Comparison of Loaded and Empty Unit Train Derailment Characteristics

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ABSTRACT

Freight train derailment rate has declined substantially over the past decade. Although various aspects of this improvement in train safety have been studied, there has been only limited research examining the effect of train loading condition on derailment occurrence, causes and severity. Unit trains operate loaded in one direction and return empty, and their operation has become more frequent over the past several decades transporting a variety of bulk products. This paper describes research in which an algorithm was developed to identify mainline derailments of loaded and empty unit trains in the US DOT Federal Railroad Administration database. This process was used to develop a dataset of these incidents for the period 2001 to 2015. The number of derailments of loaded and empty trains, the principal causes of these derailments, and their average severity in terms of number of cars derailed are quantified and described.

INTRODUCTION

Railroads play a critical role in the transportation and economic prosperity of the United States. Train safety has improved considerably over the past decade. This trend continues; in 2016 the derailment rate was the lowest it has been since the Federal Railroad Administration began recording data. Nevertheless, with the large volume of traffic flowing over the network, incidents still occur. Derailments are the most common type of train accident, comprising almost 70% of these incidents in the fifteen-year period from 2001 – 2015. Freight train derailments, especially those involving hazardous materials, have the potential to cause serious damage if there is a release. These types of incidents have received increased attention from the rail industry and government in recent years due to expanded transportation of flammable liquids, and several high-profile derailments involving these products.

Unit trains are a specific type of rail service in which an entire train transports a single commodity from one origin to one destination. Unit trains increase railroad freight transportation efficiency through reductions in operating expenses, bulk loading, and economies of scale (*1-3*). Historically, unit trains were used to transport coal and certain other bulk commodities (*1*). More recently, flammable liquid tank cars have begun traveling in unit-train-like movements. For the purposes of this paper, "unit" trains will refer to fully loaded or empty trains having train type prefixes (aka "symbols") designating them as unit trains; however, a more precise definition can be found in Starr (*1*). In terms of loading condition, unit trains are either fully loaded or empty, resulting in a substantial weight difference (over 4:1). Most previous research on unit trains has focused on operational and economic questions, including productivity and profitability (*1-5*).

Previous research on train operating safety has included analyses of derailment frequency and consequences based on train speed (*6*) and derailment causes (*7-9*), but relatively little attention has been given to the effect of loading condition. Liu et al. developed a zero-truncated negative binomial (ZTNB) regression model for derailment severity that factors in loading condition (*10*). The authors are unaware of any prior research that has focused on loaded and empty unit trains and the relationship with derailment occurrence and causes. In this paper, both the frequency and severity of freight train derailments were analyzed based on different train loading conditions. Frequency and severity for the most common derailment causes for each loading condition were investigated.

RESEARCH OBJECTIVE

The objective of this paper is to identify and quantify the effect of loading condition on freight train derailments and compare derailment causes of loaded and empty unit trains. To achieve the objective, the following steps were taken:

- Develop a methodology to identify loaded and empty unit trains from the Federal Railroad Administration (FRA) database
- Build a database for derailments of loaded and empty unit trains
- Analyze the resulting dataset to quantify the relationship between train loading condition and derailment frequency and severity
- Evaluate the top derailment causes by derailment frequency and average severity

METHODOLOGY

Previous studies have used monetary damage and number of cars derailed (*7*) to assess the severity of train derailments. In this paper, derailment severity is defined as the average number of cars derailed in a derailment accident, and derailment frequency is defined as the number of train derailments.

Data Source

The U.S. Department of Transportation (U.S. DOT) Federal Railroad Administration (FRA) compiles train accident data based on reports submitted by railroads operating in the United States. The train derailment data used in this study were from the FRA's Rail Equipment Accident/Incident (REA) database. The REA database provides detailed accident information, including operational factors, environmental factors, train characteristics, damage conditions, and other information useful for accident analysis. Railroads are required to submit accident reports to the REA database for all accidents that exceed a monetary threshold for damage and loss. This reporting threshold is periodically adjusted to account for inflation, rising from $6,600 in 2001 to $10,500 in 2015 (*11*). Freight train derailment accidents for Class 1 railroads over the period from 2001 to 2015 were used for the analysis in this paper.

Classification Method

A dataset was developed using the FRA REA database. It included Class I railroad freight train derailments of trains that were 30 or more cars in length and operating on Class I owned mainline and siding tracks. There were about 6,000 such derailments in the fifteen-year period.

A simple algorithm was developed to identify loaded and empty unit trains in the REA dataset (Figure 1). The number of empty cars, the number of loaded cars, and train length are recorded in the REA database. To account for buffer cars, a train was classified as a loaded train if 95% of the cars were loaded and was classified as empty if 95% were empty. These percentages were calculated by dividing either the number of loaded cars or the number of empty cars by the total number of cars for each train. As required by federal regulations, buffer cars need to be placed between locomotives and loaded cars transporting hazardous materials in unit trains (*12*). Buffer cars can be either empty or loaded with inert material. Because of how unit trains are operated, the buffer car loading condition is independent of the loading condition of the rest of the train, consequently the use of the 95% criteria, rather than 100%.

After obtaining all loaded and empty train derailments, the remaining derailments were filtered based on train symbol. Train symbol information was obtained through online resources (*13,14*). This was done to eliminate all trains with train types indicating that they run as non-unit trains, including manifest trains, intermodal trains, local trains, and work trains. Using this classification process illustrated in Figure 1, 1,536 loaded unit trains and 303 empty unit trains were identified out of over 6,000 Class I railroad freight train derailments on Class I owned mainline and siding track.

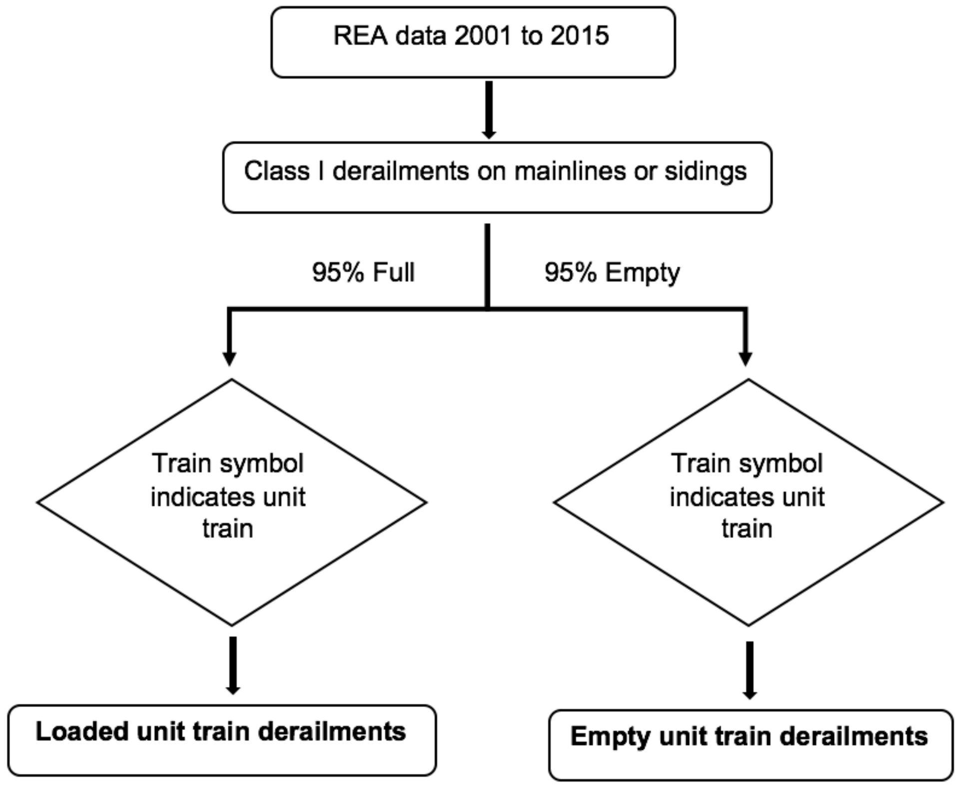


FIGURE 1 Classification Flowchart for Loading Condition Database

LOADING-CONDITION SPECIFIC DERAILMENT ANALYSIS

The purpose of this paper is to investigate characteristics of loaded and empty train derailments. Non-unit train derailments were classified into "other" category. As noted above, there were about five times more records of loaded trains derailing than empty. Several pertinent characteristics of derailments were summarized, including tonnage of the train, train length, speed at derailment, number of cars derailed, point-of-derailment (POD), and normalized point-of-derailment (NPOD), where NPOD is the POD normalized by train length (Table 1). T-tests were used to test the difference of these characteristics in loaded and empty trains with p-values recorded in Table 1, and characteristics of other derailments were also included for comparison. The average derailment speed of loaded and empty trains was not statistically different (25.1 and 24.8 mph respectively), nor was the average train length (106.9 and 106.8 respectively). Loaded unit trains derailed an average of 11.5 cars, and empty unit trains derailed an average of 8.9 cars. This difference in derailment severity was found to be significant (p-value = 0.0007), which is consistent with Liu et al.'s results, who suggest that derailment severity depends on derailment speed, residual length, and loading factor (*10*). In addition to derailing more cars, loaded unit trains also tend to have the POD farther back in the train compared to empty trains. Given the similarity in average train length, the NPODs also differed significantly. This outcome could be due to a difference in derailment cause distributions (*15,16*), which will be discussed later.

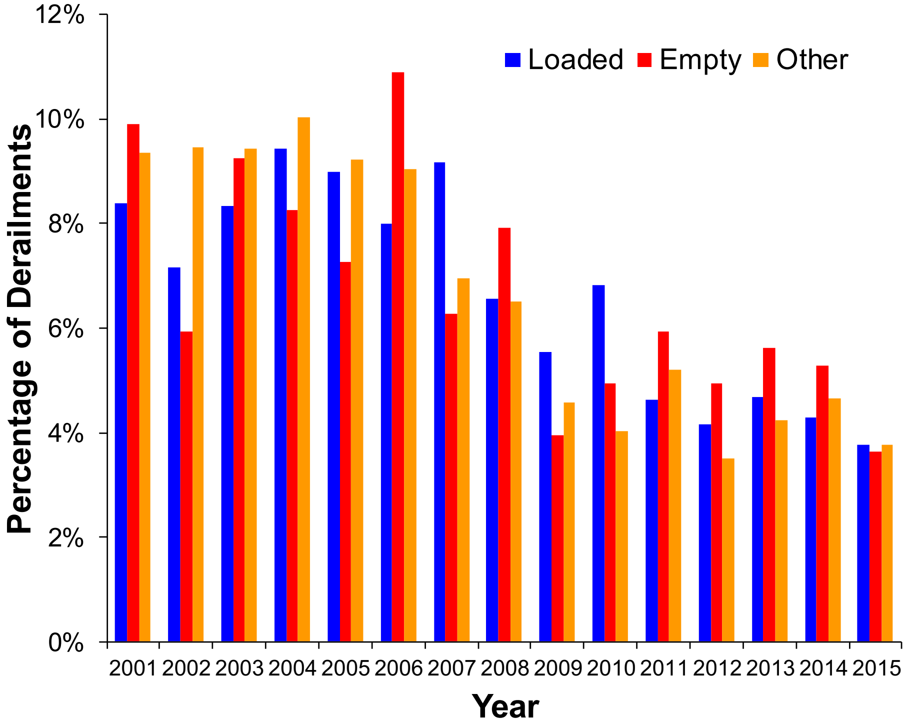
TABLE 1 Summary Statistics of Derailments for Loaded and Empty Trains (2001 – 2015)

Loading Condition	Number of Accidents	Tons (1,000s)	Average Train Length	Average Speed	Average Number of Cars Derailed	Average POD	Average NPOD
Other	4,180	7.1	77.9	22.5	8.3	11.4	45.0%
Loaded	1,536	14.2	106.9	25.1	11.5	54.4	51.0%
Empty	303	3.0	106.8	24.8	8.9	41.8	40.2%
P-Value	--	<0.001	0.945	0.786	0.001	<0.001	<0.001

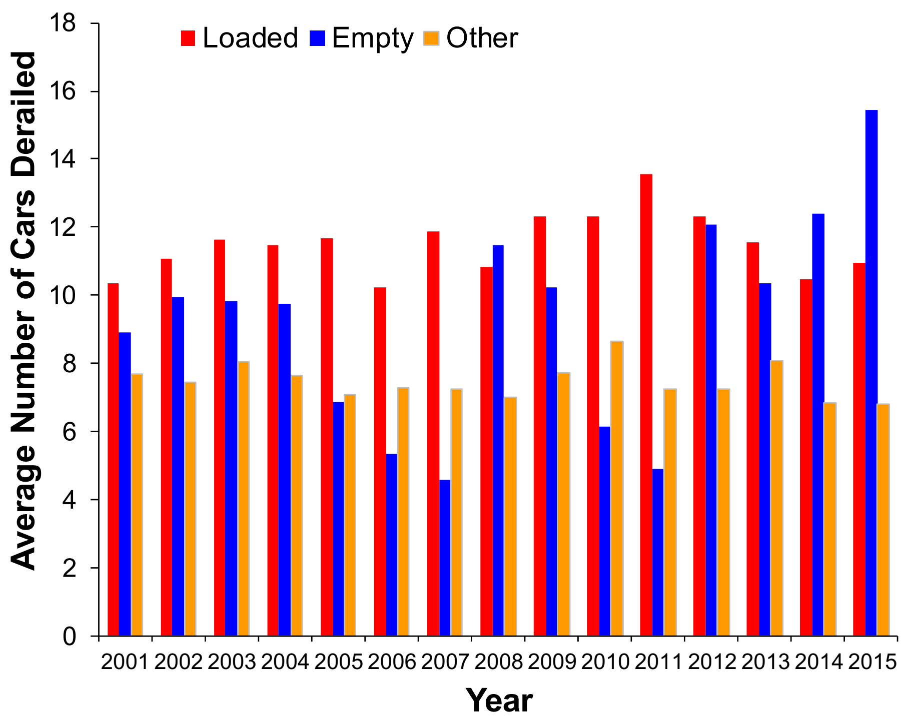
Derailment Frequency and Severity Trend

To investigate possible differences over time, the frequency and severity of derailment accidents were first analyzed by year (Figure 2). Since the number of derailments for the three categories differ, percentage was used instead of absolute numbers to facilitate comparison. Derailment frequency for loaded unit trains, empty unit trains, and other trains declined about 55%, 63% and 60% over the 15-year period respectively (Figure 2a). This is consistent with the trend of all derailments, as all derailment frequency declined about 58% over 15 years. Table 1 shows that empty train derailment severity was generally less than loaded train derailment severity, but fluctuated widely from year to year (Figure 2b). For example, in 2015, derailment severity for empty unit trains was higher than that of loaded trains. However, this was due to a single incident in Iowa in which 87 cars in an empty unit train were derailed by a tornado. Since the sample size for empty unit trains was relatively small, extreme incidents such as this sometimes shifted the average for a given year. While other train derailment severity is less than unit train derailment severity, it exhibits the same fluctuating trend.

Although extreme incidents can influence average derailment severity, they are uncommon. To understand the distribution of derailment frequency and severity, the number of derailments was plotted against the number of cars derailed per accident (Figure 3). Due to the large difference between the number of derailments for unit trains and non-unit trains, the cumulative percentage for number of cars derailed was used to compare the derailment distributions. The blue line in Figure 3 represents the cumulative percentage of empty trains. For all derailments with more than one car derailed, this cumulative curve is left of the red line for loaded trains, further corroborating the finding that empty train derailment accidents result in fewer cars derailed. The orange line for non-unit trains is closer to that for empty unit train derailments than loaded unit train derailments.



(a)



(b)

FIGURE 2 Distribution of Freight Derailment (a) Frequency and (b) Severity by Year, U.S. Class I Railroad Mainlines and Sidings, 2001-2015

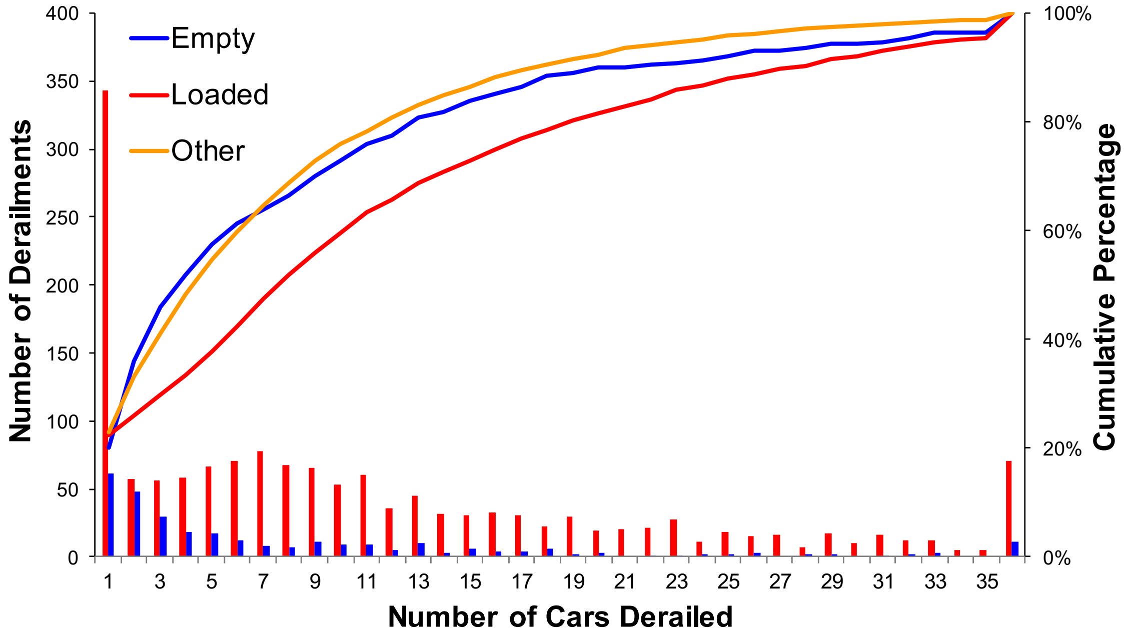


FIGURE 3 Derailment Frequency vs. Severity for Loaded and Empty Train, U.S. Class I Mainlines and Sidings, 2001-2015

Causal Analysis

ADL Accident Cause Comparison

FRA provides a detailed list of accident causes for railroads to use when reporting incidents in the REA database (*17*). A more concise list of causes was developed by Arthur D. Little (ADL) Inc. and the Association of American Railroads in the early 1990s based on input from railroad engineering and mechanical experts (*18*). The ADL cause groups combine similar FRA cause codes, and all FRA cause codes map to an ADL cause group. The first step of causal analysis was to identify the top ten ADL cause groups for the two loading conditions and rank them by number of derailments (Table 2). The causes in red are unique to loaded unit trains; the causes in blue are unique to empty unit trains; and the causes in black are shared by both.

The top ten causes for the two loading conditions were plotted on a frequency versus severity graph (Figure 4). The graph is divided into four quadrants by the average frequency and the average severity of the top ten derailment causes. The most severe causes fall in the upper right quadrant. Causes in this quadrant have both above-average severity and above-average frequency (*7,19,20*). The top ten derailment causes for loaded trains and empty trains have different distributions (Figure 4). For loaded trains, broken rails or welds was the leading cause in terms of both frequency and severity. It caused about 20% of loaded unit train derailments with about 15 cars derailing in these incidents on average. Broken rails or welds was also the second leading cause of empty train derailments; however, obstructions accounted for the highest percentage of empty train derailments at 16.5% and had the highest number of cars derailed with 18 cars on average. Causes that both loading cases shared include broken rails or welds, track geometry excluding wide gauge, and buckled track.

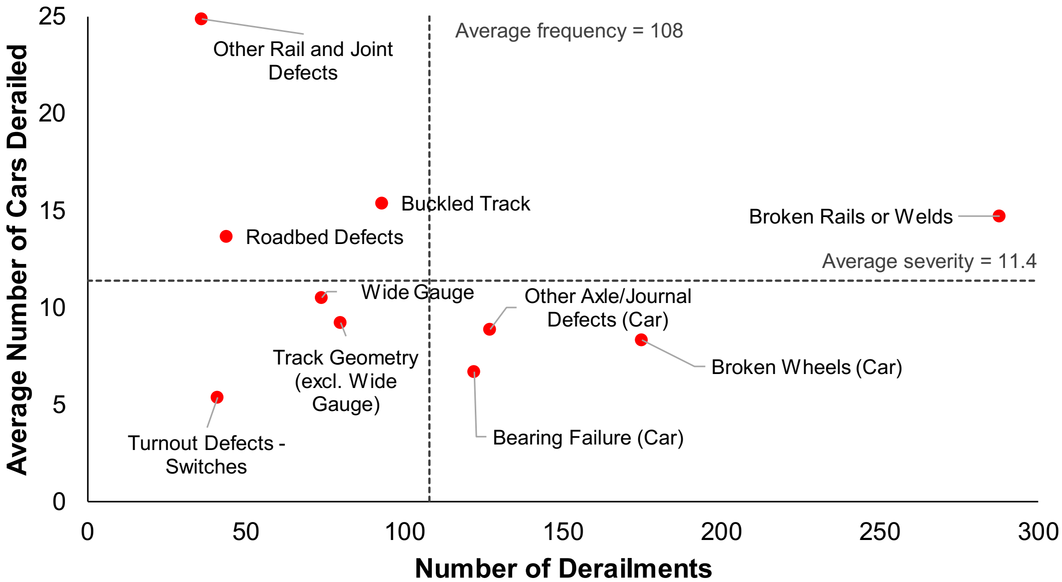
TABLE 2 Frequency and Severity of the Top 10 Derailment Causes for (a) Loaded and (b) Empty Unit Trains.

(a) Loaded Trains

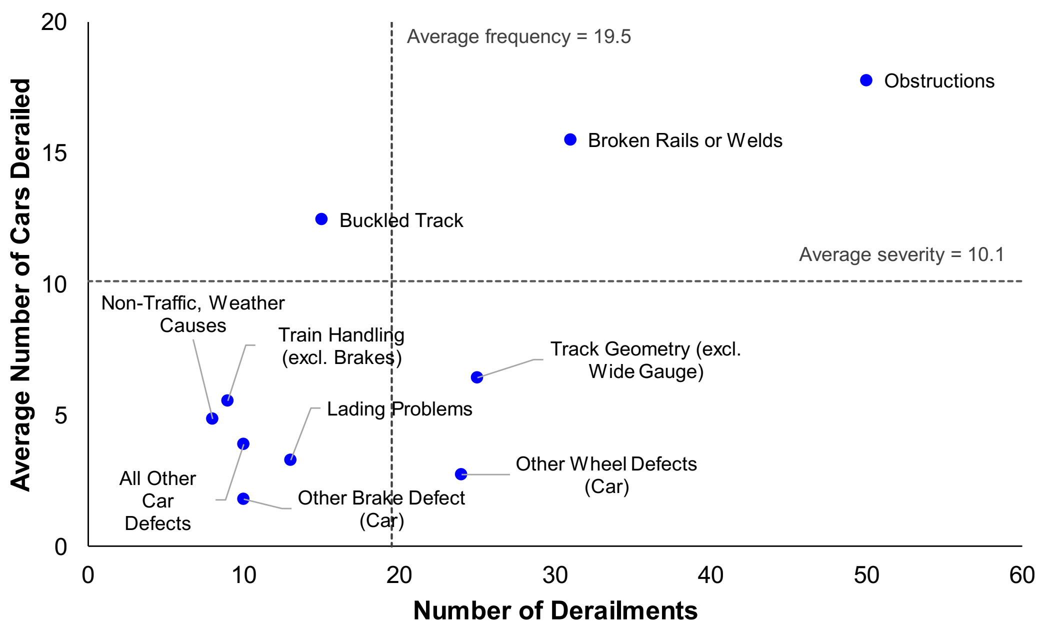
Rank	ADL Cause Group	Number of derailments	Percentage	Average Number of Cars Derailed
1	Broken Rails or Welds	288	18.8%	14.7
2	Broken Wheels (Car)	175	11.4%	8.3
3	Other Axle/Journal Defects (Car)	127	8.3%	8.9
4	Bearing Failure (Car)	122	7.9%	6.7
5	Buckled Track	93	6.1%	15.4
6	Track Geometry (excl. Wide Gauge)	80	5.2%	9.2
7	Wide Gauge	74	4.8%	10.5
8	Roadbed Defects	44	2.9%	13.7
9	Turnout Defects - Switches	41	2.7%	5.4
10	Other Rail and Joint Defects	36	2.3%	24.9

(b) Empty Trains

Rank	ADL Cause Group	Number of derailments	Percentage	Average Number of Cars Derailed
1	Obstructions	50	16.5%	17.8
2	Broken Rails or Welds	31	10.2%	15.5
3	Track Geometry (excl. Wide Gauge)	25	8.3%	6.4
4	Other Wheel Defects (Car)	24	7.9%	2.8
5	Buckled Track	15	5.0%	12.5
6	Lading Problems	13	4.3%	3.3
7	Other Brake Defect (Car)	10	3.3%	1.8
8	All Other Car Defects	10	3.3%	3.9
9	Train Handling (excl. Brakes)	9	3.0%	5.6
10	Non-Traffic, Weather Causes	8	2.6%	4.9



(a)



(b)

FIGURE 4 Frequency vs. Severity of Derailments under ADL's Top Ten Causes: (a) Loaded and (b) Empty, U.S. Class I Mainlines and Sidings, 2001-2015

Considering the substantial difference in the number of derailment incidents for loaded and empty trains, comparison is facilitated by standardizing by the total number of derailments per loading condition (Figure 5). The lines dividing the quadrants are the averages for the top ten derailment causes of both loading conditions combined. Causes shared by both loading conditions are highlighted in yellow. Figure 5 enables comparison of the relative frequency and severity of derailment causes under the two loading conditions. For example, derailments caused by track geometry excluding wide gauge resulted in derailments with similar severity in both conditions, but they contribute to a greater percentage of empty unit train derailments.

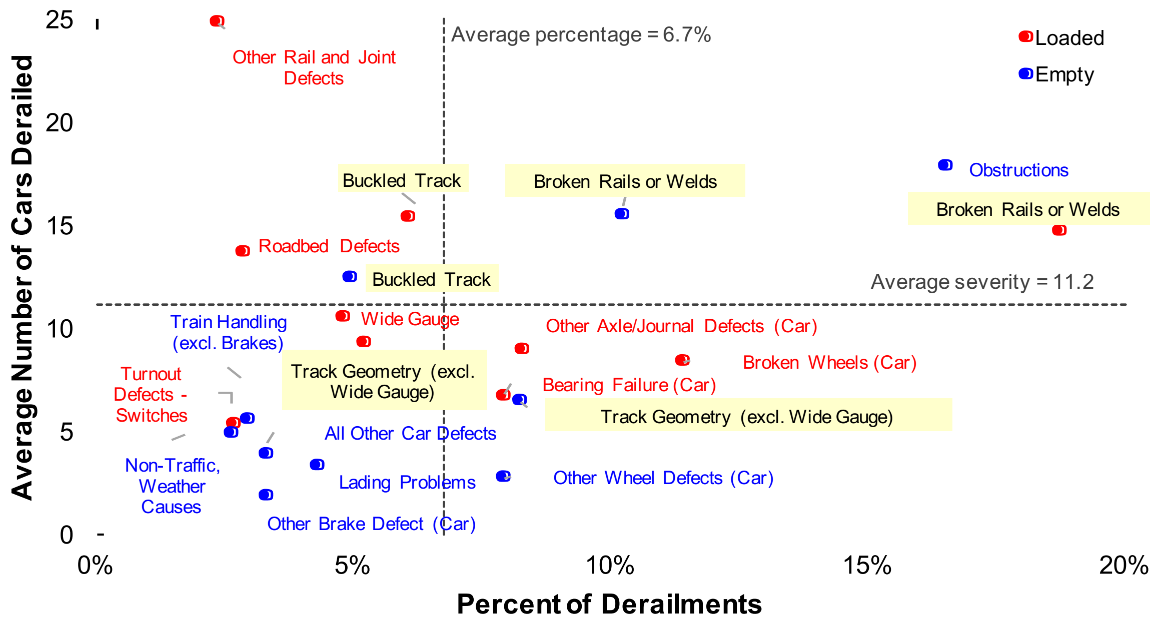


FIGURE 5 Frequency in Percentage vs. Severity of Derailments, Two Loading Conditions Combined, U.S. Class I Mainlines and Sidings, 2001-2015

To understand the top causes for loaded and empty unit trains, broken rails or welds caused loaded unit train derailments and obstruction caused empty unit train derailments were further broken down to more detailed FRA causes. As reflected in Table 3, the broken rails tended to fail due to detail fracture from shelling or head check and transverse/compound fissure, while most obstructions were resulted from extreme wind velocity and snow, ice, mud, etc. on track. Tornado was the most severe cause in this table, derailing 52 cars on average.

TABLE 3 Breakdown of the Top Causes for Loaded and Empty Unit Trains
Frequency and Severity of Broken Rails or Welds Caused Loaded Trains Derailments

Rank	FRA Cause	Number of derailments	Percentage	Average Number of Cars Derailed
1	Broken Rail - Detail fracture from shelling or head check	95	33.0%	16.4
1	Broken Rail - Transverse/compound fissure	95	33.0%	14.2
3	Broken Rail - Vertical split head	28	9.7%	12.1
4	Broken Rail (field)	24	8.3%	15.9
5	Broken Rail - Head and web separation (outside joint bar limits)	21	7.3%	10.1
6	Broken Rail - Base	14	4.9%	17.3
7	Broken Rail - Engine burn fracture	4	1.4%	13.8
8	Broken Rail - Horizontal split head	4	1.4%	14.3
9	Broken Rail - Piped rail	2	0.7%	9.5
10	Broken Rail - Weld (plant)	1	0.3%	23.0

Frequency and Severity of Obstruction-Caused Empty Trains Derailments

Rank	FRA Cause	Number of derailments	Percentage	Average Number of Cars Derailed
1	Extreme environmental condition - Extreme wind velocity	27	54.0%	19.9
2	Snow, ice, mud, gravel, coal, sand, etc. on track	11	22.0%	3.0
3	Extreme environmental condition - Tornado	5	10.0%	52.0
4	Object or equipment on or fouling track (other than above)	4	8.0%	6.3
5	Extreme environmental condition - Flood	2	4.0%	10.0
6	Other extreme environmental conditions	1	2.0%	15.0

Top Ten Causes on Mainline versus Siding Track

Since the data used in this study include derailments on both mainline and siding track, another question is whether these two types of track differ. For instance, sidings might be expected to have more switch related derailments. For loaded unit train derailments, there were 1,426 incidents on mainline track and 110 incidents on siding track. Because the number of empty unit train derailments was limited, the effect of mainline versus siding track was investigated using only loaded unit train derailments.

TABLE 4 Top Ten Derailment Causes

Frequency and Severity of Loaded Trains on Mainline Track

Rank	ADL Cause Group	Number of Derailments	Percentage	Average Number of Cars Derailed
1	Broken Rails or Welds	262	18.4%	15.2
2	Broken Wheels (Car)	174	12.2%	8.3
3	Other Axle/Journal Defects (Car)	126	8.8%	8.9
4	Bearing Failure (Car)	121	8.5%	6.8
5	Buckled Track	90	6.3%	15.5
6	Track Geometry (excl. Wide Gauge)	72	5.0%	9.7
7	Wide Gauge	53	3.7%	11.6
8	Roadbed Defects	42	2.9%	13.9
9	Coupler Defects (Car)	36	2.5%	7.4
10	Other Rail and Joint Defects	34	2.4%	25.9

Frequency and Severity of Loaded Trains on Siding Track

Rank	ADL Cause Group	Number of Derailments	Percentage	Average Number of Cars Derailed
1	Broken Rails or Welds	26	23.6%	9.8
2	Wide Gauge	21	19.1%	7.8
3	Turnout Defects - Switches	12	10.9%	5.1
4	Track Geometry (excl. Wide Gauge)	8	7.3%	4.8
5	Switching Rules	6	5.5%	4.2
6	Use of Switches	4	3.6%	3.5
7	All Other Car Defects	3	2.7%	5.3
8	Buckled Track	3	2.7%	11.3
9	Joint Bar Defects	3	2.7%	7.7
10	Misc. Track and Structure Defects	2	1.8%	6.0

Table 4 shows the top ten derailment causes, ranked by number of derailments, for loaded trains on mainline and siding track. Three out of the top ten causes for derailments on siding track are switch related (Table 4). Broken rails or welds, wide gauge, track geometry excluding wide gauge, and buckled track were common for both mainline and siding track. Comparing the top ten causes for loaded train derailments on mainline track and those for derailments on both mainline and siding track from Table 2, the top ten causes are all the same except for cause number nine, which for mainline and siding track is coupler defects while for only mainline track it is turnout defects - switches. Mainline derailments accounted for about 93% of both mainline and siding derailments for loaded unit trains and about 91% for empty unit trains, meaning that eliminating the derailments on sidings changes the result minimally.

CONCLUSION

Derailments are the most common type of train accident in the United States, and unit trains transporting hazardous materials have received more attention in recent years. A fully loaded unit train is more than four times heavier than the same train when it is empty. Few studies have investigated the relationship between loading condition and derailments, mainly due to data constraints. In this study, a methodology was developed to classify loaded and empty unit trains using FRA REA data. The results suggest that loading condition influences derailment frequency, severity and cause. Over the fifteen-year period, the frequency of derailments in both loading conditions declined over 50% while the average derailment severity for both loading conditions fluctuated throughout the time.

Broken rails or welds and obstructions were the most common derailment causes for loaded and empty trains respectively, in terms of both frequency and severity. Some derailment causes appear on the top ten lists for both loading conditions, suggesting that risk mitigation strategies will most likely yield satisfactory results independent of the loading condition. While derailment causes on mainline and siding track have different compositions, over 90% of derailments on mainline and siding track occur on mainline track. Thus, including derailments on sidings changed the overall cause distribution minimally.

FUTURE WORK

The results presented in this paper indicate that there were approximately five times more loaded unit trains recorded in the FRA REA database than empty unit trains. This might indicate a difference in derailment rate; however, traffic data for the two loading conditions are not available. The next step would be to develop such data so that these rates can be calculated and compared. More generally, some derailment causes are more likely to be influenced by the mass of a rail vehicle, whether it is certain components on the railcar, or elements of the track structure it is traveling over. The causal breakdown of loaded versus empty trains should be further investigated to better understand these possible effects.

ACKNOWLEDGEMENTS

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