Principal factors contributing to heavy haul freight train safety improvements in North America: a quantitative analysis

B. Wang & C. Barkan
University of Illinois At Urbana-Champaign, Urbana Illinois, United States
R. Saat
Association of American Railroads, Washington, D.C., United States

ABSTRACT: Heavy haul freight railways play an important role supporting North American economic and environmental sustainability. Train accidents have declined considerably over the past decade; however, when they do occur they can damage infrastructure and rolling stock, interfere with transportation, and may cause causalities and releases of dangerous goods. Consequently, continuous improvement in train safety is an ongoing priority of the rail industry. Extensive, detailed data from the US DOT Federal Railroad Administration (FRA) were used to quantify the most important factors contributing to the declining accident trend. The objective is quantitative understanding of where the greatest safety improvements have occurred, and what are the most important opportunities for further improvement in train safety. The rates of derailments, collisions, highway-rail grade crossing accidents and others combined, all declined, but the largest reduction was in mainline derailments. The derailment causes that showed the greatest reduction were broken rails and welds, track geometry and railcar bearing failure, followed by 16 other causes. However, the rate of buckled track derailments, and to a lesser degree roadbed failures and obstructions increased. Previous work investigating the correlation between derailment rate and FRA track class, method of operation and annual gross tonnage were analyzed and updated. The results indicate a general decline in accident rate across nearly all mainline conditions. The results can be used to guide priorities for research and investment of resources to further improve train safety in the most effective and efficient manner.

1 INTRODUCTION

North American railroads play a major role in freight transport, moving 42 percent of the intercity freight in the United States or approximately 40 tons of freight per person per year (FRA 2010). Due to this large volume of traffic, safe operation has broad implications. Freight train derailment accidents have declined over the past decade, from 2,197 in 2006 to 1,344 in 2015, a 39 % reduction (FRA 2016). Despite this improvement, derailments have the potential to damage infrastructure and rolling stock, disrupt services, cause casualties, and may result in release of hazardous materials.

Improvements in freight train safety and derailment reduction have been an ongoing priority for the rail industry and government. Some safety measures reduce risk more effectively than others, so understanding the relative importance of different causes is important if safety is to be improved in the most efficient manner. This paper uses freight train accident data from the U.S. Department of Transportation Federal Railroad Administration (FRA) to examine the contributing derailment causes over the past decade and quantify how they have changed.

The objective is to provide insights to assist decision makers in choosing the most effective approaches to further reduce or eliminate accidents.

The principal objective of this paper is to identify the derailment causes having the greatest effect on train safety and risk, and to quantify and rank changes in the number and distribution of derailment causes. The study focus on mainline derailments on the major U.S. railroads (Class 1) and is separated into two time periods: 2006 to 2010 and 2011 to 2015. This approach provides a robust data set in terms of total gross ton-miles (tonne-kilometres). The two time periods were roughly equivalent in terms of total traffic, 16.7 trillion gross ton-miles (24.4 tonne-kilometres) during the first time period and 17.2 trillion ton-miles (25.1 tonne-kilometres) during the second.

2 DATA AND METHODOLOGY

The Rail Equipment Accident/Incident Report (REAIR) form is used by the U.S. railroads to report accidents that exceed a monetary threshold for damages to equipment or infrastructure and it is periodi-

cally adjusted for inflation (FRA 2011a). The REAIR database contains details for each accident including date, railroad, weather, as well as types of track – mainline, siding, yard, or industry. The database also identifies thirteen types of accidents including derailment, collision, and various others. The FRA classification of accident types is based on the initial cause, but may include a secondary cause as well. For example, if a collision caused a derailment, the initial cause would be collision and the secondary cause would be derailment. In this study, such an accident would be classified as a collision. The principal information used in this paper includes date, track type, number of cars derailed, and accident cause.

The FRA lists approximately 400 different cause codes in five categories using single-letter codes as follows: (T) track, roadbed, and structure, (S) signal and communication, (H) train operation, (E) mechanical and electrical failures, and (M) miscellaneous (FRA 2011b). Each of the five categories contains more specific sub-categories with an additional level of detail. This is useful for many studies; however, identification of certain trends benefits from some modified aggregation of related causes. In the early 1990s, Arthur D. Little Inc. (ADL) worked with the Association of American Railroads (AAR) and developed an alternative grouping to the FRA accident cause categorization (ADL 1996; Schafer and Barkan 2008) that consolidated various causes into groups while enabling distinction between certain other cause groups (Anderson and Barkan 2004). For example, the FRA sub-categorization combines broken rails or welds, joint bars, and rail anchors; whereas the ADL method separates broken rails or welds, joint bar defects, and rail anchors into three separate groups. Another example is that FRA combines buckled track as a sub-group within track geometry while the ADL method separates those into two groups. These distinctions are important because the underlying causes and consequent solutions differ.

Estimation of accident rates requires traffic exposure data. FRA provides partial exposure data and the AAR provides additional railroad traffic data. The annual gross ton-miles (tonne-kilometres) for Class 1 railroad freight trains were used as a metric for traffic exposure for calculation of accident rates (AAR 2006 - 2015). Three candidates for traffic exposure were considered: car-miles (car-kilometres), train-miles (train-kilometres), and ton-miles (tonne-kilometres). Ton-miles were chosen because of its availability compared to the other two (Nayak and Palmer 1980).

3 TRAIN DERAILMENT CAUSE ANALYSIS

Developing the most effective derailment prevention strategies requires understanding the root causes of derailments. The most frequent causes included broken rails or welds and track geometry (excluding wide gauge) (Table 1). The five most frequent causes consist of almost 40% of the all the causes in terms of derailment frequency. Eight of the top ten causes were track, roadbed, and structure or mechanical and electrical category, labeled in red and blue, respectively in the table. Higher derailment rate does not necessarily correlate with higher derailment severity (average number of cars derailed). In the next section, the relationship between the frequency (number of derailments) and severity of accident causes simultaneously.

Table 1. Top Ten Frequent Derailment Causes and Respective Derailment Rates, 2006 – 2015

ADL Cause Group	Cause Type	Derailments	Average Number of Cars Derailed	Derailments per Trillion Tonne-Kilometre
Broken Rails or Welds	Track, roadbed and structure	397	12.9	17.0
Track Geometry (excl. Wide Gauge)	Track, roadbed and structure	188	6.6	8.1
Broken Wheels (Car)	Mechanical and electrical	166	7.6	7.1
Obstructions	Miscellaneous	166	13.2	7.1
Bearing Failure (Car)	Mechanical and electrical	155	4.6	6.6
Buckled Track	Track, roadbed and structure	131	12.8	5.6
Train Handling (excl. Brakes)	Train operation and human factors	121	7.1	5.2
Other Axle/Journal Defects (Car)	Mechanical and electrical	107	8.3	4.6
Coupler Defects (Car)	Mechanical and electrical	97	5.4	4.2
Other Wheel Defects (Car)	Mechanical and electrical	92	3.7	3.9

3.1 Derailment Frequency and Severity

Dick et al (2003) and Barkan et al (2003) introduced a graphical approach to illustrate the relationship between train derailment causes' frequency and severity. Individual derailment cause is plotted in terms of its average frequency and average severity (Figure 1) and the graph is divided into four quadrants. Data points to the right of the vertical line indicate above-average frequency and points above the horizontal line indicate above-average severity. The relative impact of different cause groups can be evaluated in terms of their respective quadrant. Previous research has found that in addition to derailment frequency, number of cars derailed is a good predictor variable for the derailment severity and risk of hazardous material release due to the higher amount of kinetic energy from more cars derailed (Barkan et al 2003).
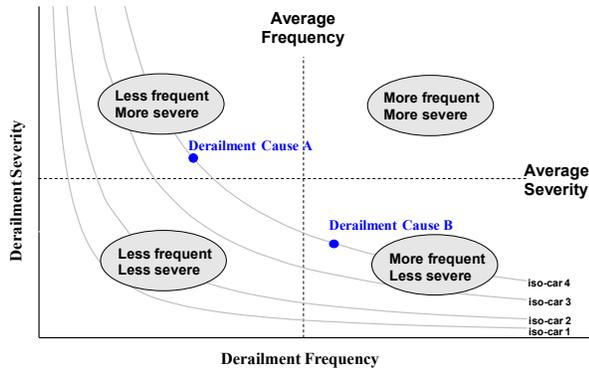
Figure 1 Example of a frequency-severity graph including iso-car lines

Figure 2 Frequency-severity graph from 2006 to 2015 (Causes with iso-car greater than 20 are labelled)

Derailment causes in the upper right quadrant occur more frequently and are more severe thereby posing the greatest risk in terms of number of cars derailed. Conversely, causes in the lower left quadrant are rare and tend to be lower severity derailments. The causes in the upper left quadrant have more severe consequences, but their lower frequency makes it more difficult to make consistent predictions. The lower right quadrant includes less severe, but higher frequency derailment causes, which are of secondary interest.

A graphical technique is also introduced here referred to as "iso-car" lines; these represent equal levels of risk in terms of numbers of cars derailed. Iso-car lines are an inverse function of the average number of cars derailed and the number of derailments. Iso-cars provide additional resolution for comparison of derailment causes relative to one another. The distance from the origin represents risk level with higher iso-car numbers indicating higher risk levels. For example, in the absence of iso-car lines, derailment cause A cause would be classified as "less frequent and more severe" while derailment cause B is classified as "more frequent and less severe". Use of iso-car lines indicates that these two causes pose the same risk level in terms of number of cars derailed.

This paper used the iso-car approach to evaluate frequency and severity in which the normalized derailment frequency and average severity per derailment were plotted. Mainline freight train derailment causes over the study period were compared using a frequency-severity plot such as described above (Figure 2). Throughout the study period, broken rails or welds were the most frequent derailment cause, with the highest iso-car level of 85. This finding is consistent with previous studies (Anderson 2005; Liu 2013). Other rail and joint defects were, on average, the most severe derailment cause, although they occurred much less frequently.
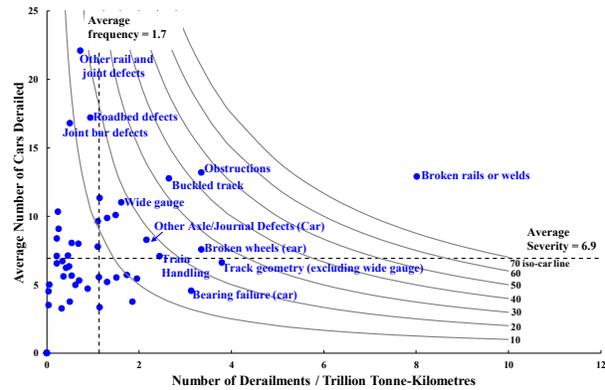
As discussed above, comparison of cause-specific derailment trends is the objective of this paper so the frequency-severity plot was adapted for this comparison by using different symbols to plot the two time-periods on the same graph (Figure 3). Considering broken rails or welds again, there was a slight increase in severity, but a substantial reduction in frequency when comparing 2006-2010 to 2011-2015. Despite this decrease, broken rails or welds remained the leading cause of large derailments and the highest iso-car level. Track geometry other than wide gauge also declined substantially. Other rail and joint defects were supplanted by joint bar defects as the cause with the highest severity.
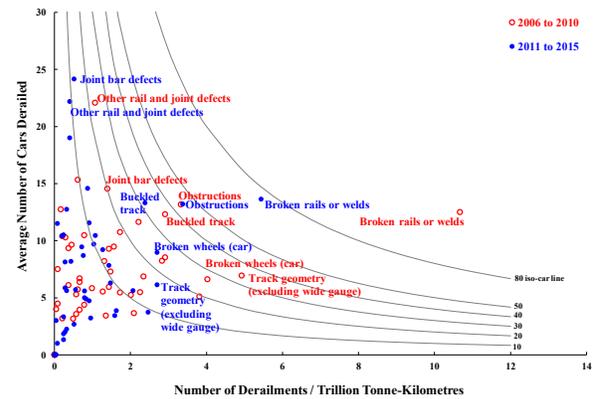

Figure 3 Frequency-severity graph of two time periods (Causes in the first time period with iso-car greater than 40 are labelled)

The graphical technique with iso-cars (Figures 2 and 3) offers a means to simultaneously compare the relative changes among causes' relative frequency and severity; however, quantitative comparison of changes is more difficult. To study the changes quantitatively, the change in the number of derailments and number of cars derailed per trillion tonne-kilometres between the two time periods were compared (Figures 4 and 5).
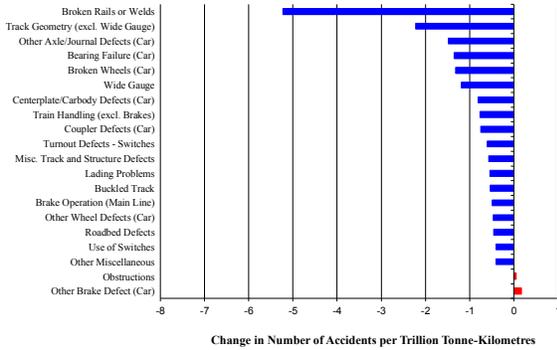
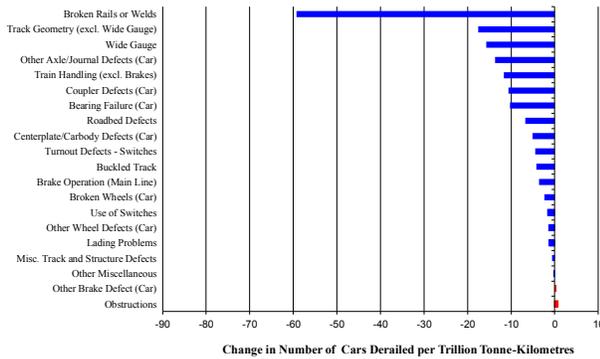Figure 4 Change in derailment rate by cause group from 2006 – 2010 to 2011 – 2015

Figure 5 Change in number of cars derailed by cause group from 2006 – 2010 to 2011 – 2015

Comparison of the derailment frequency and severity for the two periods, showed that broken rails or welds were the most frequent and severe in both periods, track geometry (excluding wide gauge) was the second most frequent cause in 2006 to 2010, and obstructions ranked second in terms of severity for both time periods. Although broken rails or welds had the largest number of derailments; they also had the greatest reduction in both derailment frequency and overall number of cars derailed (Figure 4 and 5). Track geometry (excluding wide gauge) showed the second largest reduction in frequency and number of cars derailed. This reduction in derailment rate is consistent with recent studies (Liu 2015). Most derailment causes declined in occurrence rate between the two periods, but two causes, obstructions, and other brake defects (car), showed an increase in terms of derailment rate and number of cars derailed.

A final question considered was whether the decline in most accident causes was proportional to their relative frequency, or whether some declined disproportionately, i.e. more or less rapidly than average. This was addressed by comparing the magnitude of change of each cause group to its frequency in the first time period (Figure 6). The linear regression line represents the average change for all the cause groups. Causes above the regression line had relatively less change between the two periods,

whereas causes below the regression line indicate disproportionately greater reduction in derailment frequency. The same approach was used for the number of cars derailed (Figure 7).
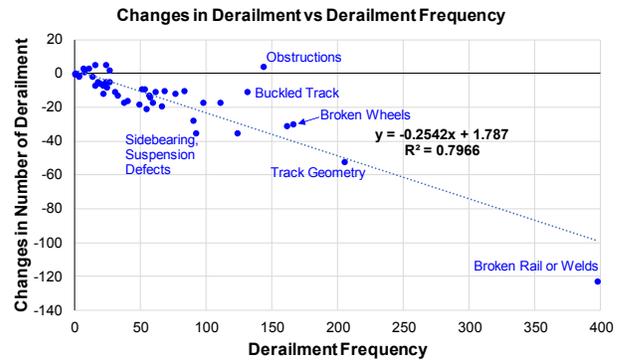

Figure 6 Change in Derailment Frequency vs Derailment Frequency, 2006 – 2010 to 2011 – 2015
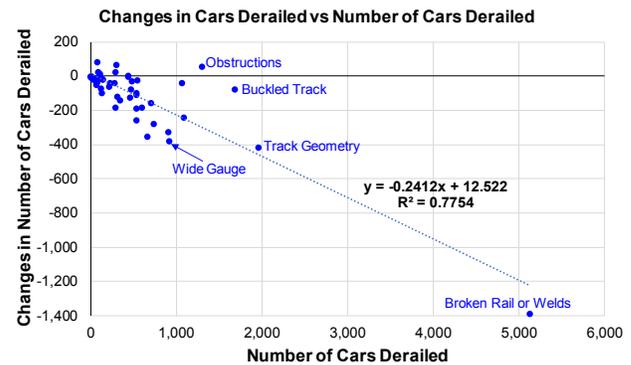

Figure 7 Change in Number of Cars Derailed vs Number of Cars Derailed, 2006 – 2010 to 2011 – 2015

Broken rails or welds, wide gauge, and other axle or journal defects showed greater reduction in terms of both derailment frequency and number of cars derailed, while buckled track, obstructions, and broken wheels had relatively less change in both derailment frequency and number of cars derailed.

4 CONCLUSIONS

U.S. Class I railroad mainline freight train derailment causes were analyzed and a generally decreasing trend was found in derailments caused by broken rails or welds, track geometry, and most other cause groups. The exceptions were obstructions and other brake defects that showed a modest increase in frequency and severity. Broken rails or welds, wide gauge, and other journal or axle defects showed a disproportionately greater reduction compared to their frequency in the earlier time period, while obstructions, buckled track, and broken wheels showed less reduction relative to their fre-

quency. These results provide insights regarding progress in train safety and derailment reduction efforts.

5 ACKNOWLEDGEMENTS

6 REFERENCES

Arthur D. Little (ADL). 1996. Risk Assessment for the Transportation of Hazardous Materials by Rail, *Supplementary Report: Railroad Accident Rate and Risk Reduction Option Effectiveness Analysis and Data,* 2nd rev.

Association of American Railroads (AAR) 2006 - 2015. Analysis of Class I Railroads. *Association of American Railroads.*

Anderson, R.T. 2005. Quantitative Analysis of Factors Affecting Railroad Accident Probability and Severity. *M.S. Thesis. University of Illinois at Urbana-Champaign,* 2005.

Barkan, C.P.L., C.T. Dick & R. Anderson. 2003. Railroad derailment factors affecting hazardous materials transportation risk. *Transportation Research Record: Journal of the Transportation Research Board* 1825: 64-74

Federal Railroad Administration 2010. National rail plan progress report. *U.S. Department of Transportation.*

Federal Railroad Administration 2011a. Rail Equipment Accident/Incident Form F 6180.54 Accident Downloads on Demand Data File Structure. *U.S. Department of Transportation.*

Federal Railroad Administration 2011b. FRA Guide for Preparing Accident/Incident Reports. *U.S. Department of Transportation.*

Federal Railroad Administration 2014. U.S. Track Safety Standards; improving rail integrity: Final rule. U.S. *Department of Transportation.*

Federal Railroad Administration 2016. Accident Query. *FRA Office of Safety Analysis, U.S. Department of Transportation.*

Liu, X. Statistical Temporal Analysis of Freight-Train Derailment Rates in the United States : 2000 to 2012. 2015. *In Transportation Research Record: Journal of the Transportation Research Board* 2476: 119-125.

Nayak, P.R., & Palmer, D.W. 1980. Issues and Dimensions of Freight Car Size: A Compendium. *Report FRA/ORD-79/56, Federal Railroad Administration, U.S. Department of Transportation.*

Saccomanno, F.F., & El-Hage, S.M 1991. Establishing Derailment Profile by Position for Corridor Shipments of Dangerous Goods. *Canadian Journal of Civil Engineering* 18: 67-75.