Analysis of Derailments by Accident Cause

Evaluating Railroad Track Upgrades to Reduce Transportation Risk

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The risk of train derailment associated with rail transportation is an ongoing concern for the rail industry, government, and the public. Various approaches have been considered or adopted to analyze, manage, and reduce risk. Upgrading track quality has been identified as one possible strategy for preventing derailment. The quality of freight railroad track is commonly divided into five principal classes by FRA on the basis of track structure, track geometry, and inspection frequency and method. The higher the track class, the more stringent are the track safety standards and thus a higher maximum train speed is allowed. Upgrading track class is likely to prevent certain track-related derailments; however, this upgrade may also increase the risk of certain types of equipment failure that are more likely to occur at higher speeds. Consequently, more sophisticated approaches need to be developed to examine the interactions among accident causes that may be differently affected by upgrades to track infrastructure. This paper analyzes several critical parameters for predicting train derailment risk by using derailment statistics from the FRA accident database and related literature. A general method was developed to assess derailment risk by accident cause and FRA track class. The safety benefits of track class upgrade in reducing the risks from certain accident causes were quantitatively evaluated. The model can be extended by incorporating additional risk factors to more accurately assess the effectiveness of various derailment prevention efforts for reducing transportation risk.

Train derailments are the most common type of main-line railroad accident in the United States, causing property damage and service disruptions. Reducing derailment risk is an ongoing objective of the rail industry and government. Derailment risk analysis provides a scientific basis for evaluating various risk reduction options. It is concerned with derailment rate, which reflects the likelihood that a train is involved in a derailment, and the consequences of the derailment. FRA requires reporting and identification of specific accident cause(s) for all derailments that exceed a specified monetary damage threshold. The monetary threshold is periodically adjusted for inflation; in 2010, the reporting threshold was $9,200. Different accident causes may have different effects on derailment rate, derailment severity, and the corresponding risk for any given combination of infrastructure and operational conditions. Track-related and equipment-related accident causes collectively result in the majority of train derailments in the United States. Understanding how they may be affected by approaches to derailment prevention is useful for developing and evaluating cost-effective strategies to reduce railroad transportation risk. Upgrading track quality is one possible derailment prevention strategy. FRA divides track quality into five principal classes commonly used by freight railroads in accordance with FRA track safety standards. Higher track classes have correspondingly higher maximum train speeds and more stringent track safety standards (*1*).

Research has analyzed various safety and economic impacts of track class upgrade. Higher track classes are statistically correlated with lower derailment rates (*2–4*). Saat and Barkan developed an analytical model to compare the safety benefits of enhanced tank car safety design versus infrastructure improvement (*5*). Lai et al. developed an optimization framework to determine optimal track class assignment based on the minimization of track maintenance and transportation costs (*6*). Liu et al. presented a benefit–cost analysis framework to consider the trade-off between reduced accident rates and increased track maintenance costs in evaluating track class upgrade as a risk reduction strategy (*7*). Kawprasert proposed a biobjective model that simultaneously considers risk and investment costs in determining the best track infrastructure upgrade strategy (*8*). However, none of these investigations addressed how track class upgrade affects the risk pertaining to certain accident causes. Although upgrading track class is expected to prevent certain track-related derailments, it may also increase the risks from certain types of equipment failure that are more likely to occur at higher speeds.

This study developed an accident cause–specific derailment risk model that simultaneously accounts for the interactions among different accident causes that may be differently affected by track class upgrade. The paper is structured as follows: a general framework for derailment risk analysis is introduced, followed by analyses and modeling of derailment rate, severity, and the corresponding risks. Finally, accident cause–specific derailment risk by FRA track class is estimated using derailment statistics from the FRA Accident/Incident Reporting System database and recent literature.

FRAMEWORK FOR DERAILMENT RISK ANALYSIS

Risk has been defined as the function of system failure and the severity of losses or damages from the system failure (*9*). In the context of railroad transportation, train derailment risk is defined as a product of derailment frequency and the average consequences of the derail-

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ment. Derailment frequency is a product of derailment rate and traffic exposure (*2, 10–13*). Equation 1 is a general framework for derailment risk analysis:

$$R = Z \times M \times D \tag{1}$$

where

R = derailment risk,
Z = derailment rate,
M = traffic exposure, and
D = average consequences of a derailment.

Other than traffic volume, the two probability terms of most importance are derailment rate and severity. Derailment rate is a critical metric to measure railroad transportation safety performance. It is defined as number of derailments normalized by some measure of traffic exposure, that is, gross ton-miles, car miles, or train miles. Derailment occurrence can be modeled as a Poisson process in which the Poisson parameter is numerically equal to derailment rate (*8, 14–16*). The probability of k derailments within a traffic interval M can be expressed as follows:

$$P\{N(M) = k\} = \frac{\exp(-ZM)(ZM)^k}{k!} \tag{2}$$

where

$P\{N(M) = k\}$ = probability of k derailments for traffic exposure M;
$N(M)$ = number of derailments for traffic exposure M;
k = 0, 1, 2, . . . ; and
Z = derailment rate (train derailments per billion car miles).

Consequently, the expected number of derailments within traffic level M can be estimated using Equation 3, which shows that predicted derailment frequency is a product of derailment rate and traffic exposure:

$$\begin{aligned} E[N(M)] &= \sum_k P[N(M) = k] \times k \\ &= \sum_k \left\{ \frac{\exp(-ZM)(ZM)^k}{k!} \right\} \times k \\ &= ZM \end{aligned} \tag{3}$$

Many factors demonstrate a correlation with derailment rates, including FRA track class (*2–4, 10*), type of track and railroad (*17*), train length (*18, 19*), track geometry (*20, 21*), and train control system (*22, 23*). Train accident rates in the United States have declined substantially since the early 1980s as a result of major capital investments in infrastructure and equipment, employee training, and implementation of new technologies (*17, 24*). Derailment severity also varies widely, depending on train speed, infrastructure conditions, and derailment cause. When risk analysis is concerned with the release of hazardous materials, the general risk model can be extended by adding a series of possible release consequences and associated probabilities.

The objective of this research was to analyze several critical factors that affect derailment risk analysis. The study focused on main-line derailments on Class I railroads (gross annual revenue in 2006 ≥ $346.8 million) using data from the FRA accident database from 1999 to 2008.

CAUSE-SPECIFIC DERAILMENT RATE

Higher track classes are statistically correlated with lower derailment rates (*2–4*). Anderson and Barkan used FRA safety statistics to develop the most recent published estimates of main-line freight train derailment rates for Class I railroads (Table 1) (*4*). Their estimates are used in this paper to account for the rates of all main-line derailments on Class I railroads. It was assumed for this study that the overall Class I main-line derailment rates did not change significantly during the study period. However, an approach that allows for varying future derailment rates could be developed for a longer-term analysis.

FRA requires the identification of a primary accident cause (and other contributing causes if applicable). These causes are categorized into five major groups in the FRA accident database: track, equipment, human factors, signals, and miscellaneous. Track-related causes and equipment-related causes collectively account for the majority of derailments and are the focus of this research. A three-digit numeric code was assigned to an individual cause that specifies the exact cause(s) of an accident. Different accident causes may be associated with different track class–specific derailment rates. In addition, some causes may have no relationship or only an indirect relationship with track class. It is of interest to analyze accident cause–specific derailment rates by FRA track class. The FRA accident database contains 389 unique accident causes (*25, 26*). A study by Arthur D. Little Inc. combined similar FRA causes into the same cause group on the basis of expert opinion (*27*). Accident cause–specific derailment rates by FRA track class were estimated using the overall derailment rates for all causes developed by Anderson and Barkan (*4*), multiplied by the conditional probability that a derailment is the result of a certain accident cause (Equations 4 and 5). This approach assumed that the distribution of accident cause on each track class remained constant in the study period. In other words, the conditional probability that a derailment is the result of a certain cause was held constant. An alternative method is to divide the number of derailments that resulted from a certain accident cause by the corresponding track class–specific traffic exposure. This method requires information regarding freight rail traffic distribution by track class from 1999 to 2008, which is not publicly available.

$$Z_{ck} = Z_{ak} \times P_{ck|ak} \tag{4}$$

$$P_{ck|ak} = \frac{F_{ck}}{F_{ak}} \tag{5}$$

TABLE 1 Derailment Rates by FRA Track Class for Class I Main-Line Freight Trains (*4*)

Class	Train Derailments per Million Freight Train Miles	Train Derailments per Billion Freight Car Miles
X and 1	48.54	720.1
2	6.06	92.7
3	2.04	31.5
4	0.53	7.8
5	0.32	4.9
All classes	1.00	14.8

where

Z_{ck} = derailment rate from cause c on track class k (per billion car miles),
Z_{ak} = derailment rate from all causes on track class k (per billion car miles),
$P_{ck|ak}$ = conditional probability that a derailment on track class k is from cause c,
F_{ck} = number of derailments from cause c on track class k,
F_{ak} = number of derailments from all causes on track class k,
c = accident cause, and
k = track Class 1, 2, 3, 4, or 5.

In general, track-related derailments are more frequent than equipment-related derailments on lower track classes, while equipment-related derailments are more frequent than track-related derailments on higher track classes (Figure 1).

Table 2 presents Class I main-line train derailment rates by track class and accident cause. Several observations can be made:

- Broken rails or welds have the highest derailment rate on each track class among all track-related (*T*) and equipment-related (*E*) causes;
- Bearing failures and broken wheels have higher derailment rates than the other equipment-related causes on track Classes 3, 4, and 5; side bearing and suspension defects have higher derailment rates than the other equipment-related causes on track Classes 1 and 2; and
- Broken rails or welds (08T), bearing failures (10E), track geometry defects (04T), and broken wheels (12E) are the principal track-related and equipment-related causes.

An analysis of variance (ANOVA) was conducted to examine the effects of FRA track class and accident cause on derailment rate. The p-value for FRA track class was less than .05 for both track cause group and equipment cause group, indicating that FRA track class is significantly related to derailment rate. The different track-related causes did not have a significantly different relationship in terms of track class (p = .202). However, the relationship for equipment-related causes did differ significantly with track class (p < .05). The results of the ANOVA show that FRA track class is a significant factor affecting derailment rates and that the relationship with accident causes varies depending on major cause group. To better understand the relationship between derailment rate and FRA track class for specific accident causes, a Pearson product–moment correlation coefficient was calculated. It was assumed that there is no significant linear relationship between derailment rate and track class if $|r| < .5$; otherwise, a linear correlation is expected (*28*). A positive r value indicates that derailment rate increases with a higher track class; a negative r value means that a higher track class is correlated with a lower derailment rate. In general, higher track classes were correlated with lower derailment rates for all track-related causes and the majority of equipment-related causes. However, two equipment-related causes, truck structure defects (08E) and especially hunting (20E), showed a positive relationship between higher track class and derailment rate. Some equipment-related causes, such as bearing failure (10E) and air hose defect (01E), had no relationship with track class.

It is interesting to observe that some equipment-related accident causes, such as broken wheels (12E), also have lower derailment rates on higher track classes. This might be attributable to the reduced dynamic forces on the vehicle components resulting from the higher track quality. In addition, installation of advanced wayside detectors (*29–35*), such as wheel impact load detectors, may result in certain equipment defects being more likely to be identified and corrected before causing a derailment. Sampling error may also be a factor when there are few derailment records for a particular cause group.

The differences in derailment rates by track class are not solely explained by track quality variations in track classes. Some derailments may occur on curves with lower allowable speeds or on sections with temporary slow orders. These segments are likely to be classified as lower FRA track classes; however, when such circumstances occur on high-density main-line routes that are otherwise being maintained for higher track class standards, most of the same maintenance standards will prevail. The effect will be to reduce the estimated derailment rates on these lower track class segments. Additionally, railroads may maintain their infrastructure to a higher standard than the minimum required by FRA, thereby causing possible variations in track quality within the same track class. FRA has developed a set of objective track quality indices from measured track

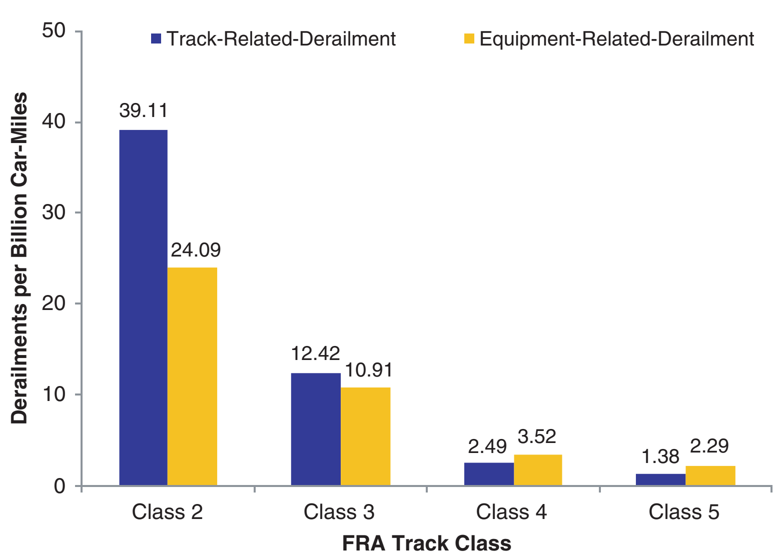

FIGURE 1 Track-related and equipment-related derailment rates.

TABLE 2 Derailment Rates by FRA Track Class, Class I Main-Line Freight Train, 1999 to 2008 (Derailments per Billion Car Miles)

Cause Group	Description	Class 1	Class 2	Class 3	Class 4	Class 5	All Classes	Correlation Coefficient with Track Class, r
Track Related								
08T	Broken rails or welds	129.07	16.78	5.01	0.94	0.59	2.17	−.78
04T	Track geometry (excl. wide gauge)	61.14	10.01	2.43	0.40	0.07	0.99	−.79
03T	Wide gage	81.52	4.06	0.66	0.10	0.02	0.48	−.73
05T	Buckled track	6.79	1.89	1.14	0.33	0.09	0.45	−.86
10T	Turnout defects: switches	44.84	1.49	0.59	0.12	0.08	0.33	−.73
07T	Joint bar defects	2.72	0.41	0.48	0.18	0.15	0.24	−.78
12T	Miscellaneous track and structure defects	31.25	1.62	0.26	0.07	0.06	0.22	−.73
01T	Roadbed defects	17.66	0.81	0.63	0.10	0.02	0.21	−.74
09T	Other rail and joint defects	4.08	0.95	0.41	0.10	0.05	0.16	−.83
06T	Rail defects at bolted joint	4.08	0.27	0.22	0.09	0.18	0.16	−.72
02T	Nontraffic, weather causes	5.43	0.68	0.48	0.05	0.02	0.12	−.78
11T	Turnout defects: frogs	1.36	0.14	0.11	0.03	0.04	0.05	−.76
Total		389.94	39.11	12.42	2.49	1.38	5.59	−.76
Equipment Related								
10E	Bearing failure (car)	0.00	1.89	1.99	0.85	0.46	1.01	−.02
12E	Broken wheels (car)	5.43	2.03	2.03	0.51	0.46	0.78	−.90
13E	Other wheel defects (car)	10.87	3.52	0.99	0.31	0.11	0.48	−.87
11E	Other axle, journal defects (car)	4.08	1.62	0.85	0.31	0.24	0.44	−.90
09E	Sidebearing, suspension defects	13.59	4.06	1.03	0.21	0.08	0.43	−.86
07E	Coupler defects (car)	2.72	1.22	0.77	0.37	0.08	0.41	−.94
06E	Centerplate, car body defects (car)	5.43	1.89	0.88	0.18	0.14	0.33	−.88
Loco	Locomotive defects	8.15	1.62	0.44	0.16	0.19	0.28	−.80
19E	Stiff truck (car)	5.43	3.25	0.41	0.08	0.04	0.21	−.91
20E	Track–train interaction (hunting)	0.00	0.00	0.07	0.15	0.18	0.17	.97
18E	All other car defects	6.79	0.95	0.37	0.07	0.08	0.15	−.78
05E	Other brake defects (car)	0.00	0.81	0.44	0.08	0.04	0.14	−.30
08E	Truck structure defects (car)	0.00	0.00	0.22	0.09	0.12	0.12	.57
02E	Brake rigging defects (car)	2.72	0.54	0.22	0.07	0.06	0.11	−.81
01E	Air hose defects (car)	0.00	0.14	0.15	0.05	0.01	0.05	−.16
Unclassed	FRA causes not classified by ADL	2.72	0.41	0.04	0.02	0.01	0.04	−.78
04E	UDE (car or locomotive)	0.00	0.00	0.00	0.02	0.00	0.01	.35
14E	TOFC, COFC defects	0.00	0.14	0.00	0.01	0.00	0.01	−.33
03E	Hand brake defects (car)	1.36	0.00	0.00	0.00	0.00	0.00	−.71
Total		69.29	24.09	10.91	3.52	2.29	5.20	−.88

NOTE: Excl. = excluding; ADL = Arthur D. Little Inc.; UDE = undesired emergency (brake application); TOFC = trailer on flat car; COFC = container on flat car. For track-related cause group, $p = .202$ (>.05); for equipment-related caused group, $p = .020$ (<.05); for track class (both groups), $p = .000$ (<.05).

geometry data that can quantitatively describe the relative condition of quality within each track class (*36*). Additional factors related to track quality, track geometry, and environmental conditions should also be considered for a more accurate estimation of derailment rate.

DERAILMENT SEVERITY

Monetary damage is often used to assess the severity of railroad accidents. However, this is subject to additional sources of variance such as the cost to repair regular track versus special track and the difference in cost between damaged locomotives and freight cars (*17*). In this paper, number of cars derailed is used as a proxy for derailment severity to reflect the impact forces resulting from the kinetic energy of the derailed train. A positive correlation between number of cars derailed and speed is expected (*2, 3, 11, 17, 37*). The number of cars derailed may also vary among different accident causes. For instance, derailments caused by broken rails or welds tend to derail more cars than those caused by bearing failure (*11, 17*). Average number of cars derailed can be modeled as a function of speed and accident cause by using a power regression model (*2, 11, 37*) (Equation 6). The estimates for parameters A_c and B_c are presented in Table 3.

$$N_c = A_c \times S^{B_c} \tag{6}$$

TABLE 3 Regression Results for Estimating Average Number of Cars Derailed

Cause Group	Description	A_c	B_c	R^2	p
08T	Broken rails or welds	1.830	0.622	.986	<.01
04T	Track geometry (excl. wide gage)	2.952	0.257	.911	<.01
All T	All track causes combined	1.528	0.636	.982	<.01
10E	Bearing failure (car)	3.012	0.196	.497	<.01
12E	Broken wheels (car)	1.265	0.506	.917	<.01
All E	All equipment causes combined	1.665	0.397	.985	<.01
All	All accident causes	1.852	0.486	.981	<.01

where

N_c = average number of cars derailed in a train derailment for accident cause c,
A_c, B_c = model coefficients for accident cause c, and
S = train derailment speed (mph).

The regression relationship between average number of cars derailed and derailment speed by accident cause is plotted in Figure 2, which shows that

- Derailments with higher train speeds tend to have more cars derailed within the same cause group.
- The average number of cars derailed varies by accident causes even at the same derailment speed:
  – Broken rails or welds are likely to derail more cars than other causes and
  – Bearing failures result in relatively less severe derailments.

It appears that track-related accident causes result in a larger number of cars derailed than equipment-related causes. This may be because different accident causes vary in the typical point of derailment (POD) (the position of the first car that is derailed). Track-related accident causes, such as broken rails, tend to initiate derailments near the front of the train; equipment failures appear to have the POD more uniformly distributed throughout the train (*11*). When the POD is located near the front, the larger residual train length (number of cars behind the POD), would result in more cars derailing. Understanding that different accident causes may result in different numbers of cars derailed is useful for analyzing the risk pertaining to a specific accident cause.

Train length and car loading were not considered in the risk model since this study analyzed accident cause–specific derailment risk by FRA track class. No significant differences have been found in average train length and average car weight between track classes on the national freight rail network (*11*). But train length and train weight are likely to affect derailment rate, derailment severity, and the corresponding risk in a route-specific risk analysis (*11, 19*). In that case, more operational and infrastructure information should be incorporated into the model.

DERAILMENT SPEED

Higher track classes allow higher maximum train-operating speeds, which leads to correspondingly higher average derailment speeds. Nevertheless, these speeds were lower than the maximum allowable speeds, especially on higher track classes (Table 4). Higher track classes were also shown to have a larger standard deviation for derailment speed, probably because higher track class derailments occur at a wider range of speeds. This larger standard deviation implies a greater range of derailment severity on higher track classes, making the prediction of number of cars derailed subject to greater uncertainty.

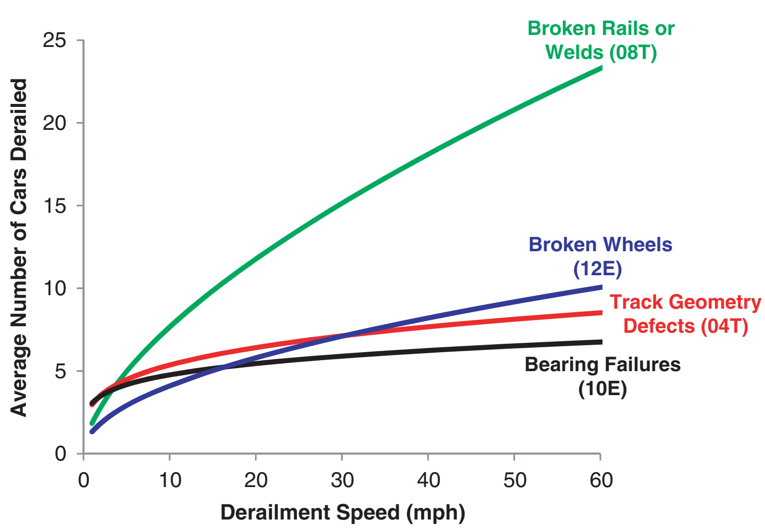

FIGURE 2 Regression relationship between number of cars derailed and speed by accident cause.

TABLE 4 Average Derailment Speed by Track Class: All Accident Causes

Class	Number of Derailments	Average Speed (mph)	Standard Deviation (mph)	Freight Train Maximum Speed (mph)
1	530	7.7	3.0	10
2	685	16.9	7.1	25
3	855	25.0	11.2	40
4	1,551	33.2	15.5	60
5	416	37.4	18.0	80
All classes	4,037	25.7	15.9	

Table 5 illustrates the average derailment speed by FRA track class and accident cause. ANOVA indicated that different accident causes have a similar statistical relationship between average derailment speed and track class ($p > .05$). Estimates of accident cause–specific derailment severity were based on the regression relationship between number of cars derailed and train speed (Table 3) and the average derailment speed pertaining to a certain cause on each track class (Table 5). Table 6 illustrates the predicted average number of cars derailed by track class for certain accident cause groups. Broken rails or welds (08T) are likely to result in more cars derailed than the other causes on each track class.

CAUSE-SPECIFIC DERAILMENT RISK

Derailment rates were shown to decline on higher track classes, but derailment severity (average number of cars derailed) may also increase as a result of higher operating speeds. Derailment risk, a product of derailment rate and severity, is dominated by the former; consequently, higher track classes have lower derailment risk (Figure 3).

Derailment risks from certain accident causes by track class were analyzed (Table 7). Track-related derailment risk declines on higher track classes because the net result of the reduced derailment rate outweighs the increase in derailment severity. Broken rails or welds (08T) pose greater risk than the other causes on each track class, which is why the detection and prevention of broken rails is a high-priority safety activity for U.S. railroads. Although important on low track classes, derailment risk that results from track geometry defects is relatively low on higher track classes, probably because of more stringent track geometry and maintenance standards. The average derailment risk for all track-related causes is approximately two times that of equipment-related causes. Upgrading track Class 3 to Class 4 is correlated with a fivefold reduction in track-related derailment risk. Although the derailment risk caused by bearing failures and broken wheels increases when track Class 2 is upgraded to Class 3, the overall derailment risk for all causes declines on higher track classes.

UPGRADING TRACK CLASS TO REDUCE RISK

Three track class upgrade strategies were considered: upgrading Class 2 to 3, Class 3 to 4, and Class 4 to 5. It was assumed that maximum train speeds increase in accordance with track class upgrade, indicating that higher track classes have greater average derailment speeds. The statistics from Table 7 were used to analyze the reduction in derailment risk for a certain accident cause group as a result of track class upgrade. Upgrading track Class 2 to Class 3 offers the greatest risk reduction per billion car miles for track-related causes, but this upgrade is also correlated with an increase in risk caused by broken wheels and bearing failures. Upgrading Class 4 to

TABLE 5 Average Derailment Speed (mph) by Accident Cause and Track Class

Cause Group	Class 1	Class 2	Class 3	Class 4	Class 5	All Classes
Broken rails or welds (08T)	8.1	18.1	29.1	36.8	36.0	26.5
Track geometry (excl. wide gage) (04T)	8.5	18.2	26.4	32.5	30.5	23.0
All track causes	8.1	17.5	27.3	36.5	39.9	25.8
Bearing failure (10E)	NA	21.6	27.4	36.3	42.1	34.6
Broken wheels (12E)	7.8	17.7	25.2	36.3	38.9	38.9
All equipment causes	7.2	17.8	24.9	34.8	39.5	30.3
All accident causes	7.7	16.9	25.0	33.2	37.4	25.7

NOTE: NA = not applicable. For cause group, $p = .98$ (>.05); for track class, $p = .000$ (<.05).

TABLE 6 Estimated Average Number of Cars Derailed by Accident Cause and Track Class

Cause Group	Class 1	Class 2	Class 3	Class 4	Class 5	All Classes
Broken rails or welds (08T)	6.7	11.1	14.9	17.2	17.0	14.0
Track geometry (excl. wide gage) (04T)	5.1	6.2	6.9	7.2	7.1	6.6
All track causes	5.8	9.4	12.5	15.1	15.9	12.1
Bearing failure (10E)	NA	5.5	5.8	6.1	6.3	6.0
Broken wheels (12E)	3.6	5.4	6.5	7.8	8.1	8.1
All equipment causes	3.6	5.2	6.0	6.8	7.2	6.5
All accident causes	5.0	7.3	8.9	10.2	10.8	9.0

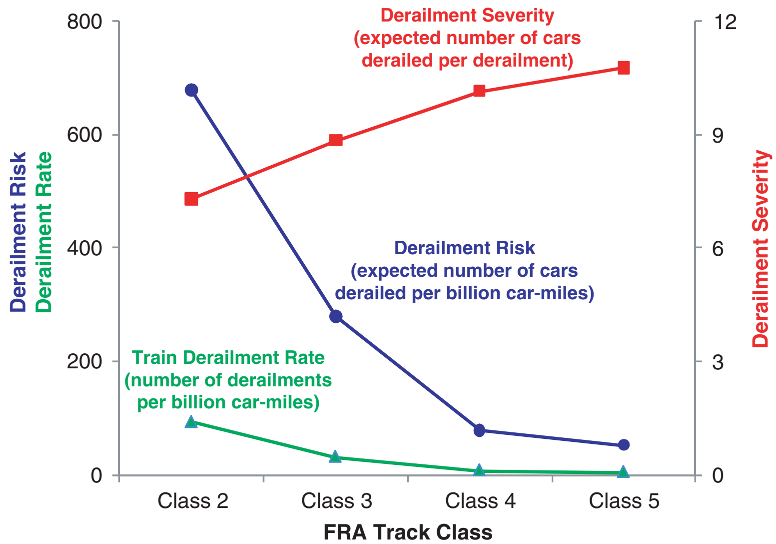

FIGURE 3 Relationship between track class, derailment rate, and derailment severity for all accident causes.

TABLE 7 Derailment Risk by Accident Cause and Track Class, per Billion Car Miles

Cause Group	Class 2	Class 3	Class 4	Class 5	All Classes
Broken rails or welds (08T)	186.3	74.6	16.2	10.0	30.4
Track geometry (excl. wide gage) (04T)	62.1	16.8	2.9	0.5	6.5
All track causes	367.6	155.3	37.6	21.9	67.6
Bearing failure (10E)	10.4	11.5	5.2	2.9	6.1
Broken wheels (12E)	11.0	13.2	4.0	3.7	6.3
All equipment causes	125.3	65.5	23.9	16.5	33.8
All accident causes	676.7	280.4	79.6	52.9	133.2

Class 5 offers less risk reduction than upgrading Class 3 to Class 4 (Table 8).

The derailment risk discussed above is normalized by car miles. Traffic distribution varies among track classes. Track Classes 3, 4, and 5 collectively account for more than 90% of national freight rail traffic, with the majority of traffic on track Class 4 (unpublished data from the University of Illinois). Therefore, track class upgrade between these higher track classes contributes to greater risk reduction. In addition to safety improvement, track class upgrade may also reduce transportation time and enhance rail line capacity. However, upgrading track class also incurs an initial track upgrade cost, and increases operating and ongoing capital costs for track maintenance (*7, 38*). The trade-offs between the benefits and costs, budget, engineering constraints, and many other criteria need to be considered when making decisions regarding infrastructure improvement for a specific rail route or network.

TABLE 8 Derailment Risk Reduction by Upgrade to Track Class, per Billion Car Miles

Cause Group	Class 2 to 3	Class 3 to 4	Class 4 to 5
Broken rails or welds (08T)	111.7	58.4	6.2
Track geometry (excl. wide gage) (04T)	45.3	13.9	2.4
All track causes	212.3	117.7	15.7
Bearing failure (10E)	−1.1	6.3	2.3
Broken wheels (12E)	−2.2	9.2	0.3
All equipment causes	59.8	41.6	7.4
All accident causes	396.3	200.8	26.7

CONCLUSIONS

Train derailment risk analysis relies on the accurate estimation of derailment rate and derailment severity, both of which are subject to a variety of factors. Track class has been used as a proxy for track quality and as a parameter for estimating derailment rate because of its strong correlation with derailment rate. However, the relationship is complex. Some accident causes show a strong relationship, but others do not. On lower track classes track-related derailments are more likely to occur than derailments caused by equipment failures. Higher track classes are statistically associated with lower derailment rates for the majority of track-related and equipment-related accident causes. However, some equipment-related causes, notably hunting and truck structure defects, tend to have higher derailment rates and the corresponding higher risk on higher track classes. Although some equipment failures are common, such as bearing failures, they are likely to result in less severe derailments than track defects. Of particular interest are broken rails or welds, which are likely to cause more severe consequences. Speed was found to be a proxy to estimate the average number of cars derailed in an accident, but the specific severity and speed relationship varies among different accident causes. When all these factors are considered, there are interactions among accident causes that are differently affected by track class upgrade. Upgrading track class will generally reduce track-related derailment risk, but it increases the derailment risks pertaining to certain equipment-related causes. These and other factors need to be properly accounted for when evaluating the safety benefits and costs associated with infrastructure upgrade as a risk reduction strategy.

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