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Railroad Derailment Factors Affecting Hazardous Materials Transportation Risk

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U.S. freight railroad accident and hazardous materials release rates have declined substantially since 1980. Ironically, this trend has made the identification and implementation of further safety improvement options more challenging because less empirical information exists on which accident causes present the greatest risks. Consequently, more sophisticated methods are needed to identify the best options for transportation risk reduction. Of particular interest is identifying the principal causes of accidents that can result in a tank car release of hazardous materials, which can harm people, property, and the environment. Because large hazardous materials release accidents are relatively rare, railroads cannot effectively manage safety improvement efforts solely in response to the causes of specific accidents. Instead, a risk-based approach is needed to better understand predictive factors for conditions that can cause a release. Railroad derailment data were analyzed to identify the conditions most likely to lead to a release accident. The objective was to identify proxy variables that can be used as performance measures. The speed of derailment and number of derailed cars highly correlated with hazardous materials releases. Some accident causes are much more likely to lead to release conditions than others. Accident prevention efforts to reduce these causes are more likely to reduce the risk of major railroad hazardous materials release accidents.

The U.S. railroad mainline accident rate has declined by more than 75% since 1980 (Figure 1). The rate of releases caused by hazardous materials accidents has declined by nearly 90% (*1–3*). The improvements are the result of major capital investments in infrastructure and equipment, improved safety design of tank cars, employee training, and development and implementation of new technology (*4, 5*). Most safety improvements occurred in the 1980s. Although the downward trend in the mainline accident rate continued through the 1990s, albeit at a low rate, it has leveled off in recent years (Figure 1). Major accident-caused hazardous materials releases have declined to such an extent that identifying and implementing further safety improvements have become more challenging because less empirical information exists on the causes contributing to the greatest risks.

The principal objectives of this analysis were as follows:

- Present examples in which finer-grained analysis of the data reveals more precise information for hazardous materials risk analysis,
- Provide new or up-to-date statistics on parameters of importance in calculating risk,
- Introduce new parametric relationships that can serve as proxy variables for railroad risk management and risk reduction performance measurements,
- Introduce new graphical techniques for identifying causes with the greatest risks, and
- Present preliminary results on the importance of these causes.

TRAIN ACCIDENT AND HAZARDOUS MATERIALS RELEASE DATA AND ANALYSIS

FRA requires railroads to submit detailed reports using the Rail Equipment Accident or Incident Report Form (FRA F 6180.54) on all accidents that exceed a specified monetary threshold for damage to roadbed, track, track structures, signals, and equipment (*3*). The threshold level is periodically adjusted for inflation, and has increased from $6,300 in 1992 to $6,700 in 2002. This amount is relatively low when considering the value of the railroad property damaged in accidents; consequently, most accidents of significance are reported. FRA compiles these reports into the Rail Equipment Accident Database and publishes an annual report containing a variety of summary statistics (*3*). The database is available at the FRA Office of Safety website (*6*). The analyses described herein are based primarily on data downloaded from the website for the period 1992–2001 or published in FRA annual reports for various years (*3*).

Mainline Railroad Accident Rate on Large and Small Railroads

Although statistics viewed at an aggregated industry level are useful in monitoring high-level trends, more detailed analyses can reveal additional information needed for risk analysis and management purposes (*3*). For example, most hazardous materials traffic is on Class I railroad mainline trackage. Over the period 1997–2001, Class I railroads (gross revenues > $261.8 million) averaged 1.40 mainline accidents per million train miles, compared with Class II and III railroads (gross revenues ≤ $261.8 million) that averaged 6.09 mainline accidents (Figure 1). Use of an industry average accident rate masks the potential differences in risk.

The reason for the difference in accident rate is not fully understood but may be related to a difference in average track quality. FRA specifies minimum standards for numerous railroad track parameters, depending on the maximum speed of operation for a specific track (*7*). FRA categorizes track used for freight trains into classes ranging from Class 1 through Class 6, with higher track classes required for higher-speed operation. The engineering standards for higher-track classes are correspondingly more stringent. Although FRA standards are not intended to completely specify the engineering design

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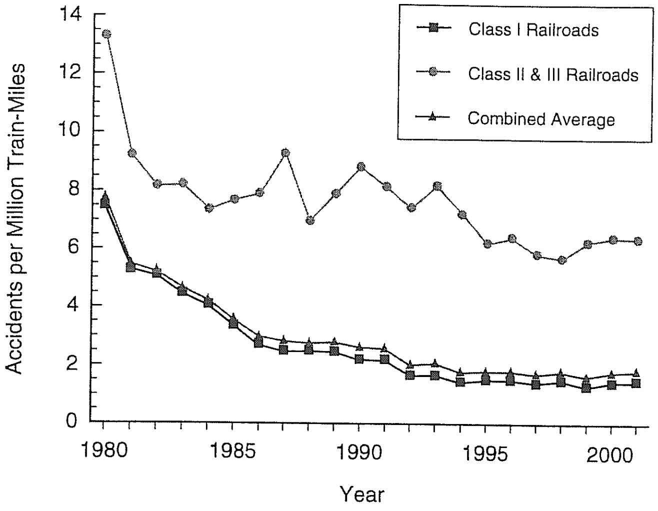

FIGURE 1 Mainline freight railroad accident rate, 1980–2001.

and maintenance characteristics of track, several earlier studies have shown an inverse correlation between FRA track class and derailment rate [*8, 9;* Association of American Railroads (AAR), unpublished data]. Much of the mainline trackage for Class I railroads is FRA Class 4 or above, whereas mainline trackage for Class II and III railroads is generally Class 3 or lower. Consequently, it is not surprising that the average derailment rate of Class I railroads is lower than for Classes II and III. The most recent data on track-class–specific derailment rate are more than a decade old. More up-to-date analyses of track-class–specific derailment rates are needed to better understand the risk of transporting hazardous materials on different track classes.

Hazardous Materials Railcar Release Rates for Large and Small Railroads in Mainline and Yard Derailments

Railroads are allowed to operate at greater speeds on higher FRA track classes, and the probability of derailment for these classes is lower. However, more energy is involved in accidents at higher speeds and thus hazardous materials railcars may be subjected to greater forces. Because Class I railroads generally operate on higher-class track, they can be expected to operate at higher average speeds and experience a higher release rate than Class II and III railroads. For the three railroad classes, mainline derailments generally occur at higher speeds than yard derailments, thereby suggesting a higher release rate in mainline accidents. A Wilcoxon rank-sum test was conducted on FRA data to compare the average percentage of derailed or damaged hazardous materials cars that released in mainline and yard derailments on Class I versus Class II and III railroads for the period 1992–2001 (Table 1) (*10*). No significant difference was found between large and small railroads in either mainline or yard derailment release rate (mainline, $P = 0.229$; yard, $P = 0.220$). However, a significantly higher release rate was found for mainline versus yard derailments for both large and small railroads (Class I, $P < 0.001$; Classes II and III, $P < 0.01$).

MAINLINE ACCIDENTS

Accident Parameters and Hazardous Materials Derailments

In efforts to avoid serious hazardous materials release accidents, the focus has been properly directed toward mainline accidents, which involve more cars, higher release probabilities, and larger releases because of more substantial damage to the railcar. The FRA database enables further analysis of the first two of these relationships but not the latter. Several derailment parameters were examined to determine their general relationship with hazardous materials accidents (Table 2). FRA groups the data into three categories according to whether the hazardous materials on a train involved in an accident are (*a*) in the train consist, (*b*) in damaged or derailed cars, or (*c*) are released.

The FRA data were examined for relationships among the three hazardous materials situations and other measures of accident severity (Table 2). Several variables appear to be related to the hazardous materials releases, including the average speed of derailment, average number of cars derailed, and average monetary damage. Each of these variables was further investigated to determine its ability to predict the likelihood of a hazardous materials release accident.

Monetary damage is often used to assess the severity of railroad accidents. Although Table 2 indicates that damage appears to be correlated with hazardous materials releases, it was decided that monetary damage was unsatisfactory as a predictive metric for release probability in this analysis. Monetary damage is subject to many variables, such as the difference in cost between locomotives and freight cars and the difference in repairing regular track versus special track work such as turnouts and crossings. Variations in any or all of these factors contribute to a wide range of values for monetary damage. However, this variability is unrelated to the physical forces that cause damage to railcars and the resultant hazardous materials releases.

TABLE 1 Hazardous Materials Release Rates in Mainline and Yard Derailments: 1992–2001

		Hazardous Materials Derailments*	Average Proportion of Hazardous Materials Cars That Released†
Class I Railroads	Mainline	676	0.107
	Yard	405	0.039
Class II & III Railroads	Mainline	194	0.104
	Yard	60	0.020

* Number of derailments in which at least one hazardous materials car was damaged or derailed

† Average proportion of damaged or derailed hazardous materials cars that released

TABLE 2 Average Train Length, Speed, Number of Cars of All Types Derailed, and Cost of Derailments with Hazardous Materials in the Consist, 1992–2001 (±2 Standard Errors, Categories Mutually Exclusive)

	Hazardous Materials Cars Not Derailed	Hazardous Materials Cars Derailed but Not Released	Hazardous Materials Cars Released
Number of Accidents	962	674	165
Average Train Length	82.1±16.0	76.3±17.4	80.8±17.1
Average Speed (mph)	24.9±1.0	26.6±1.2	34.7±2.37
Average Number of Cars Derailed	6.1±2.3	10.4±3.2	17.6±3.9
Average Damage	$228,391±1,136	$326,211±1,293	$836,148±2,237

Railcars in accidents are subject to forces from impacts by other rail vehicles, track, and wayside structures. A direct physical relationship between derailment speed and these parameters is expected because the kinetic energy of the train increases with speed. This energy is dissipated by derailed railcars and locomotive impacts with track structures, wayside objects, and other rail vehicles. These parameters have a direct physical basis for affecting railcar release probability and are a focus of this analysis.

Regression Analyses

Three regression analyses were conducted on FRA accident data for 839 mainline freight derailments in which at least one hazardous materials car was damaged or derailed over the period 1992–2001. The data for each independent variable were combined into bins, and an average for each bin was calculated and compared with the corresponding dependent variable. In each analysis, a linear regression was performed and its significance tested (*11*).

Speed and Number of Cars Derailed

A significant linear relationship was found between derailment speed and average number of cars derailed: $y = 0.282x + 3.928$, $R^2 = 0.962$, df = 9, $P < 0.01$ (Figure 2). This result is not surprising and is consistent with the premise that derailment forces increase with speed. Besides providing insight on this aspect of accident severity, the result also quantifies the relationship. If data on the distribution of operating speeds are available, the equation can be used with other data, such as train length and derailment probability, to compute weighting factors for the probability that a particular car or cars will be involved in a derailment.

Speed and Hazardous Materials Release Probability

The same positive relationship between accident energy and speed is also expected to affect hazardous materials car release probability. Tank cars are built to various specifications, which often affect the probability of hazardous materials release in accidents (*4, 12*). Packaging requirements for hazardous materials are specified by the U.S. Department of Transportation and AAR and are determined by the physical and chemical characteristics of the freight that cars transport (e.g., gases, liquids, pressurized materials, corrosive materials). The damage-resistant design requirements for tank cars are as important as the hazard posed by the product. Design-specific estimates of the relationship between speed and release require data on the accident frequency of different types of tank cars and their performance in these accidents (which is beyond the scope of this analysis). The data analyzed herein represent the average performance of all hazardous materials cars combined. The average percentage of hazardous materials cars releasing hazardous materials was compared with accident speed, for cases with at least one hazardous materials car derailed or damaged (Figure 3). A significant linear relationship was found between speed and release probability: $y = 0.0029x + 0.0243$, $R^2 = 0.702$, df = 9, $P < 0.01$.

Previous analyses of data on speed and hazardous materials release probability found that a third-order polynomial equation provided a significantly better fit than a linear equation (*13;* AAR, unpublished data). However, that result could not be replicated in this analysis

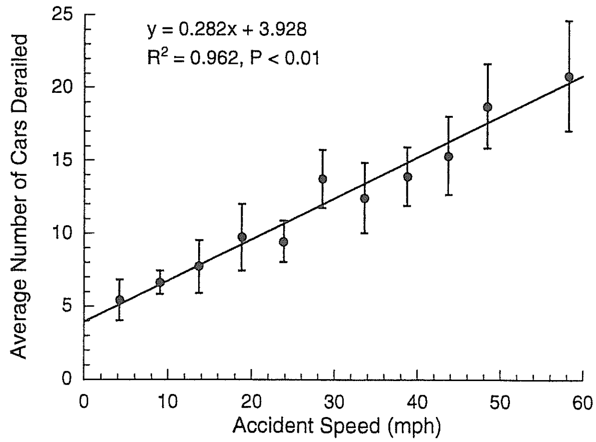

FIGURE 2 Relationship between accident speed and average number of cars derailed in mainline freight derailments (with at least one hazardous materials car derailed) reported to FRA, 1992–2001.

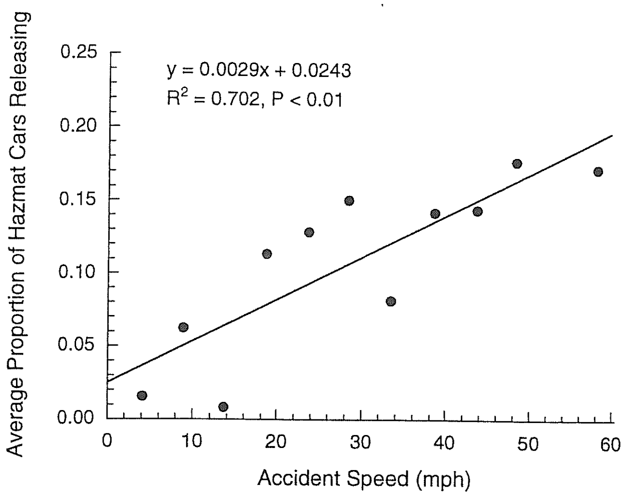

FIGURE 3 Relationship between the average proportion of derailed cars with hazardous materials release (at least one such incident) and accident speed in mainline freight derailments, 1992–2001.

using data for the period 1992–2001. This finding could be related to the reduced exposure of hazardous materials cars to speeds above 50 mph over the past decade. In the early 1990s, the AAR member railroads established a recommended practice for a speed limit of 50 mph for "key" trains, which were defined as trains having more than a specified number of hazardous materials tank cars in the consist (*14*). Although this practice does not apply to all hazardous materials tank cars, presumably it has reduced their overall exposure to speeds above 50 mph.

Predictive Metric for Hazardous Materials Release Accidents

Lower accident rates have made the identification of critical causal factors more challenging. Relying on direct analysis of the few serious accidents provides relatively little data. And in view of the large number of potential accident causes, the robustness of conclusions becomes even more questionable. The severity of a particular hazardous materials accident is likely to relate more to the particular circumstances and location of the release than the underlying accident cause.

An alternative approach is to use data on hazardous materials releases to identify a metric that highly correlates with hazardous materials releases. Ideally, such a metric would have a plausible causal relationship with hazardous materials releases and be measurable in most or all accidents. Identifying such a metric would enable more robust analysis of accident causes that likely lead to hazardous materials releases (*13, 15*).

Cars Derailed and Hazardous Materials Release Probability

A promising candidate for such a metric is a variable recorded in the FRA database on the total number of cars of all types that derail in an accident. The number of derailed cars appears to be a good metric for the amount of energy in an accident. Consequently, this factor should also be a good predictor of the forces to which a hazardous materials car is likely to be subjected. To test this idea, the average percentage of hazardous materials cars releasing was compared with the number of cars derailed in that accident, in cases with at least one hazardous materials car derailed or damaged (Figure 4). The analysis showed a significant, linear relationship: $y = 0.0047x + 0.0547$, $R^2 = 0.721$, $\text{df} = 6$, $P < 0.01$.

The relationship between the occurrence of hazardous materials releases and derailment severity as measured by number of cars derailed is also evident if the data are plotted using a normalized cumulative distribution for accidents in which derailed hazardous materials cars did or did not release (Figure 5). This graphic approach is similar to the F/N curves often used in risk analysis (*9, 16*). Severity is measured on the abscissa by the number of cars derailed in accidents, X. The percentage of occurrences greater than the corresponding value of X is plotted on the ordinate. For example, 50% of the accidents in which hazardous materials cars derailed but did not release involved derailments of more than seven cars, whereas 50% of the accidents in which hazardous materials did release involved 14 or more cars. It is evident that accidents with hazardous materials release tend to involve more cars (and presumably more energy) than accidents in which hazardous materials cars derail but do not release.

The finding that the number of derailed cars apparently is a good predictor of the conditions for a hazardous materials release is encouraging for both risk analysis and risk management. The number of derailed cars is a variable recorded in virtually every accident reported to FRA, so abundant data are available. Different factors introduce variance into the outcome of particular accidents; notably, where the derailment begins in the train consist relative to where the hazardous materials cars are located. However, because of the abundant data, results from these analyses should be robust relative to the most important risk factors. These results also may be promising as a performance measure for railroads trying to prioritize derailment prevention and risk management in relation to the greatest risks.

Derailment Severity and Frequency Analysis

A more detailed investigation was conducted of the potential value of the number of derailed cars variable as a proxy variable for conditions

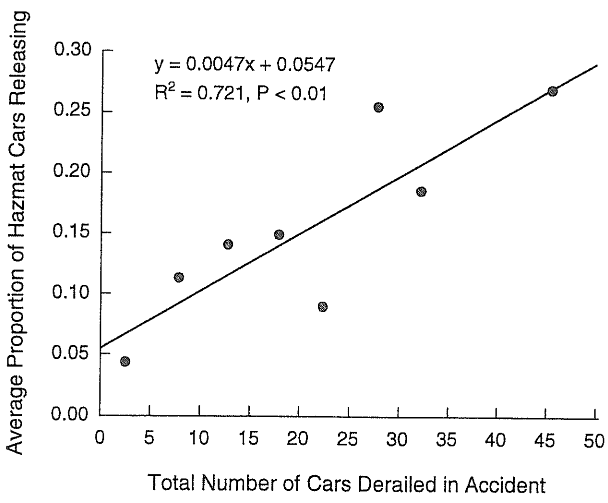

FIGURE 4 Relationship between the average proportion of derailed cars with hazardous materials releases (at least one such incident) and total number of cars derailed in mainline freight derailments, 1992–2001.

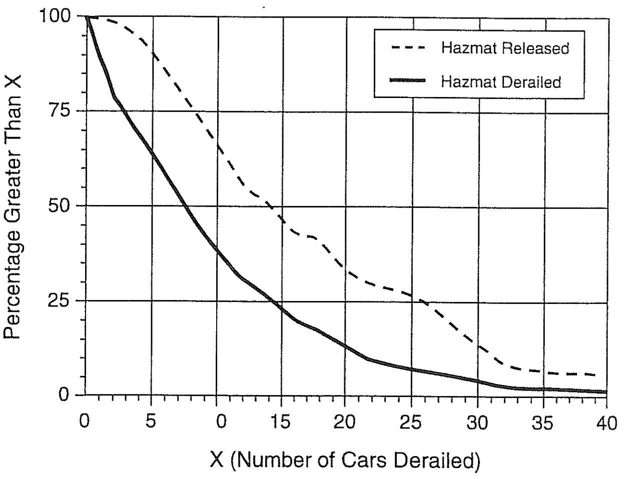

FIGURE 5 Negative cumulative distribution of the total number of hazardous materials cars derailed with no releases compared with derailment accidents with releases.

that predict hazardous materials release accidents. The FRA reporting system requires the identification of a primary cause (and other contributing causes if applicable) (*6*). These causes are hierarchically organized, ranging from aggregated major cause groups to specific cause codes. FRA categorizes accidents into six major cause groups—track, equipment, human factors, signal, miscellaneous, and highway or rail. Data were analyzed for the first five groups. The last group was excluded because it represents a different set of accident processes that were not the intended focus of this research. In each major group, individual causes were assigned a three-digit numeric code that provides further resolution of the exact cause or causes of an accident (e.g., distinguishing between several different types of rail defect causes for broken rails.) The focus was on accident causes that most often cause severe derailments as measured by number of cars derailed.

FRA cause codes were used to categorize each of 5,716 mainline freight derailments during the 10-year study period. The three-digit cause codes were grouped according to a system sometimes used by AAR that is similar to the FRA's subcause grouping but allows greater resolution of certain causes. For example, at the FRA subcause level, broken rail, welds, joint bars, and rail anchors are combined, whereas the system in this analysis distinguishes broken rails from joint bars. After the accidents were grouped, a graphical technique was used to present the FRA accident data to help identify and quantify accident causes most likely to lead to a hazardous materials release.

Two statistics were developed for each of the modified cause groups—number of accidents for each cause (frequency) and average number of cars derailed (severity) in accidents attributed to the cause (Tables 3–5). These statistics were plotted against one another, with frequency on the abscissa and severity on the ordinate (Figure 6). This technique enabled easy comparison of the relative frequency and severity of different causes.

The graph in Figure 6 is divided into four quadrants on the basis of the average along each axis. These averages are denoted by the vertical and horizontal lines on the graph. The vertical line represents the average frequency of accidents for all recorded causes combined (112.1), and the horizontal line is the average number of cars derailed due to all causes (7.8). Causes above or below these lines are, by definition, above or below average for the respective axis.

The four quadrants in Figure 6 are of different interest. The causes in the lower left quadrant are least interesting because they are uncommon, low-consequence events. The causes in the upper left quadrant occur infrequently but are above average in severity, which makes them interesting. However, their low frequency means that it is more difficult to predict how consistently these causes will lead to events with significant consequences. It also means that sufficient data to isolate contributing factors may be difficult to develop. The causes in the lower right are also of secondary interest. Although on average, their severity is lower, their high frequency makes them a source of some concern. The causes in the upper right quadrant are the ones most likely to pose the greatest risk because they are both more frequent and more severe than average and include

- Broken rails or welds,
- Buckled track,
- Improper train handling (excluding use of brakes),
- Broken wheels, and
- Other miscellaneous.

These five causes are candidates for closer scrutiny in research and potential use of resources to reduce their occurrence. The other miscellaneous cause may sometimes be used as a placeholder category for certain serious accidents being investigated. If so, some accidents should be assigned to another cause when the investigation is completed.

Although all of these causes are above average as far as the number of cars derailed, speed affects hazardous materials release probability as well. The data presented in Figure 6 are for all speeds combined. To investigate the speed effect, data on the 5,716 accidents were divided into two groups—those occurring below 25 mph (3,367 accidents) and those at 25 mph and above (2,349 accidents) (Figure 7). Note that the scales have changed, reflecting the smaller group of accidents in each speed group.

In comparing the lower-speed with the higher-speed accidents, the average number of cars derailed increases, from an average of 5.6 cars to 11.2 cars. Certain causes change in characteristic ways. Broken rails or welds, buckled track, and other miscellaneous causes all maintain their relative frequency but double in severity in the higher-speed grouping. Other track causes—track geometry and wide gage—do not change much in severity but substantially decline in relative frequency because they are primarily accidents associated with low-speed trackage. Accidents caused by improper train handling also become relatively less common at higher speed, although their severity increases somewhat. Two equipment causes—bearing failure and, to a lesser extent, wheel failures—are considerably more frequent at higher speed. This finding is not surprising—these components are subjected to greater stresses as speeds increase and are more likely to reach critical failure levels.

What is more surprising is that, although bearing-failure derailments relate to speed and are common, they are less severe than average. Broken rails, which are equally common, are much less forgiving, resulting in more than twice as many cars derailing on average than bearing failures. Although less common, the other rail-related failure causes (other rail and joint defects, rail defects at bolted joints, and joint bar defects) reveal a similar pattern.

Analysis of the frequency of cars derailed because of rail versus bearing failure is insightful (Figure 8). The distributions for the two accident causes are completely different, irrespective of the derailment speed. Both the median and mode for the number of cars derailed because of bearing failure is one, and more than half of the bearing-

TABLE 3 Frequency and Severity (Average Number of Cars Derailed) of Mainline Accidents, 1992–2001, Sorted by Cause Group

Cause Group	Description	Frequency	Severity
01T	Roadbed Defects	130	7.0
02T	Non-Traffic, Weather Causes	55	7.0
03T	Wide Gage	353	7.8
04T	Track Geometry (excl. Wide Gage)	531	5.8
05T	Buckled Track	254	10.2
06T	Rail Defects at Bolted Joint	50	15.5
07T	Joint Bar Defects	68	15.2
08T	Broken Rails or Welds	800	12.7
09T	Other Rail and Joint Defects	79	15.1
10T	Turnout Defects - Switches	179	6.6
11T	Turnout Defects - Frogs	13	14.0
12T	Misc. Track and Structure Defects	110	8.7
01S	Signal Failures	20	10.7
01E	Air Hose Defect (Car)	17	7.0
02E	Brake Rigging Defect (Car)	31	4.7
03E	Handbrake Defects (Car)	2	2.0
04E	UDE (Car or Loco)	12	11.0
05E	Other Brake Defect (Car)	30	5.2
06E	Centerplate/Carbody Defects (Car)	105	4.6
07E	Coupler Defects (Car)	98	6.6
08E	Truck Structure Defects (Car)	17	7.5
09E	Sidebearing, Suspension Defects (Car)	131	6.1
10E	Bearing Failure (Car)	455	6.2
11E	Other Axle/Journal Defects (Car)	62	6.4
12E	Broken Wheels (Car)	175	8.0
13E	Other Wheel Defects (Car)	169	6.3
14E	TOFC/COFC Defects	6	2.5
15E	Loco Trucks/Bearings/Wheels	19	8.9
16E	Loco Electrical and Fires	8	20.0
17E	All Other Locomotive Defects	19	6.7
18E	All Other Car Defects	55	7.7
19E	Stiff Truck (Car)	96	7.9
20E	Track/Train Interaction (Hunting) (Car)	58	8.5
01H	Brake Operation (Main Line)	63	9.5
02H	Handbrake Operations	26	4.9
03H	Brake Operations (Other)	20	8.7
05H	Failure to Obey/Display Signals	16	5.8
06H	Radio Communications Error	10	6.1
07H	Switching Rules	42	5.8
08H	Mainline Rules	16	9.4
09H	Train Handling (excl. Brakes)	288	8.5
10H	Train Speed	76	6.2
11H	Use of Switches	139	4.9
12H	Misc. Human Factors	49	9.4
01M	Obstructions	92	12.2
03M	Lading Problems	162	7.0
04M	Track-Train Interaction	221	6.4
05M	Other Miscellaneous	289	10.9
	Total	5,716	
	Average	112.1	7.8

NOTES: UDE = undesired emergency (brake application); TOFC = trailer on flatcar; COFC = container on flatcar; Loco = locomotive.

TABLE 4 Frequency and Severity (Average Number of Cars Derailed) of Mainline Accidents, 1992–2001, Sorted by Frequency

Cause Group	Description	Frequency	Severity
08T	Broken Rails or Welds	800	12.7
04T	Track Geometry (excl. Wide Gage)	531	5.8
10E	Bearing Failure (Car)	455	6.2
03T	Wide Gage	353	7.8
05M	Other Miscellaneous	289	10.9
09H	Train Handling (excl. Brakes)	288	8.5
05T	Buckled Track	254	10.2
04M	Track-Train Interaction	221	6.4
10T	Turnout Defects - Switches	179	6.6
12E	Broken Wheels (Car)	175	8.0
13E	Other Wheel Defects (Car)	169	6.3
03M	Lading Problems	162	7.0
11H	Use of Switches	139	4.9
09E	Sidebearing, Suspension Defects (Car)	131	6.1
01T	Roadbed Defects	130	7.0
12T	Misc. Track and Structure Defects	110	8.7
06E	Centerplate/Carbody Defects (Car)	105	4.6
07E	Coupler Defects (Car)	98	6.6
19E	Stiff Truck (Car)	96	7.9
01M	Obstructions	92	12.2
09T	Other Rail and Joint Defects	79	15.1
10H	Train Speed	76	6.2
07T	Joint Bar Defects	68	15.2
01H	Brake Operation (Main Line)	63	9.5
11E	Other Axle/Journal Defects (Car)	62	6.4
20E	Track/Train Interaction (Hunting) (Car)	58	8.5
02T	Non-Traffic, Weather Causes	55	7.0
18E	All Other Car Defects	55	7.7
06T	Rail Defects at Bolted Joint	50	15.5
12H	Misc. Human Factors	49	9.4
07H	Switching Rules	42	5.8
02E	Brake Rigging Defect (Car)	31	4.7
05E	Other Brake Defect (Car)	30	5.2
02H	Handbrake Operations	26	4.9
01S	Signal Failures	20	10.7
03H	Brake Operations (Other)	20	8.7
15E	Loco Trucks/Bearings/Wheels	19	8.9
17E	All Other Locomotive Defects	19	6.7
01E	Air Hose Defect (Car)	17	7.0
08E	Truck Structure Defects (Car)	17	7.5
05H	Failure to Obey/Display Signals	16	5.8
08H	Mainline Rules	16	9.4
11T	Turnout Defects - Frogs	13	14.0
04E	UDE (Car or Loco)	12	11.0
06H	Radio Communications Error	10	6.1
16E	Loco Electrical and Fires	8	20.0
14E	TOFC/COFC Defects	6	2.5
03E	Handbrake Defects (Car)	2	2.0
	Total	5,716	
	Average	112.1	7.8

TABLE 5 Frequency and Severity (Average Number of Cars Derailed) of Mainline Accidents, 1992–2001, Sorted by Severity

Cause Group	Description	Frequency	Severity
16E	Loco Electrical and Fires	8	20.0
06T	Rail Defects at Bolted Joint	50	15.5
07T	Joint Bar Defects	68	15.2
09T	Other Rail and Joint Defects	79	15.1
11T	Turnout Defects - Frogs	13	14.0
08T	Broken Rails or Welds	800	12.7
01M	Obstructions	92	12.2
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03M	Lading Problems	162	7.0
01T	Roadbed Defects	130	7.0
02T	Non-Traffic, Weather Causes	55	7.0
01E	Air Hose Defect (Car)	17	7.0
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10T	Turnout Defects - Switches	179	6.6
07E	Coupler Defects (Car)	98	6.6
04M	Track-Train Interaction	221	6.4
11E	Other Axle/Journal Defects (Car)	62	6.4
13E	Other Wheel Defects (Car)	169	6.3
10E	Bearing Failure (Car)	455	6.2
10H	Train Speed	76	6.2
09E	Sidebearing, Suspension Defects (Car)	131	6.1
06H	Radio Communications Error	10	6.1
04T	Track Geometry (excl. Wide Gage)	531	5.8
07H	Switching Rules	42	5.8
05H	Failure to Obey/Display Signals	16	5.8
05E	Other Brake Defect (Car)	30	5.2
11H	Use of Switches	139	4.9
02H	Handbrake Operations	26	4.9
02E	Brake Rigging Defect (Car)	31	4.7
06E	Centerplate/Carbody Defects (Car)	105	4.6
14E	TOFC/COFC Defects	6	2.5
03E	Handbrake Defects (Car)	2	2.0
	Total	5,716	
	Average	112.1	7.8

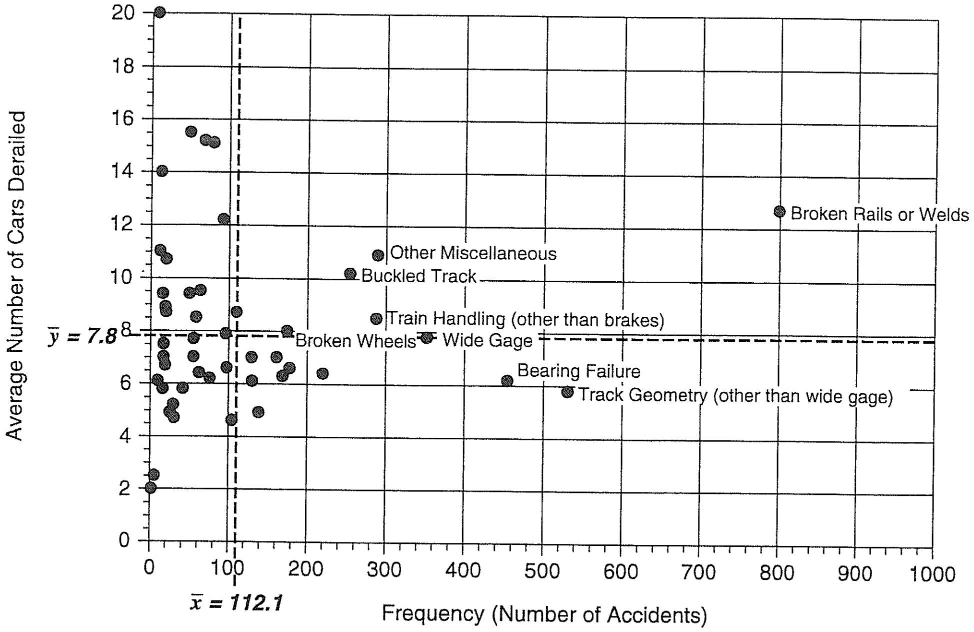

FIGURE 6 Frequency and severity graph of mainline accidents: 1992–2001 (dashed lines indicate average value along each axis).

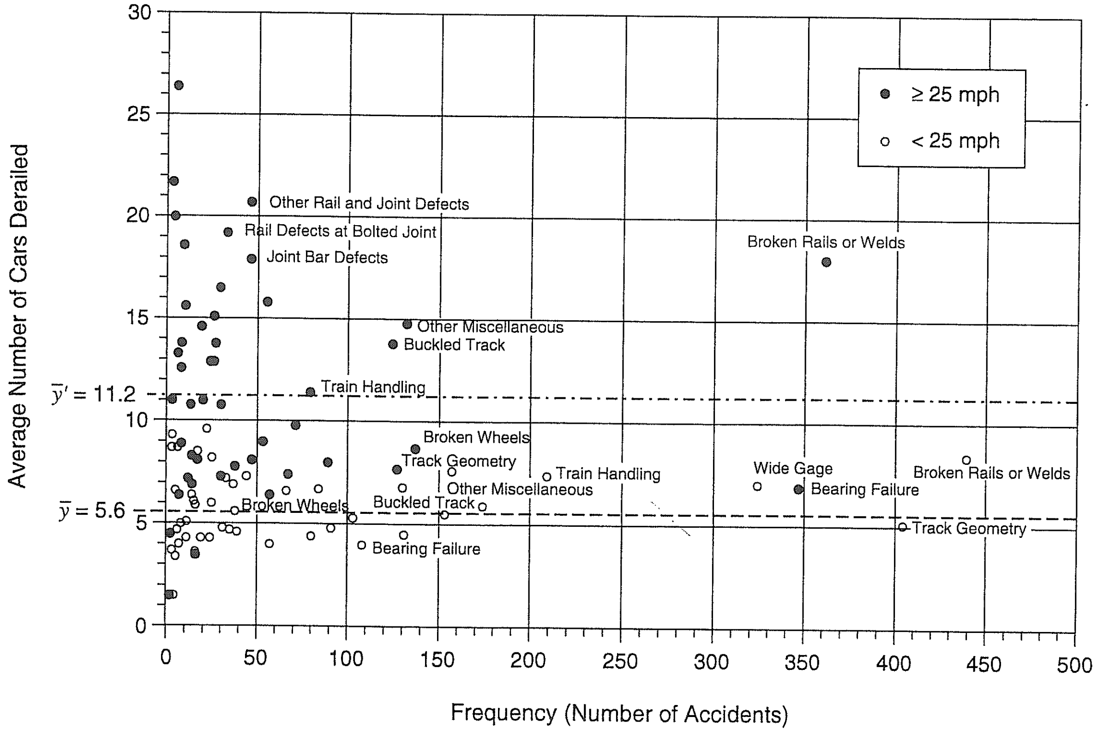

FIGURE 7 Frequency and severity graph of mainline accidents above and below 25 mph, 1992–2001 (dashed lines marked 11.2 and 5.6 indicate average severity of accidents ≥ 25 mph and < 25 mph, respectively).

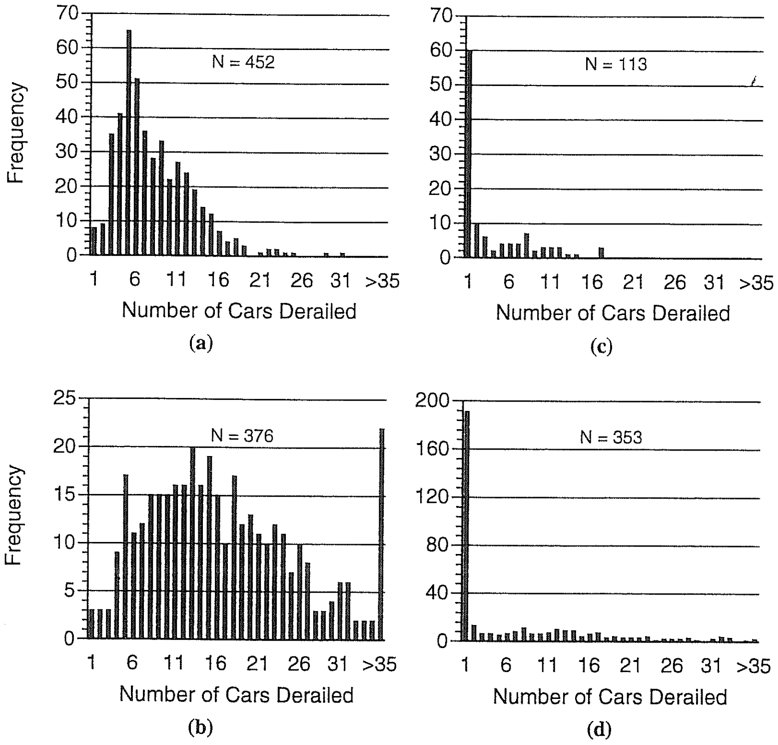

FIGURE 8 Frequency distribution of number of derailed cars in accidents from broken rails at speeds (*a*) < 25 mph and (*b*) ≥ 25 mph; from bearing defects at speeds (*c*) < 25 mph and (*d*) ≥ 25 mph (different scales shown on *y* axis).

caused derailments result in only one car derailment. By contrast, for broken rails the median value is nine and a half cars derailed and the mode is five. Also, unlike bearing failures, the distribution of broken rail derailments shifts upward in higher-speed derailments.

Hazardous materials releases generally do not occur because the car in which they were being transported caused a derailment. More often, the hazardous materials car is the victim of a derailment initiated by a failed bearing or a broken rail, for example. The hazardous materials car is typically damaged in the resultant pileup because of impacts with the track or other structure, another rail vehicle stopped ahead, or the following car. The different characteristics of derailments from broken rails versus bearing failures are revealing. A hazardous materials car is more likely to be involved in a derailment because of a broken rail rather than a bearing failure, even if both occur at high speed. Further, the forces to which a hazardous materials car is subjected are likely to be much greater because of the large number of cars involved.

CONCLUSIONS

The low frequency of serious railroad hazardous materials accidents increases the difficulty of knowing the most effective steps to improve safety. Consequently, more sophisticated methods such as risk analysis are needed to identify the most effective options. Railroads cannot efficiently manage their safety improvement efforts by responding only to the causes of specific hazardous materials accidents. Many possible options exist for investing safety resources. Identifying proxy variables predictive of circumstances most likely to lead to a hazardous materials release accident can help railroads manage safety improvements more effectively.

The speed and number of cars derailed significantly relate to hazardous materials release probability. Because these variables are recorded in most accidents, they appear to be good candidates as proxy variables to measure performance and assess accident prevention options. Certain accident causes appear to be much more likely than others to create accident conditions that cause hazardous materials to be released. Preventive efforts focused on reducing these causes are thus much more likely to reduce the risk of major railroad hazardous materials release accidents (*15*).

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