Track Geometry	11.2	Wheels	8.6	Train Handling/ Train Make-up	8.8	Rail, Joint Bar & Rail Anchoring	10.4
3	Other Miscellaneous	9.2	Environmental Conditions	6.6	Rail, Joint Bar & Rail Anchoring	7.3	Wheels	8.4	General Switching Rules	10.4
4	Axles & Journal Bearings	8.8	Highway-Rail Grade Crossing Incidents	6.0	Unusual Operating Situations	7.3	Coupler & Draft System	7.9	Frogs, Switches & Track Appliances	8.3
5	Wheels	7.2	Train Handling/ Train Make-up	5.7	Train Handling/ Train Make-up	6.6	Switches, Use of	7.5	Train Handling/ Train Make-up	8.3

The above table indicates that the “track geometry” incident cause was either the number one or number two cause in four of the five regions. “Environmental conditions” was a leading cause in western Canada, but was not within the top five in eastern Canada. Derailments related to switches and other track appliances were common in the St. Lawrence Lowlands and Appalachian regions. “Rail, joint bar and rail anchoring” was in the top five causes for four regions, and was the leading cause in the Interior Plains.

Finally, the number of derailments with dangerous goods cars was analyzed by physiographic region to examine any effects of physical geography on this type of incident (Figure 5-16). It is evident from these plots that the majority of these types of derailments occurred in the Interior Plains region. Again, a cyclical pattern is present in each region, and most regions exhibited a slight decreasing trend. An increase in derailments of this type was observed in all regions but the Cordillera in 2014, with a particularly significant increase in the Interior Plains.



(a) (b)

(c) (d)

(e)

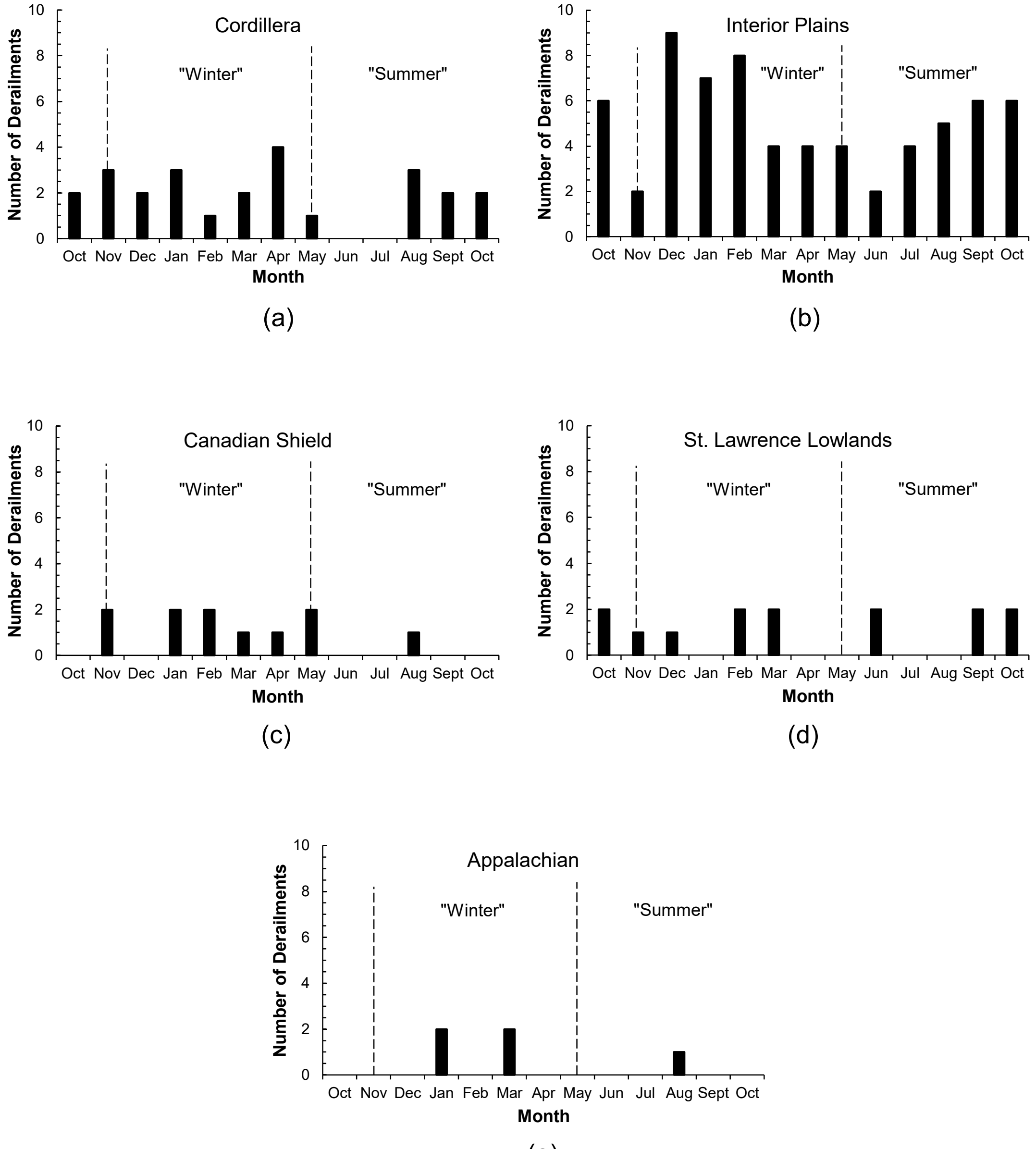
Figure 5-16. Distribution of derailments involving DG cars by physiographic region, 2001-2014; (a) Cordillera; (b) Interior Plains; (c) Canadian Shield; (d) St. Lawrence Lowlands; (e) Appalachian.

5.3.2 Seasonal Trends by Region

Seasonal trends were developed for each of the physiographic regions for same incident causes presented above in Section 5.1.2. These trends are presented in the plots below.

Rail, Joint Bar & Rail Anchoring

Figure 5-17 shows the results of this analysis for the “rail, joint bar and rail anchoring” incident cause.



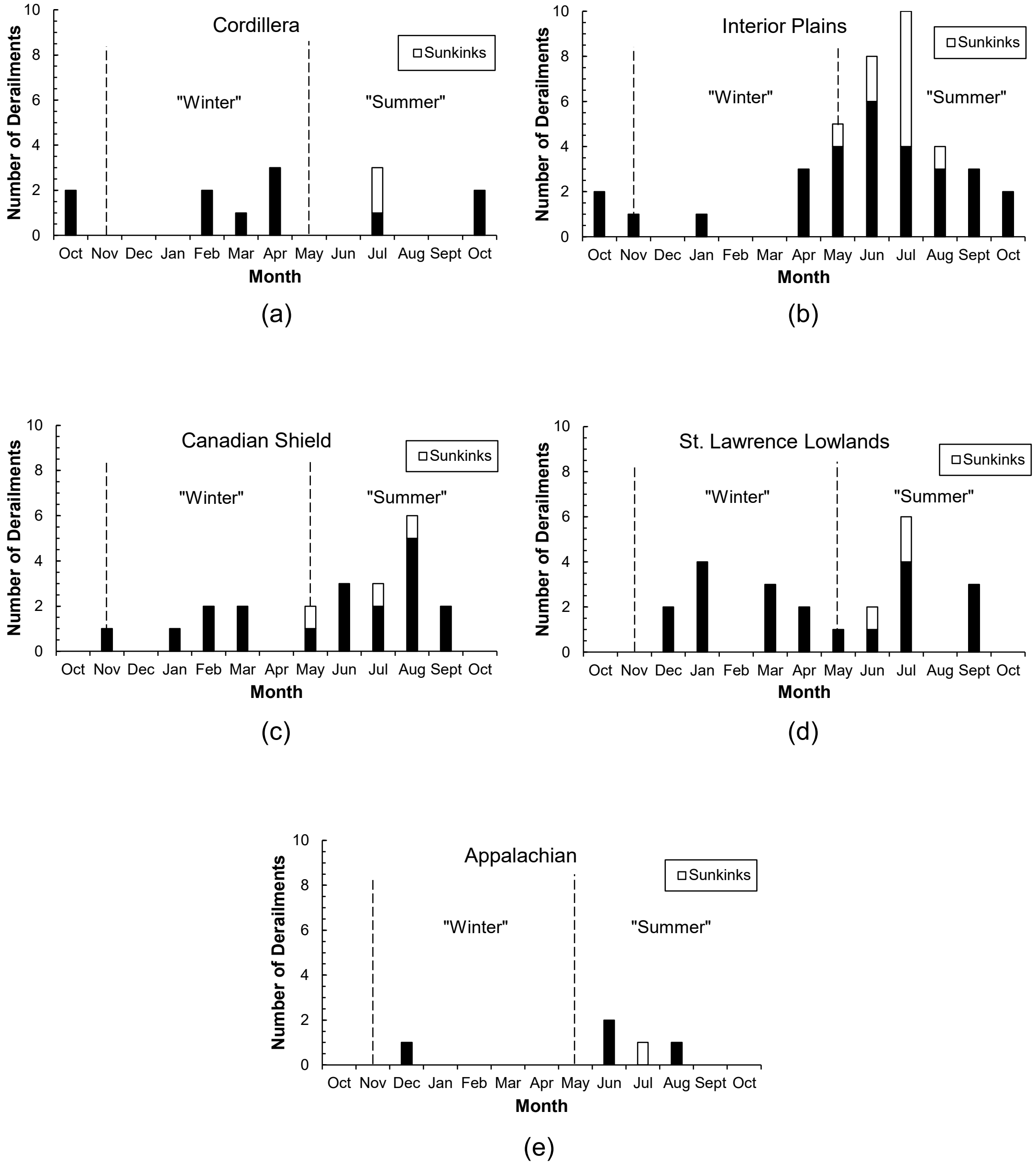
(a) (b) (c) (d) (e)

Figure 5-17. Temporal distribution of main track derailments caused by Rail, Joint Bar and Rail Anchoring, 2001-2014; (a) Cordillera; (b) Interior Plains; (c) Canadian Shield; (d) St. Lawrence Lowlands; and, (e) Appalachian.

These figures indicate that the majority of derailments associated with this incident cause occurred in the Interior Plains and Cordillera regions. This is likely due to the influence of cold winters in the prairie provinces and areas of British Columbia. The Canadian Shield, St. Lawrence Lowlands and Appalachian regions had comparatively few derailments. Another apparent trend in this data is that, in general, more derailments occurred during winter months in each of the regions.

Track Geometry

Figure 5-18 shows the distribution of main track derailments attributed to the “track geometry” incident cause.



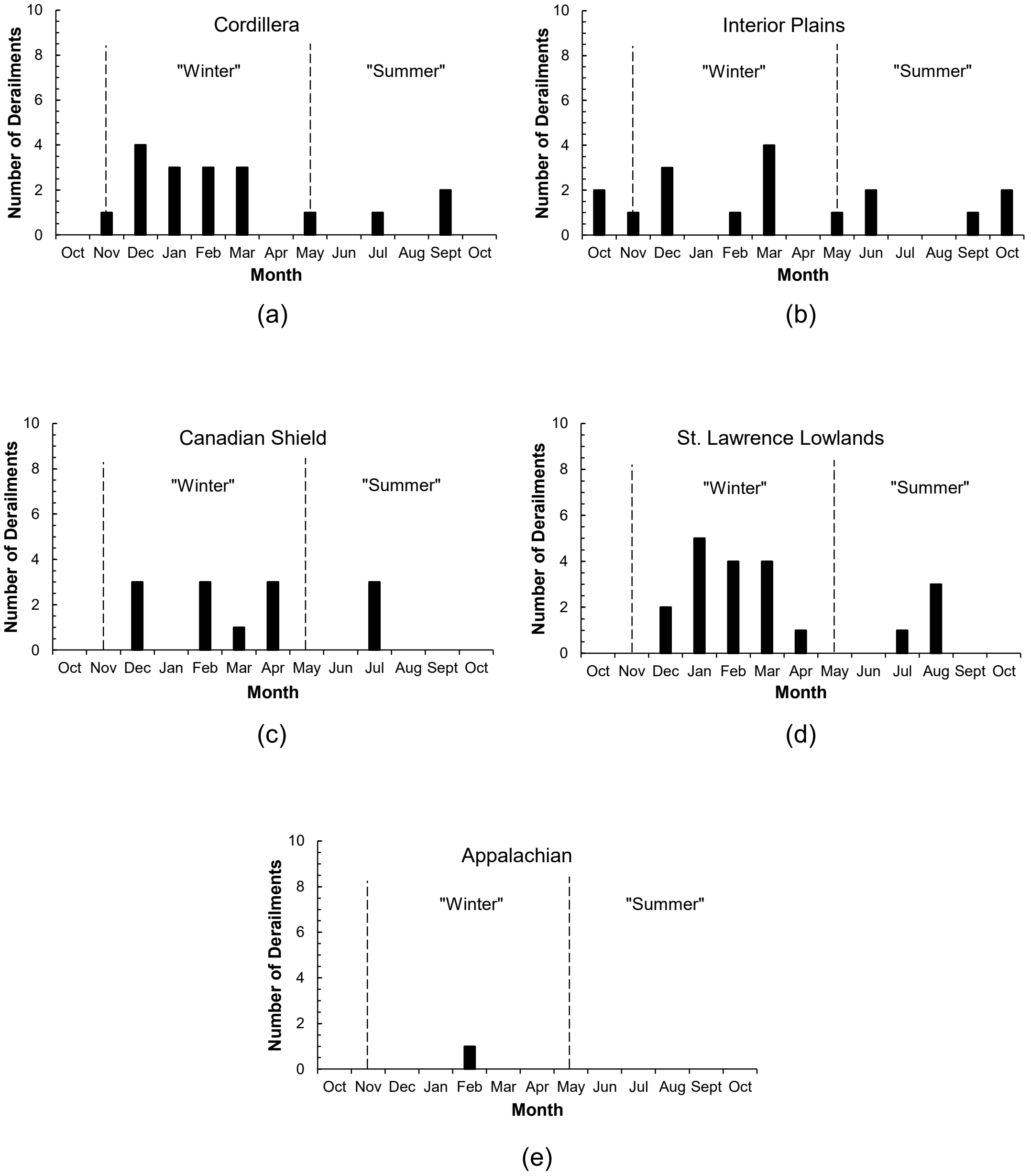
(a) (b) (c) (d) (e)

Figure 5-18. Temporal distribution of main track derailments caused by Track Geometry, 2001-2014; (a) Cordillera; (b) Interior Plains; (c) Canadian Shield; (d) St. Lawrence Lowlands; and, (e) Appalachian.

Derailments due to this incident cause were most common in the Interior Plains, Canadian Shield and St. Lawrence Lowlands regions. In most regions, the summer months resulted in a greater number of derailments, and in the Interior Plains, a number of these were attributed to buckled rail caused by sunkinks. Peaks were observed in July in both the Interior Plains and the St. Lawrence Lowlands region, which may have contributed to the July increase in derailments shown in Figure 5-4. There was also a peak in the number of derailments that occurred in the St. Lawrence Lowlands in January.

Wheels

Figure 5-19 shows the analysis results for main track derailments due to the “wheels” incident cause.



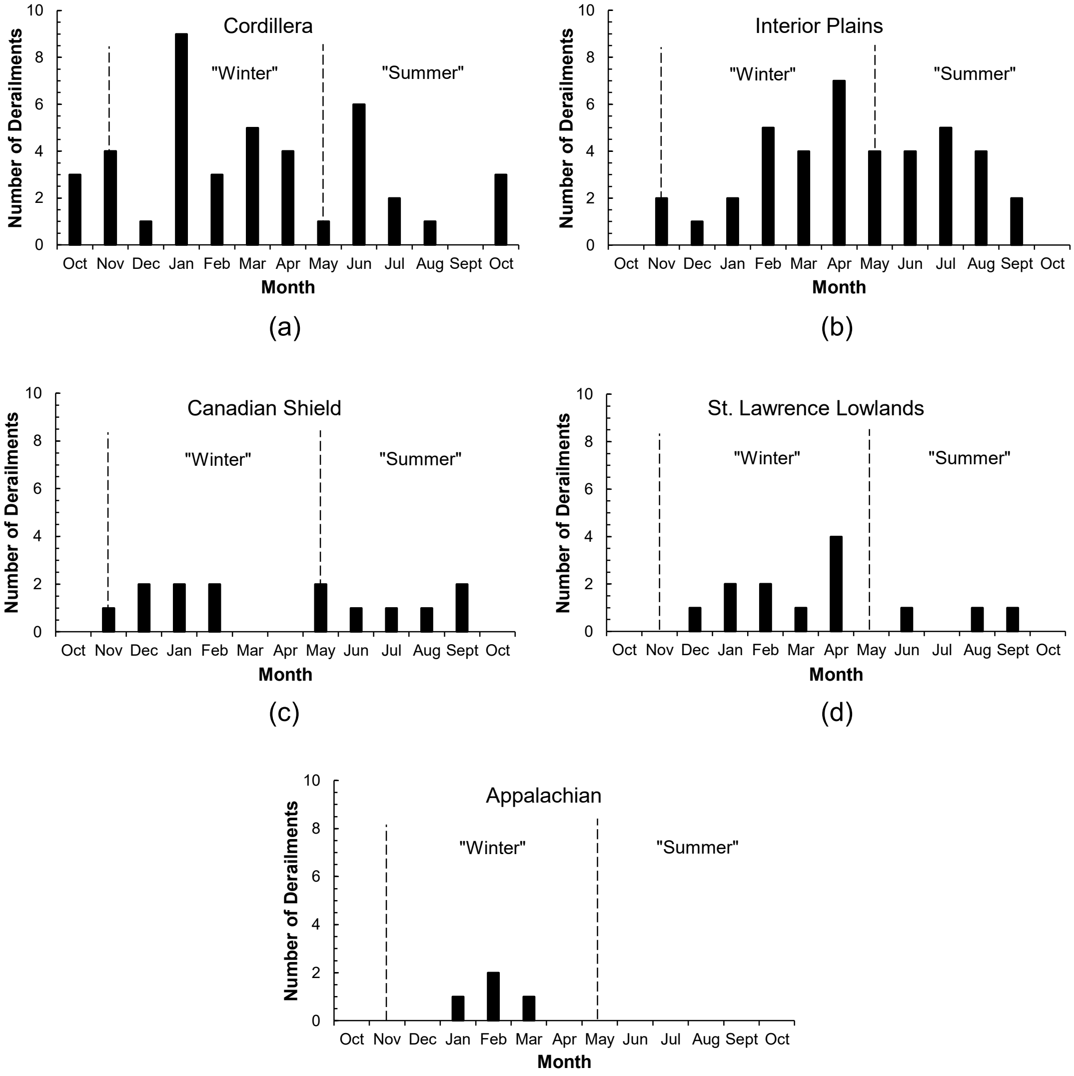
(a) (b) (c) (d) (e)

Figure 5-19. Temporal distribution of main track derailments caused by Wheels, 2001-2014; (a) Cordillera; (b) Interior Plains; (c) Canadian Shield; (d) St. Lawrence Lowlands; and, (e) Appalachian.

These plots indicate a relatively consistent number of derailments across all regions with the exception of the Appalachian region. As expected, the majority of derailments attributed to this cause occurred in the winter months in each region. Derailments in the Canadian Shield region were found to be relatively constant, with no real peaks or valleys. Again, the Appalachian region saw comparatively few derailments.

Ground Hazards

Figure 5-20 shows the distribution of main track derailments attributed to the “ground hazards” incident cause.



(a) (b)

(c) (d)

(e)

Figure 5-20. Temporal distribution of main track derailments caused by Ground Hazards, 2001-2014; (a) Cordillera; (b) Interior Plains; (c) Canadian Shield; (d) St. Lawrence Lowlands; and, (e) Appalachian.

These plots show a general trend of increases in derailments in both the winter and summer months. As mentioned above in Section 5.2.4, the winter derailments were likely to have been a result of the "environmental conditions" incident cause, while the summer derailments were likely due to the "roadbed" incident cause. This trend was particularly apparent in the Cordillera and Canadian Shield regions. A peak in the spring was evident in the Interior Plains, potentially associated with subgrade softening upon spring thaw. The number of derailments remained relatively constant throughout the summer, with a smaller peak in July. It has been observed that approximately 20% to 35% of the annual precipitation in this region occurs in June and July (McGinn 2010). The largest peak was observed in the Cordillera region in January, most likely due to accumulation of snow and ice on the track as discussed above in Section 2.4.2.

5.4 Conclusion

The purpose of this chapter was to examine temporal and spatial characteristics of main track derailments from 2001 to 2014. This was carried out by analyzing derailment data in the RODS database. Specific incident causes were examined for seasonal variation in derailment frequency. Long term and seasonal derailment trends were also considered for each of Canada's physiographic regions by assigning a region to each incident based on information obtained from Natural Resources Canada. Derailment trends were not able to be normalized to rail traffic as this information was not available by region in the CANSIM tables.

The analysis showed two periods with an increased number of derailments, with a peak in January and another smaller peak in July. A seasonal analysis was conducted for four incident causes based on a perceived susceptibility to climatic variations. These causes were:

- rail, joint bar and rail anchoring;
- track geometry;

- wheels;
- and, ground hazards (a combination of roadbed and environmental conditions).

An increase in derailments attributed to the “rail, joint bar and rail anchoring” and “wheels” incident causes was observed in the colder winter months when high thermally induced stresses are likely to develop. “Track geometry” tended to cause more derailments in warmer summer months, when increased precipitation is more likely to lead to track subgrade movement and higher temperatures can lead to higher compressive thermal stresses. The “ground hazards” cause lead to increased derailments in both winter and summer, with the winter derailments being caused by “environmental conditions” and summer derailments being caused by the “roadbed” incident cause.

The spatial analysis indicated that the Interior Plains region had the greatest overall number of derailments, while the Appalachian region had the fewest. In general, a decreasing trend was observed in the number of derailments in all regions, but was more pronounced in the St. Lawrence Lowlands and Canadian Shield regions. Most regions displayed a similar “leveling-off” trend towards the end of the study period, most notably in the St. Lawrence Lowlands.

The same four incident causes were analyzed for seasonal trends within each region and similar findings were observed. The majority of derailments attributed to the “rail, joint bar and rail anchoring” incident cause occurred in the Interior Plains region, and were more prevalent in the winter months. “Track geometry” related derailments occurred more frequently in the Interior Plains, Canadian Shield and St. Lawrence Lowlands, with the largest spike occurring in the Interior Plains. Very few derailments associated with the “wheels” incident cause occurred in the Appalachian region, compared to a relatively equal number in the remainder of the regions. The Cordillera and Interior Plains had the greatest number of derailments as a result of the “ground hazards” incident cause. The majority of the derailments that occurred in the winter were related to the “environmental conditions” cause, while the majority of derailments that occurred in the summer were due to the “roadbed” cause.

CHAPTER 6 : CONCLUSIONS AND RECOMMENDATIONS

6.1 Summary

The research presented in this thesis was developed to provide insight into what factors are leading to derailments in Canada, and what trends are being observed from 2001 to 2014. This information can then be used in the improvement of a risk assessment method being developed by the University of Alberta in conjunction with Canadian National Railway.

The specific objectives of this thesis were to:

1. Investigate temporal trends from 2001 to 2014, focusing on long term trends of total derailments from, derailments with dangerous goods cars involved, and the frequency and severity of derailments by incident cause.
2. Analyze the effect of seasonal changes of the leading incident causes to determine the effects of changing climatic conditions throughout the year.
3. Examine derailment trends spatially by Canada's physiographic regions, focusing on long term trends and seasonal trends for the leading incident causes.

This was accomplished by examining derailment incidents contained within the Railway Occurrence Database System, a database compiled and maintained by the Transportation Safety Board of Canada.

Chapter 4 presented the results of the long term derailment trends and the frequency-severity analysis. It was found that the total number of derailments had decreased by 40% from 2001 to 2014, and when normalized to rail traffic a reduction of 55% was observed. Within the last 3 to 4 years of the study period, the total number of derailments was seen to have levelled off, with a slight increase in 2014. This increase in 2014 was not present in the normalized data. A decreasing trend was observed on Class I railways, compared to an increasing trend on short line and regional railways.

The frequency-severity analysis showed a slight upward trend in the average severity – or number of cars derailed per derailment – of main track derailments from 2001 to 2014. A cyclical pattern was more apparent towards the latter years of the study period. Five incident causes were found to have been high in frequency and severity, and accounted for 40% of main track derailments, with rail breaks being the number one incident cause. These were:

- "Rail, joint bar and rail anchoring;"
- "Track geometry;"
- "Wheels;"
- "Train handling/train make-up;"
- And, "other miscellaneous."

It was further found that the speed at which a derailment initiated had an impact on the severity of the incident, with higher speeds resulting in a greater number of cars derailed per derailment. The decreasing trend in derailment speed on Canadian railways appears to be consistent when comparing the TSB (1994) study to this research.

Also considered in Chapter 4 was main track derailments with dangerous goods cars involved. This included incidents with and without a release of DG. The total number of derailments in 2014 was greater than in 2001, but when normalized to the quantity of DG being transported by rail, a reduction of 16% was determined. In both total numbers and normalized, a cyclical pattern was observed in the data, with peaks occurring every three to four years. The number of derailments with a DG release was found to have decreased when normalized to DG traffic, with small peaks in 2010 and 2013. Overall, derailments with a DG release saw a reduction of 40% during the study period, when considering the normalized data.

Finally, Chapter 5 presented the results of the seasonal and spatial analyses. Seasonal trends were developed for four of the most common incident causes with the following findings:

- The “rail, joint bar & rail anchoring” and “wheels” incident causes were more prevalent in colder months, likely due to increased thermal stresses in steel components;
- The “track geometry” and “ground hazards” incident causes were more prevalent in the summer months, likely due to subgrade softening during spring thaw and increased precipitation, and compressive thermal stresses in rail steel causing sunkinks.

The spatial analysis was conducted by physiographic region within Canada. It was shown that the number of derailments decreased in each of the regions over the 14 year study period. Some regions, such as the Canadian Shield and St. Lawrence Lowlands saw more significant decreasing trends than the other regions, followed by a relatively stable period in the later years of the study period. In general, a greater number of derailments was observed in the Cordillera and the Interior Plains, while comparatively few derailments were observed in the Appalachian region.

A similar seasonal analysis was carried out by region for the same four incident causes mentioned above. The findings included:

- The majority of “rail, joint bar & rail anchoring” related derailments occurred the winter months, and were most common in the Interior Plains;
- “Track geometry” related derailments occurred in the summer months, and again were most common in the Interior Plains;
- Derailments attributed to the “wheels” incident cause were more common in the winter months, and had a relatively even distribution between all the regions except the Appalachian region;

- The “ground hazards” incident cause was most common in the Cordillera and the Interior Plains, and had spikes in both winter and summer months. Winter spikes corresponded to the “environmental conditions” cause while summer spikes corresponded to the “roadbed” cause.

6.2 Recommendations

With the intention of assisting in the development of an improved risk assessment procedure, recommendations are proposed for two aspects: first, actions the TSB can take to improve the quality of the information in the RODS database; and second, additional research topics. It is recommended that the TSB:

- implement stricter requirements on what information is reported, as it would assist in the types of analyses conducted for this thesis. As much information as possible should be provided by the operators to aid research into safety improvements;

- require operators to note an incident cause when reporting an incident, even if the incident is still under investigation. This may improve the significance and validity of a number of the statistics presented above. The greater the number of incidents reported with an incident cause the more significant the results would be for future analyses;

- and, require operators to provide the location of each derailment in latitude and longitude coordinates so that mapping can be done to show geographic areas that experience high frequencies of derailments. Mapping can also be done to highlight a variety of features such as derailments involving dangerous goods cars and/or releases, derailments with multiple cars versus one-car derailed or viewing derailments by incident cause. These visuals would be an exceptionally useful tool for decision-makers to determine how best to effectively manage maintenance or derailment-prevention budgets.

In terms of future research areas, the following recommendations are made:

- Statistics can be developed by subdivision to evaluate areas of high frequencies of derailments. However, there may be insufficient data when broken down in this manner that the results for individual subdivisions may not have much statistical significance.

- The data presented herein were focused on main track derailments due to the economic and societal impacts of incidents on this track type. The same types of analyses conducted for this thesis could be applied to non-main and yard track to develop similar risk assessment methods for these track types.

- Additional incident causes could be analyzed for seasonal and spatial trends as necessary for input into the risk assessment program.

- Analyze the effect that climate change may have in the occurrence of extreme weather events that may lead to increased derailments.

- It is recommended that the following trends and patterns should be evaluated further:
    - The cyclical pattern observed in derailments involving dangerous goods.
    - The cause of the decreasing trend and plateau in total and normalized main track derailments.
    - The increasing trend and peak in the number of derailments by short line and regional railways.

REFERENCES

Acton, D.F., Ryder, J.M., French, H., Brookes, I.A., Slaymaker, O. (2012). *Physiographic regions.* Available at http://www.thecanadianencyclopedia.ca/en/article/physiographic-regions/. Accessed 20 May 2016.

Association of American Railroads (2015a). *Railroads: Moving America Safely*. Available at https://www.aar.org/BackgroundPapers/Railroads%20Moving%20America%20Safely.pdf. Accessed 18 April 2016.

Association of American Railroads (2015b). *U.S. rail crude oil traffic*. Available at https://www.aar.org/BackgroundPapers/US%20Rail%20Crude%20Oil%20Traffic.pdf. Accessed 18 April 2016.

Association of American Railroads (2016). *Hazmat transportation*. Available at https://www.aar.org/todays-railroads/safety?t=hazmattransportation. Accessed 18 April 2016.

Barkan C.P.L., Dick C.T., Anderson R. (2003). *Railroad derailment factors affecting hazardous materials transportation risk*. Transportation Research Record: Journal of the Transportation Research Board No. 1825: 64-74.

Bruzek, R., Biess, L., Al-Nazer, L. (2013). *Development of rail temperature predictions to minimize risk of track buckle derailments.* 2013 Joint Rail Conference. American Society of Mechanical Engineers.

Canadian Association of Petroleum Producers (2014). *Rail safety on track: New measures will improve preparedness and response.* Available at http://www.capp.ca/media/commentary/rail-safety-on-track-new-measures-will-improve-preparedness-and-response. Accessed 4 April 2016.

Canadian Transportation Accident Investigation and Safety Board Act: Transportation Safety Board Regulations (2014). *Canada Gazette Part II*, 5(1). Available http://gazette.gc.ca/rp-pr/p2/2014/2014-03-12/html/sor-dors37-eng.php.

Changnon, S. (2006). *Railroads and weather.* Boston, MA: American Meteorological Society.

Clague, J.J. (1989a). *Economic implications of Quaternary geology (Canadian Cordillera).* In Chapter 1 of Quaternary Geology of Canada and Greenland, R.J. Fulton (ed.). Geological Survey of Canada, Geology of Canada no. 1.

Clague, J.J. (1989b). *Introduction (Quaternary geology of the Canadian Cordillera).* In Chapter 1 of Quaternary Geology of Canada and Greenland, R.J. Fulton (ed.). Geological Survey of Canada, Geology of Canada no. 1.

Dobney, K., Baker, C. J., Quinn, A. D., & Chapman, L. (2009). *Quantifying the effects of high summer temperatures due to climate change on buckling and rail related delays in south‐east United Kingdom*. Meteorological Applications, 16(2), 245-251.

Dyke, A.S., Vincent, J-S., Andrews, J.T., Dredge, L.A., Cowan, W.R. (1989). *The Laurentide Ice Sheet and an introduction to the Quaternary geology of the Canadian Shield.* In Chapter 3 of Quaternary Geology of Canada and Greenland, R.J. Fulton (ed.). Geological Survey of Canada, Geology of Canada no. 1.

Environment Canada (2010). *Canadian climate normals 1981 to 2010.* Available at http://climate.weather.gc.ca/climate_normals/index_e.html. Accessed 20 May 2016.

Evans, S.G., & Gardner, J.S. (1989). *Geological hazards in the Canadian Cordillera.* In Chapter 12 of Quaternary Geology of Canada and Greenland, R.J. Fulton (ed.). Geological Survey of Canada, Geology of Canada no. 1.

Federal Railroad Administration (2016a). *About FRA*. Available at https://www.fra.dot.gov/Page/P0002. Accessed 4 March 2016.

Federal Railroad Administration (2016a). *Office of safety analysis.* Available at http://safetydata.fra.dot.gov/OfficeofSafety/Default.aspx. Accessed 21 August 2016.

Fulton, R.J. (1989). *Foreword to the Quaternary geology of Canada and Greenland.* In Quaternary Geology of Canada and Greenland, R.J. Fulton (ed.). Geological Survey of Canada, Geology of Canada no. 1.

Grant, D.R. (1989). *Quaternary geology of the Atlantic Appalachian region of Canada.* Chapter in 5 Quaternary Geology of Canada and Greenland, R.J. Fulton (ed.). Geological Survey of Canada, Geology of Canada no. 1.

Haidari, A., & Tehrani, P.H. (2015). *Thermal load effects on fatigue life of a cracked railway wheel.* Latin American Journal of Solids and Structures, 12(6), 1144-1157.

Havers, J. A., & Morgan, R. M. (1972). *Literature survey of cold weather construction practices*. Purdue Research Foundation, Lafayette, IN.

Hungr, O., Evans, S.G., Hazzard, J. (1999). *Magnitude and frequency of rock falls and rock slides along the main transportation corridors of southwestern British Columbia.* Canadian Geotechnical Journal, 36(2), 224-238.

Jackson, L.E. (1989a). *Quaternary resources in Canada.* Chapter 11 in Quaternary Geology of Canada and Greenland, R.J. Fulton (ed.). Geological Survey of Canada, Geology of Canada no. 1.

Jackson, L.E. (1989b). *The influence of Quaternary geology of Canada on man's environment.* Chapter 12 in Quaternary Geology of Canada and Greenland, R.J. Fulton (ed.). Geological Survey of Canada, Geology of Canada no. 1.

Karrow, P.F. (1989). *Quaternary geology of the Great Lakes subregion.* In Chapter 4 of Quaternary Geology of Canada and Greenland, R.J. Fulton (ed.). Geological Survey of Canada, Geology of Canada no. 1.

Kish, A., & Aten, J.P. (2012). *A "smart systems" approach for better managing CWR thermal forces at extreme temperatures*. In Core 2012, Rail – the core of integrated transport, conference on railway engineering, Perth, Austrailia, 7-10 September 2012.

Li, D., & Selig, E.T. (1995). *Evaluation of railway subgrade problems.* Transportation Research Record, 1489, 17.

Liu X., Barkan C.P.L., Saat. M.R. (2011). *Analysis of derailments by accident cause*. Transportation Research Record: Journal of the Transportation Research Board No. 2261: 178-185.

Liu X., Saat M.R., Barkan C.P.L. (2012). *Analysis of causes of major train derailment and their effect on accident rates*. Transportation Research Record: Journal of the Transportation Research Board No. 2289: 154-163.

Locat, J., & Chagnon, J-Y. (1989). *Geological hazards in central and eastern Canada.* In Chapter 12 of Quaternary Geology of Canada and Greenland, R.J. Fulton (ed.). Geological Survey of Canada, Geology of Canada no. 1.

Maclean's (2013). *10 of Canada's worst train accidents.* Available at http://www.macleans.ca/society/life/10-of-canadas-worst-train-accidents/

McGinn, S.M. (2010). *Weather and climate patterns in Canada's prairie grasslands.* Anthropods of Canadian Grasslands, 1, 105-119.

Natural Resources Canada (2010). *Atlas of Canada, 6th Ed.* Available at http://geogratis.gc.ca/api/en/nrcan-rncan/ess-sst/dcdd5e21-8893-11e0-8ea0-6cf049291510. Accessed 18 May 2016.

Quigley, R.M. (1980). *Geology, mineralogy, and geochemistry of Canadian soft soils: a geotechnical perspective.* Canadian Geotechnical Journal, 17(2), 261-285.

Quinn, P.E., Hutchinson, D.J., Rowe, R.K. (2007). *Toward a risk management framework: sensitive clay landslide hazards affecting linear infrastructure in eastern Canada.* In 1st North American Landslide Conference.

Railroad Accidents/Incidents: Reports Classification, and Investigation, 49 C.F.R § 225 (2015)

Rosetti, M.A. (2002). *Potential impacts of climate change on railroads.* The Potential Impacts of Climate Change on Transportation: Workshop Summary and Proceedings.

Rosetti, M.A. (2007). *Analysis of weather events on US Railroads*. Volpe National Transportation Systems Center, Cambridge, MA.

Scott, J.S. (1989). *Engineering geology and land use planning in the Prairie region of Canada.* In Chapter 12 of Quaternary Geology of Canada and Greenland, R.J. Fulton (ed.). Geological Survey of Canada, Geology of Canada no. 1.

Thornes, J. E., & Davis, B. W. (2002). *Mitigating the impact of weather and climate on railway operations in the UK*. Railroad Conference, 2002 ASME/IEEE Joint (pp. 29-38). IEEE.

Transport Canada (2015). *Canadian rail operating rules*. Available at https://www.tc.gc.ca/eng/railsafety/rules-tco167.htm. Accessed 4 December 2015.

Transport Canada (2016a). *Rail transportation*. Available at https://www.tc.gc.ca/eng/rail-menu.htm. Accessed 28 August 2015.

Transport Canada (2016b) *Who we are*. Available at https://www.tc.gc.ca/eng/tdg/who-233.htm. Accessed 27 August 2015.

Transportation Safety Board of Canada (1994). *A special study of main track derailments – 1994*. Available at www.tsb.gc.ca. Accessed 7 July 2015.

Transportation Safety Board of Canada (1999). *Railway investigation report R99H0010.* Available at www.tsb.gc.ca. Accessed 8 March 2016.

Transportation Safety Board of Canada (2004a). *Railway investigation report R04Q0047.* Available at www.tsb.gc.ca. Accessed 8 March 2016.

Transportation Safety Board of Canada (2004b). *Railway investigation report R04T0008.* Available at www.tsb.gc.ca. Accessed 8 March 2016.

Transportation Safety Board of Canada (2006). *Railway investigation report R06T0153.* Available at www.tsb.gc.ca. Accessed 8 March 2016.

Transportation Safety Board of Canada (2009). *Railway investigation report R09V0235.* Available at www.tsb.gc.ca. Accessed 8 March 2016.

Transportation Safety Board of Canada (2010). *Railway investigation report R10Q0037.* Available at www.tsb.gc.ca. Accessed 8 March 2016.

Transportation Safety Board of Canada (2011). *Railway investigation report R11C0118.* Available at www.tsb.gc.ca. Accessed 8 March 2016.

Transportation Safety Board of Canada (2013a). *Railway investigation report R13D0054*. ISBN 978-1-100-24860-8. Available at www.tsb.gc.ca. Accessed 8 March 2016.

Transportation Safety Board of Canada (2013b). *Lac Mégantic runaway train and derailment investigation summary*. ISBN 978-1-100-24802-8. Available at www.tsb.gc.ca. Accessed 8 March 2016.

Transportation Safety Board of Canada (2013c). *Railway investigation report R13E0142*. Available at www.tsb.gc.ca. Accessed 8 March 2016.

Transportation Safety Board of Canada (2013d). *Railway investigation report R13W0124.* Available at www.tsb.gc.ca. Accessed 8 March 2016.

Transportation Safety Board of Canada (2014). *Railway investigation report R14Q0045*. ISBN 978-0-660-04978-6. Available at www.tsb.gc.ca. Accessed 8 March 2016.

Transportation Safety Board of Canada (2015). *Railway data*. Available at http://www.tsb.gc.ca/eng/stats/rail/index-ff.asp. Accessed 27 August 2015.

Transportation Safety Board of Canada (2016a). *Rail*. Available at http://www.tsb.gc.ca/eng/rail/index.asp. Accessed 27 August 2015.

Transportation Safety Board of Canada (2016b). *Investigation process*. ISBN 978-1-100-54426-7. Available at www.tsb.gc.ca. Accessed 1 September 2015.