Railroad Accident Rates for Use in Transportation Risk Analysis

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Annual safety statistics published by FRA provide train accident counts for various groupings, such as railroad, accident type, cause, track type and class, train length, and speed. However, hazardous materials transportation risk analysis often requires more detailed accident rate statistics for specific combinations of these groupings. The statistics that are presented enable more precise determination of the probability that Class I and non-Class I railroad freight trains will be involved in an accident on various classes of main-line track. An increase in the overall accident rate from 1997 to 2001 can be largely attributed to the increase in yard accidents. During that time, the main-line derailment rate for Class I freight trains remained nearly constant. Track class-specific derailment rates for Class I main-line freight trains show two orders of magnitude difference between the lowest and highest FRA track classes. Depending on the risk analysis question, accounting for these differences in rates will often be important in developing an accurate estimate of risk over the length of a route or at particular locations along a route. A sensitivity analysis suggests that the distribution of freight train miles by FRA track class may have changed since a study conducted by the Association of American Railroads in the early 1990s. More up-to-date estimates of track class-specific accident rates would require new data on this distribution.

Accident rates are an essential element in conducting an assessment of hazardous materials transportation risk. Rail shipment of hazardous materials is of particular interest to chemical shippers and railroads because of the large volume shipped by rail and of the safety and liability consequences of a major accident. Consequently, the ability to conduct accurate risk analysis for rail transport is important. Risk analysts are fortunate to have comprehensive accident data available for rail transportation from FRA (*1*). However, the aggregated accident rate statistics published by FRA do not provide sufficient resolution for many risk analysis calculations, so more detailed analyses are required.

Risk analysis for the shipment of hazardous materials railcars involves estimating the probability that a train transporting hazardous materials will be involved in an accident, the conditional probability that a hazardous materials car will be derailed and exposed to damage, and the conditional probability that the derailed car will release its contents (*2*). Accurate assessment of the risk for a particular hazardous materials shipment requires detailed information on the railroad and trackage that it will traverse.

In this paper data from the FRA Office of Safety (*1*) are analyzed to develop better resolution estimates of accident rates pertinent to risk analysis. Train accident rates for the 10-year period of 1992 to 2001 were calculated that distinguish main-line and yard track operations, Class I and non-Class I railroads, and different FRA track classes.

TRAIN ACCIDENT RATES

The overall train accident rate is defined as the total number of independent accidents [usually excluding highway–rail grade crossing (HRC) accidents] per million total train miles. Although trends in train accident rate can be useful, they are also potentially misleading if the effects of different variables are averaged, thus masking the various factors that affect the probability of a train being involved in an accident. As an example, the main-line derailment rate for Class I freight trains, arguably the most important in regard to the risk associated with the transportation of hazardous materials by rail, has shown little variation since 1992 despite the overall increase in accident rate between 1997 and 2001 (*1, 3, 4*) as shown in Figure 1. In Figure 1, derailment rates for solid data points are calculated as derailments per million non-yard-switching train-miles while the derailment rates for open data points are calculated as derailments per million freight train miles (FTM).

Main-Line and Yard Accident Rate

Annual accident rates for yard and "other" track (main line, siding, and industry) are calculated by FRA (*3*). The yard accident rate is defined as the number of accidents occurring on yard track divided by yard-switching train miles. The accident rate for other track is defined as the number of accidents on nonyard trackage, divided by the difference between total train miles and yard-switching train miles. The majority of accidents on other track occur on main-line track; thus the main-line accident rate uses the denominator for other track to calculate the main-line rate.

For the years 1997 to 2001, the accident rate for yard track increased 27% (6.2% average annual increase), while that of main-line track increased 11.8% (3.3% average annual increase) (*4*). The rail industry has been concerned about this increase in overall accident rate, but it should be noted that most of the change is due to the increase in yard accidents. Although a matter of concern, yard accidents typically occur at low speed and are two to five times less likely to lead to a release if a hazardous materials car is involved (*5*). Subsequent to the completion of these analyses, complete data for 2002 became available that indicated a reduction in both the number of accidents and accident rate for both main-line and yard operations (*4*).

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Transportation Research Record: Journal of the Transportation Research Board, No. 1863, TRB, National Research Council, Washington, D.C., 2004, pp. 88–98.

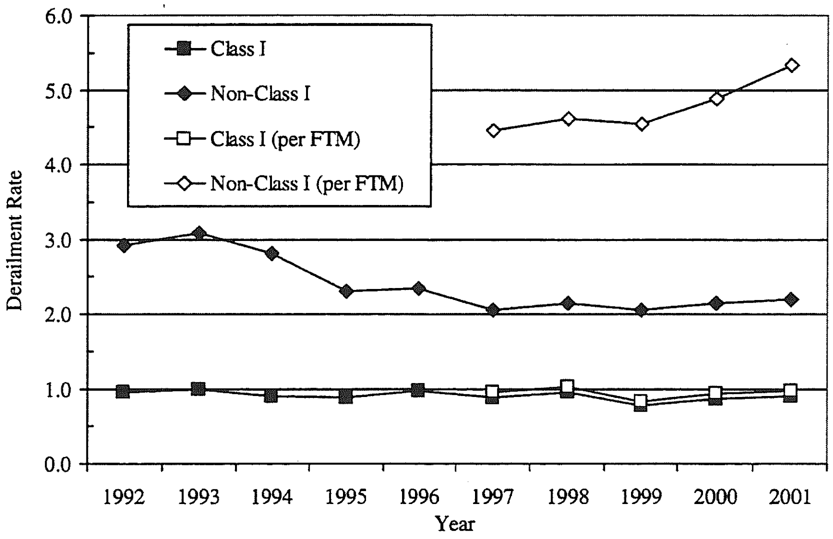

FIGURE 1 Main-line freight derailment rate for Class I and non-Class I railroads.

Derailment Rates on Main-Line and Yard Track

Derailments, collisions, HRC accidents, and other accident types are all components of the overall accident rate. Of particular importance to hazardous materials risk assessment is the derailment rate, owing to the frequency of occurrence and severity of consequences in regard to cars derailed and release probability (*5*). In 2001, of the 32 train consists that had hazardous materials released, derailments accounted for 28 (87.5%) of the accidents and 51 of the 57 cars that released (*3*).

The main-line and yard derailment rates are calculated with the same denominator values as mentioned, using the number of derailments on main-line and yard track in the numerator. The main-line derailment rate changed from 1.16 derailments per million train miles in 1997 to 1.21 in 2001 (a total increase of 4.4%), while the yard derailment rate increased 38.9%, from 9.43 in 1997 to 13.10 in 2001 (*4*).

Main-Line Derailment Rates for Class I and Non-Class I Railroad Freight Trains

Accident rates also vary among railroads and are different for Class I railroads (gross annual revenues ≥ \$266.7 million) and non-Class I railroads (< \$266.7 million) (*5, 6*). While hazardous materials frequently travel relatively short distances on non-Class I railroads, the majority of this traffic is on Class I railroads. In 2001, more than 83% of all trains carrying hazardous materials and involved in an accident, and 93% of all hazardous materials cars that released their contents, were on Class I freight railroads (*3*).

There are two problems when trying to determine the number of accidents for Class I and non-Class I railroads. The first is due to the consolidation of railroads during the interval considered in this research, which complicates trend comparisons. FRA combines information reported by predecessor railroads to make a more valid comparison of major railroad systems (*3, 7*). Owing to the unavailability of the current FRA list of consolidated railroads, the authors used the railroad type variable to separate the two groups (Table 1). However, comparison showed the differences between the two approaches to be small, because many of the railroads that were consolidated into Class I railroads during the time period analyzed were already Class I railroads. The difference between the two approaches was estimated to be approximately 2% when one looks specifically at main-line freight train accident reports.

The second problem stems from the possibility that more than one train consist or railroad may be involved in an individual accident. FRA created the "joint code" field to assist in counting accidents when multiple reports are filed for an individual accident (Table 1). For accidents involving multiple railroads or consists, or both, only one railroad accident report will be filed with a joint code of "1." All other railroads involved will have one report filed with a joint code of "2," with all other reports (for any additional consists) receiving a joint code of "3." Therefore, the number of independent accidents for all railroads can be determined by counting only those accident reports with a joint code of "1." The number of independent accidents for one specific railroad can be determined by counting the railroad's accident reports having a joint code of "1" or "2." When distinguishing between railroad groups, however, a more advanced method is needed to determine the number of independent accidents.

Assigning Unique Accident Identification

Development of accurate statistics from the FRA data requires an understanding of the database and use of appropriate methodology to extract the proper, relevant information. In this section is described the method used to link reports corresponding to the same accident by assigning a unique accident number that will be the same across all linked reports. Use of this method allows one to accurately determine the number of independent accidents among any group of consists being considered. In addition, quantitative estimates are provided on the effect of different approaches so that other investigators can adjust their data accordingly, depending on which method they choose.

By comparing report identifications for the track owner to date and location information, using "joint code" variables as checks, the authors assigned unique numbers to individual accidents for the 10 years of data analyzed (Table 1). With the use of this technique, there were 27,850 assigned accident numbers (corresponding to the

TABLE 1 FRA Accident and Incident Report Database Field Codes

FRA Field Name	Description	
JOINTCD	Joint code: Used to distinguish between multiple reports	
TRKCLAS	FRA Track Class: X, 1-9[a]	Maximum Speed (mph)
	X & 1	10
	2	25
	3	40
	4	60
	5	80
	6	110[b]
TYPE	Type of accident/incident	
	1. Derailment	7. Highway-rail crossing (HRC)
	2. Head-on collision	8. Railroad grade crossing
	3. Rear-end collision	9. Obstruction
	4. Side collision	10. Explosion-detonation
	5. Raking collision	11. Fire/violent rupture
	6. Broken train collision	12./13. Other impacts/Other
TYPEQ	Type of consist (e.g., freight train has a value of 1)	
TYPRR	Railroad type: Distinguishes between railroad groups (e.g., Class I railroads have a value of 1)	
RR3	Railroad responsible for track maintenance (track owner)	
INCDTNO3	Incident number of track owner	
YEAR4, MONTH,DAY	Date (4-digit year, 2-digit month and day) of incident	
STCNTY	Alphanumeric state and county code of incident location	
ACCAUSE	Accident cause code on "jointcd" 1 report	
ACCTRK	Track type code on "jointcd" 1 report	
ACCTRKCL	FRA track class on "jointcd" 1 report	

[a] While there are higher track classes now in service (7,8,&9), these are primarily for high-speed passenger train operations.

[b] Although FRA track safety standards allow speeds up to 110 mph on Class 6 track, FRA traffic control regulations limit train speeds to less than 80 mph on most U.S. trackage.

number of accident reports having a joint code of "1") for the 34,061 reports filed with FRA over the 10 years of 1992 to 2001. Once a unique accident number has been assigned to each report, the task of calculating the number of independent accidents for a particular consist group of interest is greatly simplified. Using this approach, there were 4,600 derailments in which there was at least one Class I freight train derailed on main-line track, and 1,803 for non-Class I railroads.

An alternative method of analyzing reports with a joint code of "1" is simpler, but it somewhat underestimates the number of accidents when distinguishing between freight train derailments of Class I and non-Class I railroads. With the use of this method, there were 4,461 Class I and 1,729 non-Class I main-line freight train derailments over the 10-year period (an error of 3% to 4% less than the actual accident counts as determined using the aforementioned method). A second alternative approach analyzes reports with a joint code of "1" or "2." Although this approach double counts some accidents, the net accident counts are much closer to the actual accident counts (with an error of less than 0.5% for both railroad groups). Future analyses that use these two approaches should recognize the limitations of the two "joint code" methods and factor the error into accident count and rate estimations.

Derailment Rate Calculations

In addition to accident counts, care must be taken in interpreting the exposure data provided by FRA that are used as the denominator in the calculation of accident rates. Beginning in 1997, FRA began distinguishing between passenger and freight train miles; previously, it had distinguished only between locomotive and motor train miles. This change is an improvement but must be accounted for when comparing derailment rate trends over intervals before 1997.

The calculated derailment rates for 1992 to 2001 (solid points in Figure 1) use the older approach in which the difference between total and yard-switching train miles is used as the denominator. By contrast, the rates calculated for the years 1997 to 2001 (open points) use the more relevant data on freight train miles as the denominator to calculate the main-line freight train derailment rates.

The difference between the rate calculations is due to the inclusion of passenger (and other) train miles in the denominator of the former approach, but not of the latter one. For Class I railroads, the difference between the two rates is minimal because passenger train miles are only a small portion of their total (~6%). However, the derailment rate changes considerably for the non-Class I railroads because passenger train miles account for about half their total mileage (*1*). The result of this difference is that while the Class I derailment rates are similar in both calculations (~7% difference), the non-Class I freight train derailment rates are more than two times higher when only freight train miles are used as the denominator.

Both approaches are included here, because the former allows for relative comparison of the years before 1997 that do not have freight train miles for both railroad groups. The latter approach uses the more appropriate denominator value for rate calculation, for it is a better metric of exposure for mainline freight trains. Using data from the Association of American Railroads (AAR) (*6*), it is possible to compare derailment rates in regard to freight train miles for Class I freight railroads for years before 1997. The difference in calculated rates is small because the AAR-reported freight train miles are nearly the same as those reported by the FRA for Class I railroads (usually varying by less than 2% and most likely attributable to the consolidation problem mentioned earlier).

The main-line derailment rate for non-Class I freight trains is as much as five times higher than for Class I freight trains and increased over the 5-year period considered, while the Class I derailment rate is virtually unchanged since 1997 (Figure 1). The difference in rates between Class I and non-Class I railroads probably reflects the general difference in the distribution of FRA track class between the two railroad types.

TRACK CLASS-SPECIFIC MAIN-LINE DERAILMENT RATES

The FRA divides track into seven "classes" commonly used by Class I freight railroads. The higher the FRA track class, the higher the maximum permissible speed (Table 1). Track class is not specifically intended as a metric for prediction of derailment probability, and there are a variety of potential confounding factors that affect its reliability for this role. Furthermore, there is not a direct causal relationship between FRA track class criteria and derailment probability. However, FRA track classes do specify certain attributes related to track quality, with higher classes having more stringent requirements (2). Because of its universal use by railroads in the United States, and in the absence of a better set of causal parameters for track quality, it is reasonable to consider track class as a proxy variable for statistical estimation of derailment probability.

Track class-specific estimates of derailment rate were first developed by Nayak et al. (*8*) in the early 1980s. These estimates are now two decades old and were developed before most of the railroad safety improvements that followed economic deregulation (*9, 10*). Consequently, AAR conducted a study in the early 1990s that developed more up-to-date estimates for these rates using data collected in the late 1980s and early 1990s. More recently, the Surface Transportation Board (STB) used the results from the unpublished AAR study and additional data from the mid-to-late 1990s as a basis to develop updated derailment (and other accident) rate estimates (*11*). All of these analyses found a clear statistical relationship between FRA track class and derailment rate.

The analysis presented in the following section attempts to update these track class-specific main-line derailment rate estimates for Class I railroad freight trains. It also provides an assessment of their current reliability.

Derailment Counts

For the 10-year period analyzed, there were 4,600 accidents classified as derailments in which one or more Class I railroad freight trains derailed on main-line track. Due to the relatively small number of accidents occurring on excepted (X) class track or on class 6 track, accidents on class X track are combined with those of class 1, and accidents on class 6 track are combined with those of class 5 (as in previous studies). Eighteen accidents could not be assigned to a specific track class group owing to incomplete or contradictory track class information for the accident. Table 2 shows the distribution of the 4,582 derailments among the five FRA track class groups and includes the 18 unassigned accidents in the total. These values were used as the numerators for derailment rate calculations.

Train Mile and Car Mile Denominator Data

Exposure data for Class I railroad freight car miles and freight train miles from AAR (*6*) were used as the denominator values in calculating derailment rates. Although the values for freight train miles published by AAR differ slightly from those reported by FRA, the AAR data are used in the calculations because freight car mileage is not available from FRA. Derailment rates per car mile may provide more accurate derailment probabilities for longer trains and will be useful in future work when calculating separate derailment rates broken down by cause group (*11*). AAR does not routinely collect mileage data broken down by FRA track class, so the distributions must be estimated.

The distribution of train miles and car miles among FRA track classes used in the STB report was based on the AAR study mentioned. The AAR survey included data for five Class I railroads, accounting for more than 70% of all Class I traffic. The distribution of traffic is given in percentages of total train miles and car miles (Table 2). These percentages are then multiplied by the total freight train miles and car miles over the 10-year period to give estimated values of the traffic distribution for each FRA track class. Use of these percentages assumes that the traffic distribution by track class has not changed substantially over the past decade, an assumption addressed later.

Derailment Rates

The current derailment rates for Class I freight trains on main-line track are estimated by dividing the total number of derailments on each track class by the estimated proportion of total train miles and car miles (Table 2). The train derailment rates and 95% confidence intervals are presented in million freight train miles and billion freight car miles. The $(1-\alpha)$ 100% confidence interval for the point estimate of the derailment rate for the ith track class, R_i, is calculated as follows (assuming a normal distribution):

$$R_i \pm z_{\alpha/2}\sigma_{Ri}$$

where

$\alpha = 0.05$;
$z_{\alpha/2} = 1.96$;
$\sigma_{Ri} = [(R_i)(1-R_i)/m_i]^{1/2}$;
$R_i = x_i/m_i$;
x_i = number of derailments; and
m_i = number of train miles or car miles.

TABLE 2 Estimated Accident Rates by FRA Track Class: 1992–2001 Class I Main-Line Freight Train Accidents (Derailments Only)

FRA Track Class	X & 1	2	3	4	5 & 6	Total[a]
Number of Derailments	671	921	1,136	1,522	332	4,600
Number of Derailed Cars	3,708	7,218	10,809	15,045	2,869	39,747
Average Number of Cars Derailed per Derailment	5.5	7.8	9.5	9.9	8.6	8.6
Average Speed (mph)	8.7	17.7	26.3	33.6	37.0	25.2
Train Mile Percentage[b]	0.3	3.3	12.1	61.8	22.6	100
Freight Train Miles (millions)	13.8	152.0	557.5	2,847.5	1,041.3	4,612
Derailments per Million Freight Train Miles	48.54 (±3.67)	6.06 (±0.39)	2.04 (±0.12)	0.53 (±0.03)	0.32 (±0.03)	1.00 (±0.03)
Car Mile Percentage[b]	0.3	3.2	11.6	63.1	21.9	100
Freight Car Miles (billions)	0.9	9.9	36.0	196.0	68.0	310.9
Derailments per Billion Freight Car Miles	720.1 (±54.5)	92.7 (±6.0)	31.5 (±1.8)	7.8 (±0.4)	4.9 (±0.5)	14.8 (±0.4)
Cars Derailed per Billion Freight Car Miles	3,979 (±128)	726 (±16.8)	300 (±5.7)	77 (±1.2)	42 (±1.5)	128 (±1.3)
Estimated Average Train Length	67.4	65.4	64.6	68.8	65.3	67.4

NOTE: 95% confidence interval in parentheses.

[a] Includes those accidents and cars derailed for which track class was indeterminable and may be larger than the total across track class categories.

[b] Individual values of train- and car-mile percentages have been rounded.

The results indicate that over the entire 10-year period, higher track classes have lower derailment rates and that there is no overlap in the 95% confidence intervals for any of the track class groups (Table 2).

Uncertainty Errors

These derailment rates are subject to error and some uncertainty. Sources for error include the estimation methods used to develop the distribution of traffic across track classes in the original study, subsequent changes in the track class traffic distribution percentages, unaccounted variance in track quality within track classes, and temporal variability that may have occurred over the 10-year period.

Annual Variation Yearly derailment rates were calculated to investigate whether the change in the number of derailments each year was proportional to the changes in traffic that occurred from 1992 to 2001 (Figure 2). The largest variations in year-to-year rates were for the two track class groups: X and 1 and 5 and 6. For both groups, the numerator values are quite small for any given year and the denominator values for Class X and Class 1 track are also small, resulting in substantial year-to-year variation in derailment rate estimates. Based on the assumption that the distribution of traffic by track class has remained unchanged since the 1992 AAR study, the following patterns are evident over the last 5 years:

- The derailment rates appear to be rising on higher track classes (4 and higher);
- The derailment rates appear to be falling for lower track classes (3 and lower), excluding the large increase from 2000 to 2001 for the X and 1 class track group (due to an additional 27 accidents); and
- The 95% confidence interval for Class 4 track overlaps the interval for Class 5 and 6 track in some years.

Track Class Traffic Percentages The STB analysis and our own analysis (Table 2 and Figure 2) assumed that the distribution of traffic over the five track class groups had not changed since 1992. This assumption may explain the yearly variation and the apparent increase in derailment rate on higher track classes, but it may be incorrect. The number of derailments is recorded annually in the FRA database, but the traffic distribution data that constitute the denominator are estimated and thus introduce uncertainty. Consequently, the authors considered some of the possible reasons for which the traffic distribution may have changed.

Traffic Changes over the Past 10 Years

Class I railroads have sold off or abandoned more than 15,000 mi of road and 23,000 mi of track from 1992 to 2001, much of this to non-Class I railroads (*6*). Sale or abandonment of light-density, low-speed lines by Class I railroads has the effect of increasing the average track class of Class I railroads. Evidence can be found in two aspects of the data: changes in the distribution of accidents

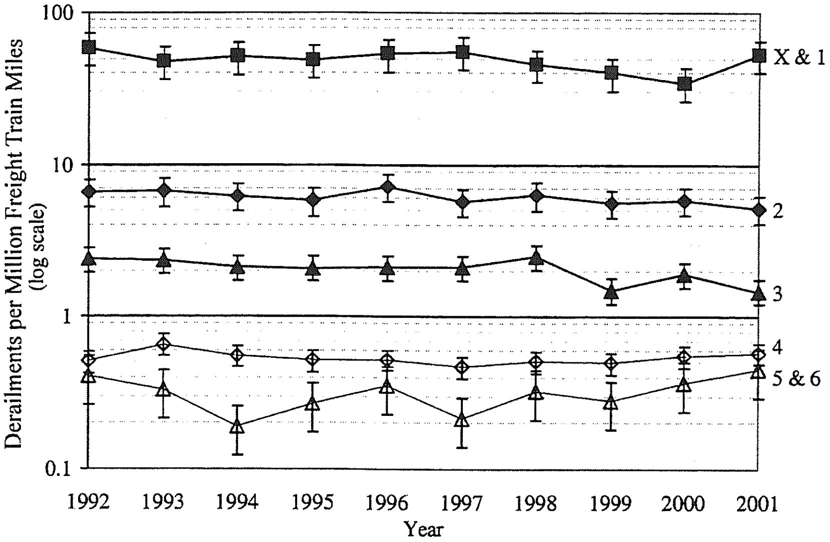

FIGURE 2 Derailment rate, by track class, with 95% confidence interval error bars—1992–2001 Class I main-line freight derailments.

among track classes, and changes in operational data observed over the past decade.

While total train miles increased for both groups of railroads over the 10-year period, yard-switching train miles decreased for Class I railroads and increased for non-Class I railroads (*1*). It may be that line sales have shifted yard trackage and operation from Class I railroads to non-Class I railroads. Because yard operation is low speed, it is usually maintained at one of the lower FRA track classes. As the distribution of Class I railroad trackage shifts toward higher FRA track classes, the relative percentage of Class I traffic will tend to shift as well.

When looking at the percentage of derailments by track class for each of the 10 years analyzed, one can see that there was little change for any of the five track class groupings from 1992 to 1997 (Figure 3). After 1997, the proportion of derailments on Class 4 and higher track increased 12% while the proportion of derailments on Class 3 track decreased 8.5% (with only a small decrease of 3.5% for Class 2 and lower track). The reason for the increase in the relative number of derailments on higher-class track may be an increase in the amount of traffic over these classes of track in 2001 compared with that of 1997.

During the 1990s, Class I railroads invested heavily in main-line trackage to accommodate higher tonnage, upgrade capacity, increase operating speed, and enhance railroad track safety performance (*6, 10;* G. A. Grimes, unpublished dissertation). Increasing speed (and capacity) was necessary to meet the demand of intermodal customers, the fastest growing segment of railroad traffic (up 35% from 1992 to 2001) (*6*). The higher-speed requirements lead directly to a need for higher FRA track classes on main-line trackage. The growth in freight, particularly intermodal traffic, combined with expansion of higher FRA track classes on main lines, would have the effect of shifting the relative proportion of train and car miles toward the upper FRA classes.

This postulated shift in track class and traffic may explain the increase in the number of derailments on Class 4 and higher track from 1997 to 2001. Using the distribution of traffic by track class based on early 1990s data would thus understate the percentage of traffic on higher track classes in recent years, resulting in overestimated derailment rates for these track classes. In the absence of more up-to-date data on traffic distribution by track class, the authors conducted a sensitivity analysis on the estimated derailment rates with variations on the assumed distribution of traffic among FRA track classes.

Sensitivity Analysis

It was assumed that the estimates of train mile distribution percentages for specific track classes developed by AAR in 1992 were representative for the years 1992 to 1994. The authors calculated a derailment rate for each track class for the 3-year interval using the number of derailments, the total freight train miles, and the estimated traffic percentages for each track class from the AAR study (Table 3). Under the assumption that Class I main-line freight derailment rates have changed little over the 10 years analyzed (Figure 1), the authors used the number of derailments in the 3-year period 1999 to 2001 to back calculate the number of train miles corresponding to constant derailment rates. The estimated total, summed across the five track class groups, was less than 2.5% different from the actual number of train miles during this interval. The estimated traffic distribution percentages are calculated and compared to the values from the AAR survey. Derailment rates for 1999 to 2001 using these estimated train mile percentages were also calculated (Table 3). The sensitivity analysis suggests the following:

- The largest differences in train mile percentages are for Class 3 track, which decreased nearly 27%, and Class 5 and 6 track, which increased about 24%;
- Derailment rates increased for those track classes having lower estimated train mile percentages (all except Class 5 and 6 track), while the rate decreased for Class 5 and 6 track; and

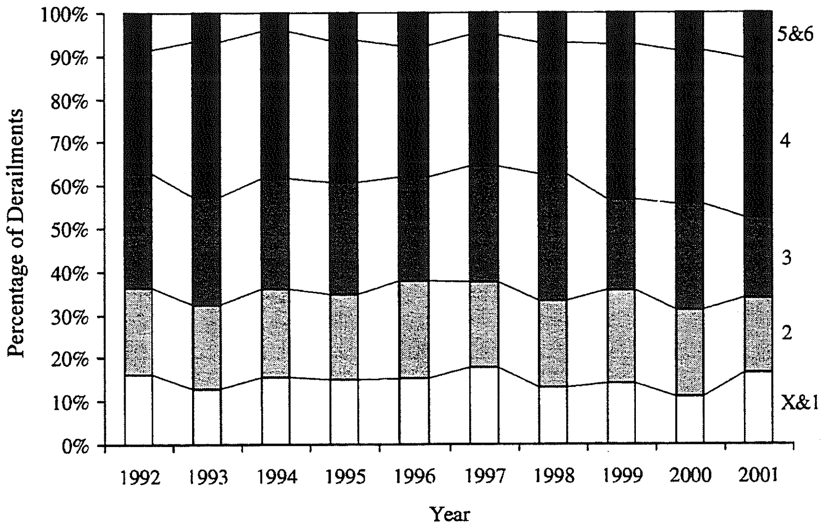

FIGURE 3 Percentage of derailments, by track class—1992–2001 Class I main-line freight derailments.

TABLE 3 Sensitivity Analysis Results Comparing Derailment Rates and Traffic Percentages: 1992–1994 and 1999–2001

FRA Track Class	X & 1	2	3	4	5 & 6	Total[a]
1992–1994						
Number of Derailments	195	264	341	438	85	1,333
Freight Train Miles (millions) *(AAR Train Mile Percentages)*	3.71 (0.3%)	40.8 (3.3%)	149.6 (12.1%)	764.2 (61.8%)	279.5 (22.6%)	1,236.6
Derailment Rate	52.56	6.47	2.28	0.57	0.30	1.08
1999–2001						
Number of Derailments	190	272	295	501	124	1,384
Derailment Rate *(Using AAR Train Mile Percentages)*	42.39	5.52	1.63	0.54	0.37	0.93
Estimated Freight Train Miles[b] (millions)	3.61	42.0	129.4	874.1	407.7	1,494[c]
Estimated Percentage of Train Miles	0.25%	2.89%	8.88%	60.00%	27.98%	100%
Derailment Rate *(Using Estimated Train Mile Percentages)*	51.26	6.31	2.22	0.56	0.30	0.93
Percent Difference Between Train Mile Distribution Percentages	-17.3%	-12.6%	-26.6%	-2.9%	+23.8%	

[a] Includes those accidents for which track class was indeterminable and may be larger than the total across track class categories.

[b] Assumes constant derailment rates between 1992–1994 and 1999–2001.

[c] Total train miles summed across track classes: 1,456,924 thousand (error of 2.5%).

- The derailment rates calculated for the period 1999 to 2001 are within the 95% confidence intervals of the 10-year rates calculated using the AAR train mile percentages for all track classes except Class 3 track.

These observations are consistent with a shift in traffic toward higher track class in the past decade. The actual track class-specific derailment rates probably lie in between the rates presented in Table 2 and the rates calculated using the estimated train miles percentages (Table 3). A better estimate of the current derailment rate would require a new survey of traffic distribution among FRA track classes.

OTHER MAIN-LINE ACCIDENT RATES

While derailments account for a majority of derailed cars and hazardous materials releases, collisions, HRC accidents, and other accidents can also derail or damage cars, or do both, and cause a hazardous materials release. Table 4 includes data for main-line accidents for Class I railroad freight trains that were not identified as derailments and gives accident rates for each of three categories: collisions (FRA #2–6, 8), HRC accidents (FRA #7), and other accidents (FRA #9–13) (Table 1). In the collision category, 16 accidents could not be assigned to a specific track class, for the value was either blank or differed between accident reports for the same accident.

Also calculated are accident statistics for non-Class I railroad freight trains on main-line track (Table 4). Accident rates for non-Class I railroads were calculated using the number of accidents occurring from 1997 to 2001 and freight train mileage data from FRA for the same years (*1*). While the number of accidents over the 10-year period is broken down by track class, the 5-year accident rates are combined across all track classes because there is no basis to estimate traffic data on different track classes for non-Class I railroads. While the Class I derailment rate is about one-fifth that of non-Class I railroads, the rates for other types of accidents differ by only about a factor of two (Tables 2 and 4).

ESTIMATED CAR DERAILMENT RATES

The train accident rates can be used to estimate the probability that a freight train will be involved in an accident. However, for some risk

TABLE 4 Estimated Accident Rates by FRA Track Class: 1992–2001 Class I Main-Line Freight Train Accidents (Not Derailments) and 1992–2001 Non-Class I Main-Line Freight Train Accidents

FRA Track Class	X & 1	2	3	4	5 & 6	Total[b]
Class I Railroads[a]						
Collisions[c]	36	47	75	132	36	342
Rate	2.60	0.31	0.13	0.05	0.03	0.07
	(±0.85)	(±0.09)	(±0.03)	(±0.01)	(±0.01)	(±0.01)
Cars Derailed	143	196	533	923	328	2,126
HRC[d] Accidents	9	46	222	616	114	1,009
Rate	0.65	0.30	0.40	0.22	0.11	0.22
	(±0.43)	(±0.09)	(±0.05)	(±0.02)	(±0.02)	(±0.01)
Cars Derailed	1	48	259	662	191	1,161
Other Accidents	42	58	100	223	77	500
Rate	3.04	0.38	0.18	0.08	0.07	0.11
	(±0.92)	(±0.10)	(±0.04)	(±0.01)	(±0.02)	(±0.01)
Cars Derailed	132	74	113	241	116	676
FRA Track Class	X &1	2	3	4	5 & 6	Total
Non-Class I Railroads[e]						
Derailments	569	773	342	98	2	1,803
Rate	n/a	n/a	n/a	n/a	n/a	4.79
						(±0.32)
Cars Derailed	2,816	4,765	2,925	975	5	11,591
Collisions	12	16	24	15	1	73
Rate	n/a	n/a	n/a	n/a	n/a	0.18
						(±0.06)
Cars Derailed	19	13	81	38	1	170
HRC Accidents	8	55	46	33	0	142
Rate	n/a	n/a	n/a	n/a	n/a	0.41
						(±0.09)
Cars Derailed	2	91	116	31	0	240
Other Accidents	19	17	17	8	1	64
Rate	n/a	n/a	n/a	n/a	n/a	0.23
						(±0.07)
Cars Derailed	47	11	21	0	0	79

NOTE: 95% confidence interval in parentheses.

[a] Accident rates in terms of train miles are given; car derailment rates for Class I railroads can be calculated by dividing the number of cars derailed by the appropriate number of car miles from Table 2.

[b] Includes those accidents and cars derailed for which track class was indeterminable and may be larger than the total across track class categories.

[c] Includes collisions at railroad grade crossings.

[d] Highway-rail grade crossing.

[e] Rates use accidents and freight train-miles for the years 1997–2001.

analyses, it is more useful to know the probability that a particular car will derail.

The FRA data permit development of track class-specific statistics for the number of cars derailed for each track class, as well as the average number of cars derailed per accident. Exposure by track class is calculated using previously determined traffic percentages and current total car mile data from AAR (*6, 11*). The individual car derailment rate is calculated by dividing the number of cars derailed by the estimated number of freight car miles for each track class, and it is not necessarily dependent on the number of independent accidents. To account for all derailed cars on a particular track class, the number of cars derailed was summed across all accident reports that had a valid track class entry, regardless of whether the track class values were in agreement across reports from the same accident. The car derailment rate can also be estimated by multiplying the average number of cars derailed per accident by the number of accidents per billion freight car miles. Both methods calculate the estimated number of cars derailed per billion freight car miles. While the number of cars derailed on each track class is given for both Class I and non-Class I railroads, car derailment rates for non-Class I railroads cannot be determined because car mile data are not available (Tables 2 and 4).

Operating speeds are generally higher on higher-class track, and there is a positive linear relationship between speed and the number of cars derailed (*5*). While derailments on higher-class track tend to derail more cars per accident, the net result is that higher track classes still have lower individual car derailment rates due to the lower probability of their being involved in a derailment (Table 2).

RELEASE PROBABILITY OF HAZARDOUS MATERIALS CAR

The other key element in the rail risk probability calculation is the likelihood that a hazardous materials car involved in an accident will be damaged or derailed, and suffer a release. Considered was the hypothesis that hazardous materials cars that derail on higher track classes might have a higher probability of releasing owing to higher operating speeds (*5*).

For the 10 years analyzed, there were 710 Class I railroad mainline freight trains derailed that had at least one hazardous materials car derailed (Table 5). Of the 2,492 hazardous materials cars derailed, 273 released their contents (none on Class X or Class 6 track) (Table 5). While the release rate on Class 1 track was substantially lower than on the higher track classes, the release rate for Classes 4 and 5 was not substantially higher than for Classes 2 and 3 track, with an average of approximately 10%. Comparing the average speed of derailment (Table 2) with the maximum operating speeds permitted on different track classes (Table 1), it is evident that many accidents occur below track speed, especially on the higher track classes (*2*). This finding may explain the small differences between the release rates on the lower track classes (Classes 2 and 3) and Class 4 and higher track.

The majority of derailed hazardous materials cars and hazardous materials releases are a result of derailments, accounting for 346 of the 377 (92%) hazardous materials cars that released on Class I and non-Class I railroads (Tables 5 and 6). The majority of releases occur on Class I railroads, which generally operate at higher speeds than do non-Class I railroads. It is thus interesting to note that the total derailment-caused release rates for Class I and non-Class I railroads are similar (Tables 5 and 6).

EXAMPLE RISK CALCULATION

To illustrate how these rates can be applied to risk assessment of hazardous materials transportation, consider the following simple example: a Class I railroad is interested in understanding the risk associated with operating a freight train carrying hazardous materials from Point A to Point B. The route is 1,000 mi long with 65% Class 4 track and 35% with Class 5 track. The probability (Pr) that this train will be involved in a derailment (der) can be calculated as follows:

$$\Pr(\text{der}) = \sum_{i=1}^{n} R_i m_i$$

where R_i is derailment rate per mile for class i track and m_i is the mileage traversed on class i track.

For the example considered, using the derailment rates in Table 2, the following derailment probability is calculated:

$$\Pr(\text{der}) = (0.53 \times 10^{-6} \times 650) + (0.32 \times 10^{-6} \times 350)$$
$$= 4.6 \times 10^{-4}$$

or a little less than 1 in 2,000.

Consider that the train has 100 cars, and the shipper wants to know the probability that a particular car will derail while en route from A to B. From the derailment rates in Table 2, the following derailment probabilities are calculated:

$$\Pr(\text{der}) = (7.8 \times 10^{-9} \times 650 \times 100) + (4.9 \times 10^{-9} \times 350 \times 100)$$
$$= 6.8 \times 10^{-4}$$

or a little more than 1 in 1,500 that the train will be involved in a derailment.

As shown in this example, longer than average trains will have higher car mile train derailment probabilities. For trains longer than about 67 cars, the risk analyst may choose to use the car mile train derailment rate for a more accurate accident probability (Table 2).

Further, one might consider the following calculation:

$$\Pr(\text{der}) = (77 \times 10^{-9} \times 650) + (42 \times 10^{-9} \times 350)$$
$$= 6.5 \times 10^{-5}$$

or a little less than 1 in 15,000 chance that a particular car will be derailed.

Thus, an individual car would have a 10% (conditional) probability of derailing given that the 100-car train is involved in a derailment. Extending this example to other train lengths would show the inverse relationship between train length and the conditional probability of an individual car's being derailed.

This probability, when combined with the conditional probability of hazardous materials cars releasing, given that they are derailed, can be used to quantify the risk associated with one train of hazardous materials over this particular line. The same approach can be adapted to other questions in regard to whatever cars or trains are of interest.

TABLE 5 Hazardous Materials Derailment and Release Statistics: 1992–2001 Class I Main-Line Freight Trains

FRA Track Class	X & 1	2	3	4	5 & 6	Total
Class I Railroads						
Derailments						
Consists with 1+ Hazmat Car Derailed	78	112	174	281	64	710
Hazmat Cars Derailed	230	409	619	1,034	197	2,492
Average Hazmat Cars Derailed	2.9	3.7	3.6	3.7	3.1	3.5
Consists with 1+ Hazmat Car Released	5	19	40	60	14	138
Hazmat Cars Released	6	37	87	116	27	273
Average Hazmat Cars Released	1.2	1.9	2.2	1.9	1.9	2.0
Average Release Rate	2.5	10.5	10.1	12.7	13.1	10.6
Collisions						
Consists with 1+ Hazmat Car Derailed	4	6	11	20	10	52
Hazmat Cars Derailed	4	18	35	64	28	150
Average Hazmat Cars Derailed	1.0	3.0	3.2	3.2	2.8	2.9
Consists with 1+ Hazmat Car Released	0	2	4	3	2	11
Hazmat Cars Released	0	2	4	5	5	16
Average Hazmat Cars Released	0.0	1.0	1.0	1.7	2.5	1.5
Average Release Rate	0.0	12.5	24.6	8.3	9.2	11.6
HRC Accidents						
Consists with 1+ Hazmat Car Derailed	1	0	5	12	4	22
Hazmat Cars Derailed	1	0	9	32	12	54
Average Hazmat Cars Derailed	1.0	0.0	1.8	2.7	3.0	2.5
Consists with 1+ Hazmat Car Released	0	0	1	4	1	6
Hazmat Cars Released	0	0	1	5	2	8
Average Hazmat Cars Released	0.0	0.0	1.0	1.3	2.0	1.3
Average Release Rate	0.0	0.0	6.7	25.0	25.0	19.7
Other Accidents						
Consists with 1+ Hazmat Car Derailed	2	3	3	6	2	16
Hazmat Cars Derailed	5	11	9	11	5	41
Average Hazmat Cars Derailed	2.5	3.7	3.0	1.8	2.5	2.6
Consists with 1+ Hazmat Car Released	0	1	0	1	1	3
Hazmat Cars Released	0	1	0	1	3	5
Average Hazmat Cars Released	0.0	1.0	0.0	1.0	3.0	1.7
Average Release Rate	0.0	33.3	0.0	16.7	37.5	17.2

TABLE 6 Hazardous Materials Derailment and Release Statistics: 1992–2001 Non-Class I Main-Line Freight Trains

FRA Track Class	X & 1	2	3	4	5 & 6	Total
Non-Class I Railroads						
Derailments						
Consists with 1+ Hazmat Car Derailed	54	72	52	21	0	199
Hazmat Cars Derailed	227	208	145	98	0	678
Average Hazmat Cars Derailed	4.2	2.9	2.8	4.7	0.0	3.4
Consists with 1+ Hazmat Car Released	6	9	13	5	0	33
Hazmat Cars Released	14	15	18	26	0	73
Average Hazmat Cars Released	2.3	1.7	1.4	5.2	0.0	2.2
Average Release Rate	8.3	6.8	15.2	13.8	0.0	10.1
Collisions, HRC Accidents, & Other Accidents[a]						
Consists with 1+ Hazmat Car Derailed	6	4	4	3	0	17
Hazmat Cars Derailed	11	7	5	9	0	32
Average Hazmat Cars Derailed	1.8	1.8	1.3	3.0	0.0	1.9
Consists with 1+ Hazmat Car Released	1	0	0	0	0	1
Hazmat Cars Released	2	0	0	0	0	2
Average Hazmat Cars Released	2.0	0.0	0.0	0.0	0.0	2.0
Average Release Rate	16.7	0.0	0.0	0.0	0.0	5.9

[a] These three accident groups are lumped together as only one accident (other category) resulted in a hazmat release.

CONCLUSIONS

Rail transportation risk analysis relies on the accurate estimation of accident rates. In hazardous materials transportation, the derailment rate for main-line freight trains is the rate most applicable, because this is where the majority of exposure occurs. The results presented in this paper provide updated track class-specific accident rate estimates for Class I and non-Class I railroads.

The importance of using more precise estimates of derailment rate is illustrated by the following comparison. The average main-line derailment rate for Class I railroads over the period 1992 to 2001 was approximately 1 per million freight train miles (Figure 1). However, much of the U.S. main-line trackage over which the bulk of rail freight is shipped is FRA Class 4 or 5 track with estimated derailment rates of 0.53 and 0.32 derailments per million train miles, respectively (Table 2). Estimating risk along segments with Class 4 or 5 track based on the average main-line rates would potentially overstate the risk by a factor of 2 or 3. Conversely, the risk along a segment of Class 2 track would potentially be understated by a factor of 6 (Table 2).

Future work aims to extend this analysis to provide more detailed analyses of other derailment factors, including accident cause, train speed, length, and position in train. These factors are also important in calculating the conditional probabilities of particular cars within the consist being derailed. Categorization of accidents into those correlated with the number of train miles versus car miles operated will enable better understanding of how specific derailment prevention measures will affect risk (*5, 11, 12*). Combining these derailment rates with up-to-date information on railcar performance in accidents will permit the risk analyst to calculate the probability of a hazardous materials release for any particular shipment or rail line segment.

ACKNOWLEDGMENTS

The authors appreciate the helpful comments and review of the analysis and manuscript provided by Peter French and all other individuals involved in railroad and hazardous materials transportation safety who have provided insight into the topic of this paper. The first author was supported by a research grant from the Burlington Northern and Santa Fe Railway during part of the time this analysis was conducted.

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Publication of this paper sponsored by Transportation of Hazardous Materials Committee.