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Abstract

The Transportation Safety Board of Canada (TSB) maintains the Railway Occurrence Database System (RODS). This database contains information on all types of rail occurrences including derailments that must be reported by all Canadian railway operators. This paper analyses the derailments that occurred on Canadian main track network between 2001 and 2014. The results from the analysis show that between 2001 to 2014 there was an overall decreasing trend in the number and intensity of main track derailments, derailments involving dangerous goods cars, and the number of derailments resulting in the release of dangerous goods. The RODS data was further analyzed to evaluate the frequency of the differing causes of derailments and the severity of the resulting incidents. The most common and severe derailment causes resulted from rail breaks, track geometry and environmental conditions. Derailment velocity was also found to have an impact on the severity, with higher velocities resulting in a greater number of derailed rolling stock.

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1 Introduction

Canada currently has the third largest railway network in the world (Transportation Safety Board of Canada [TSB] 2016a), at approximately 48,000 route kilometers of track (Transport Canada [TC] 2016a) (**Fig. 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. This trans-continental railway network was initiated in 1885 with the opening of the Canadian Pacific Railway and the bulk of it completed by the 1950's. Consequently, the operation and maintenance of the network has evolved as Canada has grown. Nonetheless the original route of the railroad remains essentially unchanged since it was first constructed.

The Canadian railway network is primarily a freight system with car weights up to 130 Mg on most routes and train lengths that can range up to 4 km. The most heavily used tracks have maximum speeds of 64 (Class 3) and 97 km/h (Class 4), with short sections of 40 km/h (Class 2). Operational constraints reduce average track speed to well below these maximums. Over the course of their operations, Canadian rail operators have experienced derailments that impacted the public, safety of railway personnel, the environment and the cost of transportation. As a result of recent major derailments, including the most catastrophic derailment in Canadian history (TSB 2013), the Canadian public has become less tolerant of railway incidents and the media regularly reports on such occurrences. The result of these derailments and the response of the public have led to increased pressure on the industry and regulators to improve safety.

The Transportation Safety Board of Canada maintains the Rail Occurrence Database System (RODS) and it is comprised of the results of the self-reporting of railway incidents, including all derailments and TSB investigations. This data is periodically analyzed by the TSB at a high level, and more extensive analyses are conducted when it is necessary, with the last extensive

analysis published in 1994 (TSB 1994). The analysis of the RODS database presented within this paper evaluates the trends in the number and intensity of derailment between the years 2001 and 2014. These results are compared to previous analyses conducted on Canadian derailment data (TSB 1994). Comparisons are also made to the results of similar analysis conducted on derailment causes from the United States (U.S.) railway industry, to which the Canadian industry is highly integrated and should have similar trends (AAR 2015a). The RODS was further analyzed to evaluate the frequency of the differing causes of derailments and the severity of the resulting incidents. This study also analyzed trends in the derailments involving cars carrying dangerous goods, and the number of derailments resulting in the release of dangerous goods.

Historically, changes in policies and practices within the industry have led to significant reductions in main track derailments within the North American railway industry. The most significant reductions were observed between 1982 and 1988 in Canada (TSB 1994) with the annual number of derailments dropping from 3.2 to 3.8 per million train miles down to 1.4 to 1.5 (Fig. 2). The train accident rate in the United States was compiled by the Association of American Railroads (AAR 2015a) and while accident reporting is not directly comparable with main track derailment reporting, similar trends can be observed for the period 1980 to 1990 (Fig. 3). The Transportation Safety Board of Canada (TSB, 1994) attributed these improvements to the installation and repair of continuous welded rail, advancements in metallurgy, the automation of track geometry measurements, and improvements in rail defect detection technology. The results of an analysis of derailment data collected by the U.S. Federal Railway Administration (FRA) between the years 2001 and 2010 by Lui *et al.* (2012) showed that broken rail or welds were the leading causes of derailments on all track types and resulted in the most severe derailments. Liu *et al.* (2012) noted that neither the rate or the severity had changed from the last

analysis of the derailment data presented in Barkan *et al.* (2003) for the 1992 to 2001-time period. When analyzing derailment trends the ever-increasing volume of freight moved by the railways adds an additional complexity. Hence simply reporting the number of derailment per year without some indicator of the volume of traffic and/or the number of cars may be misleading. While the Canadian rail industry strives to eliminate derailments, maintaining such a large network poses unique challenges. Nonetheless, understanding the derailment causes when operating and maintaining such a network is a necessary first step. The objectives of this work were to provide an analysis of the Canadian derailment trends to identify root causes, frequency and associated severity. Such Canadian network data can inform regulators when developing transportation policies.

2 Rail Occurrence Database System

2.1 Database and reporting

The Rail Occurrence Database System (RODS) is composed of all types of rail occurrences as reported by all individual rail operators. The criteria for what constitutes a reportable occurrence are defined within the *Transportation Safety Board Regulations* (Canadian Transportation Accident Investigation and Safety Board Act 2014). These include incidents that result in serious injury or fatality, a risk of collision, derailment, and the release of dangerous goods. There is no monetary threshold for reporting incidents in Canada; in contrast the U.S. FRA does not require a report for incidents that result in less than set values that was \$10,500 USD in 2014 (Railroad Accidents/Incidents: Reports Classification, and Investigation 2015). The information reported within the complete database includes the location and date of each incident, the type of occurrence, the number of derailed rolling stock, number of injuries or fatalities, attributed cause,

among others. A version of the RODS database is publicly available on-line and but does not include the attributed cause or number of cars derailed (TSB 2016c).

The RODS database is primarily comprised of reports that have not been verified by the TSB. The TSB does have the mandate to investigate each occurrence as it sees fit (TSB 2016b). However, the TSB investigates only a small percentage of the reported occurrences, and typically focuses on those that are severe, reoccurring, impact the environment, will provide new information on existing safety issues, or have political implications (TSB 2016b).

The RODS data provided by the TSB contained data since the early 1980s. The reporting requirements have evolved as to what constitutes a reportable occurrence and the details that must be reported. Large changes in data collection that were implemented in 2001 resulted in the pre-2001 data being very different and not directly comparable to the post-2001 data. The analyses in this study are limited to the post-2001 data, as these are considered representative of the current industry practices. The reporting of the causes of derailments has also evolved further since 2001. This is evident in the RODS database as causes were reported for only 30% of derailments between 2001 and 2005, while after 2006 this increased to between 80% and 90%.

The RODS database divides the railway networks into four track types as defined by Transport Canada's *Canadian Rail Operating Rules* (CORR) (TC 2015):

- 1) main - uninterrupted and continuous rail between stations
- 2) non-main - any discontinuous section of track that has a requirement to operate at a reduced speed, such as a siding used for allowing trains to pass and
- 3) yard track - used for loading or unloading cars and assembling trains.
- 4) other – not main, non-main or yard track.

These definitions have been maintained for the analyses discussed in the following sections.

2.2 Summary of rail incidents from the RODS database

A summary of rail incidents from 2001 to 2014 that resulted in derailed rolling stock is presented in **Table 1**. This information provides an overview of derailment statistics by track type and incident type. Of these types of occurrences, the derailment incident type was found to be most frequent at 90% of all incident types, followed by collisions at 5.5% and crossing incidents at 0.7%. Incident types other than derailments often lead to the derailment of cars and locomotives, the analysis of derailments within this paper included all occurrences that resulted in derailments not just those assigned to the derailment type.

An overall average of 2.6 cars derailed per derailment was observed for all incident types on all track types. Incidents on main track were found to have the highest number of cars derailed with an average of 5.2 cars compared to 1.9 cars on non-main and 2.1 cars on yard track. The crossing incidents resulted in the greatest number of cars derailed per incident, with 6.4 cars.

3 Trends in Canadian main track derailment from 2001 to 2014

3.1 Long-term Derailment Trends

Main track derailment trends are often presented in terms of the total number of occurrences that resulted in derailed rolling stock. However, when establishing long-term trends the increase in train traffic and the volume of goods over the trending period must also be factored into the analysis. For example, if the cause of a derailments is related to an axle failure, the number of kilometers the axle has travelled is likely more relevant than the number of axles in a train. Likewise, if the derailment is caused by a broken rail the annual tonnage is likely more relevant than the number of cars. Consequently, the amount of goods transported and the frequency of use

must be factored into the parameters used to establish the long-term trends. This is highlighted by the change in the amount of goods and distance these goods were transported during the study period. Rail traffic data was obtained from Statistics Canada's CANSIM database, (Statistics Canada, 2015). From 2001 to 2014, the total gross tonne-km increased 40% from 534 billion to 760 billion (**Fig. 4**) (Statistics Canada, 2015). This was accompanied by a 4% increase in the average amount goods being carried per rail car from 78.9 tonnes to 82.0 tonnes. Both of these factors have contributed to increased demand on rail infrastructure.

To account for changes in the amount of goods and distance these goods were transported, the intensity of derailments was defined as the number of derailments divided by mass of goods moved multiplied by the distance moved (tonne-km) when this information was available, and by mass of goods moved (tonnes) when it was not. The statistics presented in by Statistics Canada (2015) are broken down by year, and in some cases by month. The results from the analyses shows a decreasing trend for both metrics; including a 40% decrease in the number of derailments from 223 to 125 per year, and a 60% reduction of the intensity of derailments from 0.42 to 0.18 per billion gross tonne-km (**Fig. 5**). Inspection of **Fig. 5** shows that the reduction in annual number of derailments appears to have slowed reaching a historic low of 98 per year in 2012 and increasing to 135 per year in 2014. Such fluctuations in the trend data were also observed between 2002 and 2004. The trend in the number of derailments when normalized by billion gross tonne-km shows an overall decrease. Hence, improvements in safety are being offset by increased traffic.

3.2 *Derailments involving Dangerous Goods*

The regulations for the transportation of dangerous goods in Canada have been developed under the *Transportation of Dangerous Goods Act, 1992* (Act: S.C. 1992, c.34). This act has been adopted by all provinces and territories, and establishes the definitions of dangerous goods (DG) and safety requirements for their transportation. The more common DG include fuel and petroleum products, gaseous hydrocarbons such as liquid propane, and sulfuric acid. Canadian railways have an obligation as a *common carrier* to transport good regardless of origin or type under the *Canada Transportation Act 1996* (Act: S.C. 1996, c.10). Thus, railway operators are required to move DG as long as they are within containers approved for transporting of the specific type of DG by rail.

Transportation of DG is an important component of Canada's economy, with an increasing number of DG transported by rail in Canada every year. The amount of dangerous goods transported by rail within Canada is increasing, with a significant increase since 2009 (**Fig. 6**). With an increase of just over 50%, from 22.5 to 33.5 million tonnes of DG. Much of this growth can be attributed to increased oil production and transportation in western Canada during this time period. This increase has been primarily driven by oil production in Western Canada. According to the Canadian Association of Petroleum Producers (CAPP), more than 200,000 barrels per day of petroleum crude oil was being transported by rail in Canada in 2014, and this was forecast to grow to about 720,000 barrels per day by 2016 (CAPP 2014).

The number of derailments with DG cars involved was found to vary greatly from year to year during the study period (**Fig. 7**). A high of 45 was reported in 2004, while a low of 9 was reported in 2012. A cyclical pattern is apparent with a spike in the number of derailments every 3

to 4 years. This trend is consistent between both the frequency and intensity of derailments, and thus it is not a result of the amount of traffic. The cause of this cycle warrants further research as these cycles have an average peak-to-trough amplitude of 18 derailments involving DG per year and this is nearly as large as the long-term average of 22 per year. A long-term decreasing trend in this frequency was apparent up to 2012, recent increases may indicate the start of another cycle of derailments involving DG.

The number of DG derailments was also normalized to the million-tonnes of DG transported (Fig. 7). 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 in the trend data was again observed in the normalized derailment data.

Approximately 9% of derailments involved DG cars and resulted in a release of DG. When normalized to the amount of DG carried by rail, a decreasing trend emerged, with an overall reduction from 0.10 to 0.06 derailments with DG releases per million tonnes of DG transported (Fig. 8), representing a 40% decrease. This was most notable in the early years of the study, followed by a period where DG releases leveled off from 2007 to 2011. A rise in derailments with DG released can be observed in the latter years of the study period.

4 Derailment Cause

4.1 Cause Groups

The causes of the incidents reported in the RODS database are divided into five main cause-groups which are presented in Table 2. These 5 main cause groups have an additional two additional tiers of sub-causes that results in 490 different primary causes that can be assigned to a derailment. Though only 193 of these causes have been used in the RODS database. The second

tier of detailed cause groups are presented and defined in **Table 3**. Only the main and detailed cause groups were analyzed.

Fig. 9 presents the percentage of the derailments caused by each of the main cause groups for all the main track derailments that occurred between 2001 and 2014. Over 40% of the derailed rolling stock was attributed to *track, roadbed and structures* causes (**Fig. 9**). The *track, roadbed & structures* and *mechanical & electrical failures* groups, which represent the hardware components of the railway system, comprised and accounted for more than 55% of all main track derailments (**Fig. 9**). The failure of *Signal & communication* systems accounted for less than 1% of derailments and derailed cars. For comparison purposes, also shown in **Fig. 9** is the percentage of cars derailed for each main cause group. More cars are typically derailed where the main cause is attributed to *track, roadbed and structures* (**Fig. 6**).

4.2 Detailed Cause Groups

A ranking of detailed cause groups revealed the top ten causes for main track type in terms of frequency (**Table 4**), this is similar to the results of the study conducted on U.S. derailment data by Liu *et al.* (2012). The rankings show that on all track types, the *rail, joint bar and rail anchoring* and *track geometry* derailment causes were the most common and resulted in the greatest number of cars derailed. This is the same result as TSB (1994) for Canadian derailments from 1980-1993; and, Barkan *et al.* (2003) and Liu *et al.* (2012) for U.S. derailments from 1992-2001 and from 2001-2010. *Environmental conditions* were another common derailment cause at 6.9% of main track derailments. Incident causes associated with switches and other track appliances, as well as a number of human factors, were major contributors on non-main and yard

track. In general, mechanical components and infrastructure were the dominant causes on main track, while human factors were dominant on non-main and yard track.

4.3 Frequency-Severity Analysis

Frequency is defined by the number of derailments attributed to an incident cause over the study period (**Table 4**), and severity as to the number of cars derailed per incident, this is similar to that presented in Liu *et al.* (2012) (**Table 5**). Thus, multi-car derailments are considered more severe than single car derailments. **Fig. 10** shows the average number of cars derailed per main track derailment throughout the study period. Attempts to fit linear and non-linear trends to the data presented in **Fig. 10** resulted in R² values of less than 4%. This is due to the large and increasing short-term oscillations of up to $\pm 23\%$ which are much larger than the long-term trends (a 0.6% increase per year based on a linear fit) that may exist. **Fig. 10** indicates that average number of cars derailed per main track derailment for 2014 is higher than the long-term average.

The frequency and severity of derailments were found to vary with incident type. **Table 5** provides a ranking of the detailed cause groups by the average severity of the derailments. Both **Table 5**, and the results presented in Liu *et al.* (2012) for U.S. derailments, shows that rail breaks and track geometry were the leading causes of derailments by frequency. On Canadian main track, these two causes *rail, joint bar and rail anchoring* and *track geometry* accounted for about 20% of derailments and 36% of derailed cars.

The frequency and severity of derailments are plotted against one another in **Fig. 11** to show which causes pose greatest risk, similar to that presented in Liu *et al.* (2012) for U.S. derailment data. The plot is divided into four sections based on the average derailment frequency and severity for all incident causes. 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. The notable high frequency and high severity incident causes are labeled in **Fig. 11**.

4.4 Influence of derailment speed on severity

The speed of a train when a derailment occurs has been identified to contribute to the severity of the incident. Typically, more cars are derailed when the speed of the train is higher (Liu *et al.* 2011). This trend was found in the Canadian main track derailments from 2001 to 2014 with a linear trend between train speed and severity up to 80 km/h (**Fig. 12**). Above 80 km/h, the number of derailments became too small to develop meaningful average values for severity, with less than 78, 8 and 3 derailments occurring the speed ranges of 89-97 km/h, 98-112 km/h, and > 113 km/h, respectively (**Fig. 13**). The severity values presented in Fig. 10 for these speeds also show large variations.

Derailment causes were analyzed by initiation speed using the same FRA track classes to allow for a comparison between U.S. and Canadian trends for a similar time period (**Fig. 14**). The following findings were apparent from these plots:

- incidents attributed to “rail, joint bar and rail anchoring” resulted in the most derailments in three of the speed ranges, and the second most in the fourth (Liu *et al.* (2011) found it to be the highest for all speed ranges in the U.S.);
- incidents caused by “environmental conditions” were most 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;

- and, incidents attributed to track, roadbed and structures resulted in a greater number of derailments at lower speeds.

5 Conclusion

Despite the ever increasing amount of goods being carried by rail, the total number of derailments decreased by 40% between 2001 and 2014. This corresponds to a 60% reduction when the increase in the amount of rail traffic is accounted for. These trends in the reduced number and intensity of derailments leveled off after 2009. The total number of derailments involving the number of cars carrying dangerous goods increased over the study period, with a reduction of intensity of 16%. This is a result of the large increase in the amount of DG cars being transported and a corresponding increase in the probability that a derailed car will contain dangerous goods. However, there was a decrease in the number and intensity of derailments that resulted in a release of dangerous goods, and the intensity reduced by 40% during the study period, with peaks in 2010 and 2013. A strong cyclical pattern was observed both the number and intensity of derailments involving DG with peaks occurring every three to four years. The amplitude of this cyclic pattern is large with respect to the average frequency and intensity of derailments and warrants further research to identify the underlying causes. The number of derailments with a DG release was found to have decreased when normalized to DG traffic. Though the most recent data may show the start of another cycle of increased derailments involving DGs.

Five incident causes were found to have been high in frequency and severity, and accounted for 40% of main track derailments, with rail integrity being the number one incident cause. These were:

- 306 1. *rail, joint bar and rail anchoring;*
- 307 2. *track geometry;*
- 308 3. *wheels;*
- 309 4. *train handling/train make-up;*
- 310 5. *and, other miscellaneous.*

311 Train speed was confirmed to have an effect on the severity of an incident. Higher speeds
 312 resulted in a greater number of cars derailed per derailment up to approximately 80 km/h. Above
 313 80 km/h, the number of derailments is too small to derive meaningful averages. A decreasing
 314 trend in average derailment initiation speed was observed. This result is consistent with data
 315 from 1983 to 1993 presented by the TSB (1994), and there was an overall reduction in
 316 derailment speed of about 10 km/h.

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Tables

Table 1. Derailment frequency, severity and total cars derailed by incident type and track type, 2001-2014.

Track Type	Incident Type					Total
	Derailment	Collision	Crossing	Other ¹	Incident Type not Indicated	
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.

373 **Table 2.** Main cause groups assigned within the Rail Occurrence Database System.

Main Cause Group ID	Main Cause Group
1	Track, Roadbed and Structures
2	Mechanical & Electrical Failures
3	Train Operation – Human Factors
4	Miscellaneous
5	Signal & Communication

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374 **Table 3.** Detailed cause groups assigned within the Rail Occurrence Database System.

Main Cause Group ID	Detailed Cause Group
1	Frogs, Switches & Track Appliances
	Other Way & Structure
	Rail, Joint Bar & Rail Anchoring
	Roadbed
	Track Geometry
2	Axles & Journal Bearings
	Body
	Brakes
	Coupler & Draft System
	Doors
	General Mechanical & Electrical
	Locomotives
	Truck Components
	Wheels
3	Brakes, Use of
	Flagging, Fixed, Hand & Radio Signals
	General Switching Rules
	Loading Procedures
	Main Track Authority
	Miscellaneous
	Speed
	Switches, Use of
4	Train Handling/Train Make-up
	Environmental Conditions
	Highway-Rail Grade Crossing Accidents
	Loading Procedures
	Other Miscellaneous
5	Unusual Operating Situations
	Signal & Communication

375

376

Table 4. Top 10 incident causes of train derailments for main track by number of derailments, 2001-2014.

Rank	Main Track	
	Cause ID	%
1	Rail, joint bar and rail anchoring	10.8
2	Track geometry	9.7
3	Environmental conditions	6.9
4	Wheels	6.8
5	Train handling / train make-up	6.6
6	Other miscellaneous	6.2
7	Axles and journal bearings	5.3
8	General switching rules	5.0
9	Switches, use of	4.8
10	Brakes	3.9

Table 5. Top 10 incident causes of train derailments on main track by percentage of cars derailed, 2001-2014.

Rank	Main Track	
	Cause ID	%
1	Rail, joint bar and rail anchoring	25.9
2	Track geometry	9.9
3	Wheels	9.9
4	Train handling / train make-up	6.8
5	Other miscellaneous	6.2
6	Highway-rail grade crossing accidents	5.0
7	Environmental conditions	4.2
8	Axles and journal bearings	3.8
9	Roadbed	3.6
10	Coupler and draft system	3.5

383 **Figure Captions**

384 **Figure 1.** Map showing the extents of the Canadian rail network (NRCan, 2016).

385 **Figure 2.** Canadian derailment trends, 1980 to 1993 (*data from* TSB 1994).

386 **Figure 3.** Comparison of normalized Canadian main track derailment rate in Fig. 2 with the
387 normalized United States rail accident rate, (1980-2014, *data from* AAR 2015a).

388 **Figure 4.** Increase in rail traffic, annual billion gross tonne-km, 2001- 2014 (*data from* Statistics
389 Canada 2015).

390 **Figure 5.** Total main track derailments normalized by billion gross tonne-km, 2001-2014.

391 **Figure 6.** Transportation of dangerous goods transported by rail, million tonnes, 2001-2014
392 (*data from* Statistics Canada 2015).

393 **Figure 7.** Main track derailments with dangerous goods cars involved, 2001-2014.

394 **Figure 8.** Derailments involving dangerous goods cars that resulted in a release, normalized to
395 dangerous goods transported, 2001-2014.

396 **Figure 9.** Distribution of derailments and derailed rolling stock on main track by main cause
397 group, 2001-2014.

398 **Figure 10.** Average number of cars derailed per derailment on main track, 2001-2014.

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

400 **Figure 12.** Severity of main track derailments by initiation speed, 2001-2014.

401 **Figure 13.** Number of main track derailments by initiation velocity, 2001-2014.

402 **Figure 14.** Distribution of derailments by incident cause and speed on main track rail, 2001-
403 2014: (a) 0 to 16 km/h; (b) 16 to 40 km/h; (c) 40 to 64 km/h; and, (d) > 64 km/h.

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Figure 1. Map showing the extents of the Canadian rail network (NRCan, 2016).

Severity - Average Number of Cars Derailed

Frequency - Derailments per Billion Gross Tonne-km

Average frequency = 4.1

Average severity = 4.0