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Hazards Associated with HSR Operations Adjacent to Conventional Tracks – Enhanced Literature Review Part I: Summary Report

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6. AUTHOR(S)
M. R. Saat, C.P.L. Barkan

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
University of Illinois at Urbana-Champaign
Rail Transportation and Engineering Center –RailTEC
Department of Civil and Environmental Engineering
205 N. Mathews Ave
Urbana, IL 61801

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13. ABSTRACT (Maximum 200 words)
The Federal Railroad Administration (FRA) set out to develop a best practices document which provides information on the design considerations and potential risk mitigations for high-speed rail (HSR) systems adjacent to and sharing corridors with existing conventional railway operations. The objective of this project is to provide input to and support the development of the best practices document by conducting a comprehensive literature review of the 11 hazards associated with HSR operations adjacent to conventional tracks that were identified by FRA. This report is the first part of the three-part project that defines the scope of the literature review and summarizes the results from the literature review. Causal analysis was conducted for mainline passenger and freight train accidents to understand major factors leading to passenger and freight train accidents and identify accident causes that are more relevant to HSR systems adjacent to and sharing corridors with existing conventional railway operations.

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ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in)	=	2.5 centimeters (cm)
1 foot (ft)	=	30 centimeters (cm)
1 yard (yd)	=	0.9 meter (m)
1 mile (mi)	=	1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2)	=	6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2)	=	0.09 square meter (m^2)
1 square yard (sq yd, yd^2)	=	0.8 square meter (m^2)
1 square mile (sq mi, mi^2)	=	2.6 square kilometers (km^2)
1 acre = 0.4 hectare (he)	=	4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz)	=	28 grams (gm)
1 pound (lb)	=	0.45 kilogram (kg)
1 short ton = 2,000 pounds (lb)	=	0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp)	=	5 milliliters (ml)
1 tablespoon (tbsp)	=	15 milliliters (ml)
1 fluid ounce (fl oz)	=	30 milliliters (ml)
1 cup (c)	=	0.24 liter (l)
1 pint (pt)	=	0.47 liter (l)
1 quart (qt)	=	0.96 liter (l)
1 gallon (gal)	=	3.8 liters (l)
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1 cubic yard (cu yd, yd^3)	=	0.76 cubic meter (m^3)

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1 centimeter (cm)	=	0.4 inch (in)
1 meter (m)	=	3.3 feet (ft)
1 meter (m)	=	1.1 yards (yd)
1 kilometer (km)	=	0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2)	=	0.16 square inch (sq in, in^2)
1 square meter (m^2)	=	1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2)	=	0.4 square mile (sq mi, mi^2)
10,000 square meters (m^2)	=	1 hectare (ha) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gm)	=	0.036 ounce (oz)
1 kilogram (kg)	=	2.2 pounds (lb)
1 tonne (t)	=	1,000 kilograms (kg)
	=	1.1 short tons

VOLUME (APPROXIMATE)

1 milliliter (ml)	=	0.03 fluid ounce (fl oz)
1 liter (l)	=	2.1 pints (pt)
1 liter (l)	=	1.06 quarts (qt)
1 liter (l)	=	0.26 gallon (gal)
1 cubic meter (m^3)	=	36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3)	=	1.3 cubic yards (cu yd, yd^3)

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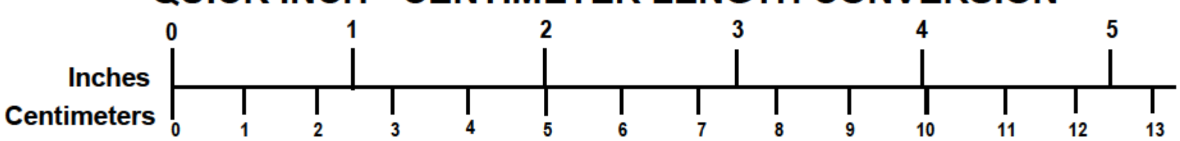

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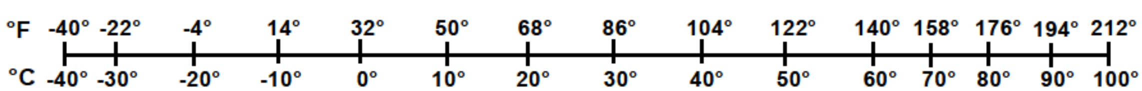

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Executive Summary

Booz Allen Hamilton (Booz Allen) and the Rail Transportation and Engineering Center (RailTEC) in the Department of Civil and Environmental Engineering at the University of Illinois at Urbana-Champaign (UIUC) were requested by the Federal Railroad Administration (FRA) to assist in the development of a best practices document which provides information on the design considerations and potential risk mitigations for high-speed rail (HSR) systems adjacent to and sharing corridors with existing conventional railway operations. With the increasing demand for HSR operations, the potential hazards between HSR tracks and adjacent conventional tracks became more pronounced and needed to be considered. The objective of this project is to provide input to and support the development of the best practices document by conducting a comprehensive literature review of the following hazards associated with HSR operations adjacent to conventional tracks:

- Derailment on adjacent tracks
- Shifted load on adjacent tracks
- Aerodynamic interaction between trains on adjacent tracks
- Ground-borne vibration and its effect on HSR track geometry
- Intrusion of maintenance-of-way (MOW) staff and equipment working on the adjacent track
- Obstruction hazard resulting from an adjacent track (non-derailment and grade-crossing collisions)
- Drainage problem affecting either the HSR track or the adjacent track
- Evacuation of passengers from trains on the adjacent track
- Hazardous materials on the adjacent track
- Fire on the adjacent track
- Electromagnetic interference between trains and wayside equipment on adjacent tracks

The initial literature review was enhanced by an additional, detailed literature review on specific hazards that FRA deems as requiring more information as well as train accident analyses to identify accident causes that are relevant to shared corridor operations. Booz Allen and RailTEC then developed a draft best practices document based on the enhanced literature review and additional risk analyses. The project consists of three parts: (1) a summary report that defines the scope of the literature review and summarizes the results from the comprehensive literature review; (2) a draft best practices document for understanding, addressing, and mitigating the risk of HSR systems adjacent to and sharing corridors with existing conventional railway operations using qualitative and quantitative risk management approaches; and (3) a complete and enhanced literature review of mitigating the risk of HSR systems adjacent to and sharing corridors with existing conventional railway operations.

This report presents the first part of the project. An overview of the literature review and a comparison of the literature review and an enhanced literature review were presented. Results from the enhanced literature review were summarized, including eminent location where the aforementioned hazards may occur, key influencing factors of these hazards, and potential risk mitigation strategies for these hazards. Causal analysis was conducted for mainline passenger and freight train accidents to understand major factors leading to passenger and freight train accidents and identify accident causes that are more relevant to HSR systems adjacent to and sharing corridors with existing conventional railway operations.

1. Introduction

The following paragraphs give the overview of this summary report, including the background and objective of the literature review, approaches used to conduct the literature review, scope of this study, and the organization of the report.

1.1 Background

To address the existing gap between the literature review and the best practices document, Booz Allen Hamilton proposed the second phase of this effort, the development of an enhanced literature review. As demonstrated in Figure 1.1, the enhanced literature review will bridge the gap between these two major efforts and result in a somewhat lower effort required to develop the best practices document. The enhanced literature review will be designed and developed to resemble the best practices document but with more technical detail to evaluate and prioritize the importance of hazards, while the objective of the best practices document is still to provide information on the design considerations, potential risk mitigations for hazards related to the operation of high-speed rail (HSR) systems adjacent to and sharing corridors with existing conventional railway operations. The enhanced literature review will therefore include a risk quantification component.

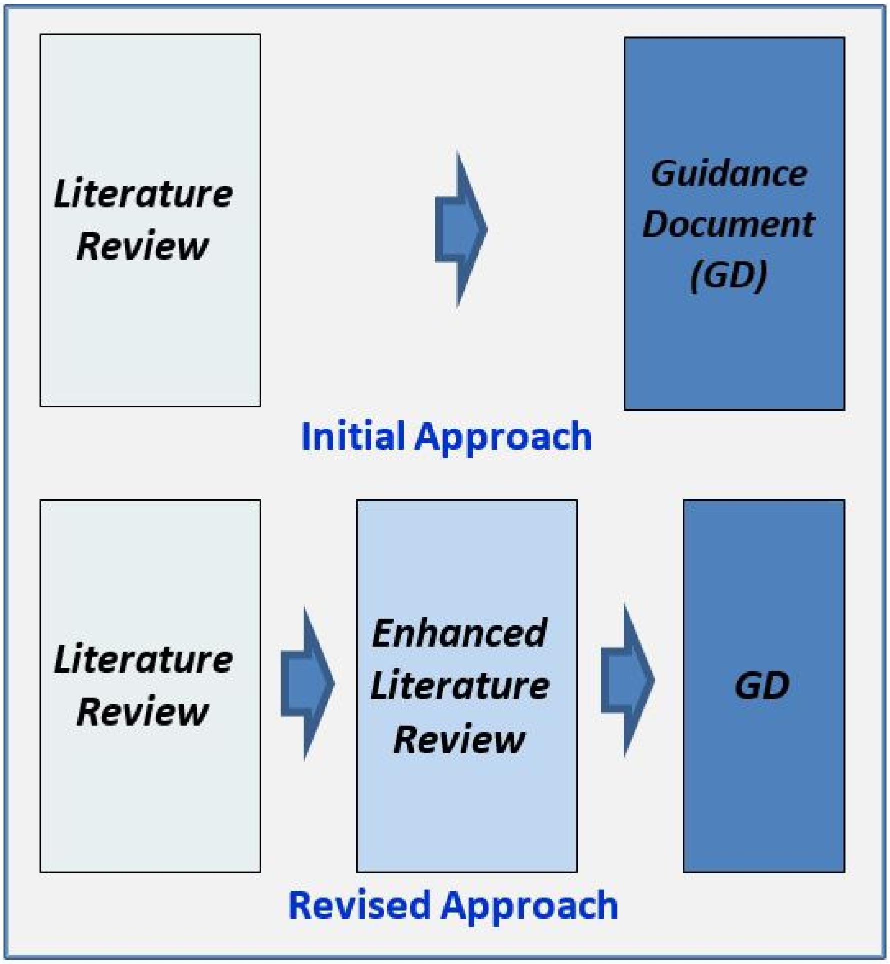

Figure 1.1 Relative Level of Effort

1.2 Objectives

The primary objectives of the enhanced literature review include the following:

1. Conduct a detailed analysis to define and/or refine and describe in enhanced detail the hazards associated with HSR and conventional rail operations.
2. Implement screening procedures to identify locations where each hazard is eminent.
3. Add influencing factors or precursors of each hazard which can be used as potential metrics to assess the hazard.
4. Propose mitigation strategies to address the hazard.

1.3 Overall Approach

Table 1.1 is a comparison of the first two phases, the literature review and enhanced literature review.

Table 1.1 Comparison of Literature Review and Enhanced Literature Review

	Literature Review (Phase I)	**Enhanced Literature Review (Phase II)**
Hazards Focus	The following hazards were researched: 1. Derailment on adjacent tracks 2. Shifted load on an adjacent track 3. Aerodynamic interaction between trains on adjacent tracks 4. Ground-borne vibration and its effect on HSR track geometry 5. Intrusion of maintenance-of-way MOW staff and equipment working on the adjacent track 6. Obstruction hazard resulting from an adjacent track (non-derailment and grade-crossing collisions) 7. Drainage problem affecting either the HSR track or the adjacent track, 8. Evacuation of passengers from trains on the adjacent track 9. Hazardous materials on the adjacent track 10. Fire on the adjacent track 11. Electromagnetic interference (EMI) between trains and wayside equipment on adjacent tracks	A secondary, more thorough, review of the 11 hazards will occur, but will focus on those FRA deems as requiring more information. The team will synthesize the literature review to identify: 1. Potential locations on a typical HSR system where each hazard is eminent 2. Influencing factors or precursors of each hazard that can be used as potential metrics to assess the hazard 3. Mitigation strategies to address each hazard. 4. Input from Class I railroads, state agencies (especially in CA and IL), and international railway operators will be gathered and evaluated.
Research Methodology	A standard literature search methodology, using a combination of academic journal subscriptions (owned by UI) as well as Internet research, was performed.	A combination of standard literature search methodology, fault tree analysis, and other risk assessment techniques, interviews, and surveys will be implemented.
	Literature Review (Phase I)	**Enhanced Literature Review (Phase II)**
FRA Rail Equipment Accident/ Incident Database Review	No review of the database was performed.	A thorough analysis of the database will be conducted to identify conventional train accident causes which may be relevant to future HSR operations adjacent to conventional tracks. The intention of the analysis is to deduce high-priority accident causes of conventional passenger and freight train operations on multiple-track or shared corridors.
Risk Identification	A risk identification phase was performed with some initial risk mitigations identified in an overall risk management framework. Limited quantitative analysis was performed for the defined hazards. However, an appendix was added to the literature review to include a semi-quantitative risk model developed by the	The identification of influencing factors and precursors of hazards will be performed to assist in the development of risk metrics and, ultimately, the best practices document. Additional risk mitigations will be identified and evaluated. Guidelines to create risk inventory or risk register to record HSR-project-specific hazards, assessments of the associated

	Literature Review (Phase I)	Enhanced Literature Review (Phase II)
	RailTEC team. This analytical model can be used to prioritize and mitigate the risk focusing on adjacent-track accidents.	influencing factors or precursors, and planned/completed risk mitigation strategies will be developed.
Human Factors (HF)	Limited recommendations on HF training was developed. HF training focused on the loading/unloading and MOW worker hazard.	Recommendations of training to improve overall HF performance will be included.
Domestic Stakeholder Outreach	Limited domestic stakeholder outreach occurred.	In this phase, the team will reach out to Class I railroads and state agencies (especially in CA and IL) to gather and review existing practices to manage associated risks. The team will incorporate their relevance to achieve the objective of this phase.
International Stakeholder Outreach	Limited international research was considered. Only publicly-available literature on the international experience was performed.	The initiation of a new survey and interviews will be performed involving rail operators and industry stakeholders in Europe (e.g., Société nationale des chemins de fer français in France, Administrador de Infraestructuras Ferroviarias in Spain, and/or ItaliaRail in Italy), and in Asia (rail operators in China, Taiwan, and/or Thailand). The purpose will be to obtain and review internal reports, manuals, or experiences they can share. To address this component fully, however, would require the development of new surveys and interviews with rail operators in those countries.

1.4 Scope

The scope of this research focuses on identifying locations with higher risk influencing factors and risk mitigation strategies related to the safety issues of operating HSR adjacent to conventional railroad corridors.

1.5 Organization of the Report

After the Introduction, Section 2 summarizes high-risk locations, influencing factors, and potential risk mitigation strategies for the 11 hazards related to HSR operations adjacent to conventional railroad systems. Section 3 presents a passenger train accident analysis on shared-use rail corridors and identified major train accident causes. Section 4 presents conclusions based on previous analyses.

2. Literature Review Summary

The previously completed literature review report from Phase III of this project was synthesized and an additional literature review was completed to identify (1) potential locations on a typical HSR system where each hazard is eminent, (2) the influencing factors or precursors of each hazard that can be used as potential metrics to assess the hazard, and (3) mitigation strategies to address the hazard. The following sub-sections summarize the key results from the literature review.

2.1 Locations Where Each Hazard Is Eminent

Different hazards occur at different places, and understanding where each hazard may occur is important for engineers and planners to appropriately address the potential risk when designing or planning a shared-use rail operation. Table 2.1 summarizes the general locations along a shared-use rail corridor where each hazard is eminent.

Table 2.1 General Locations Where Each Hazard is Eminent

	Hazard	Location
1	Derailment on adjacent tracks	Along a shared-use rail corridor with multiple tracks
2	Shifted load on adjacent tracks	Along a shared-use rail corridor with freight train services
3	Aerodynamic interaction between trains on adjacent tracks	Along a shared-use rail corridor with multiple tracks, tunnels, and stations where trains operate at high speed
4	Ground-borne vibration and its effect on HSR track geometry	Along a shared-use rail corridor where trains operating at high speed, especially at locations with subgrade and track infrastructure conditions susceptible to vibrations, and at special track locations (e.g., switches and turnouts)
5	Intrusion of MOW staff and equipment working on adjacent tracks	Along a shared-use rail corridor where track maintenance activities frequently take place and locations with limited clearances (e.g., bridges, tunnels)
6	Obstruction hazard resulting from adjacent tracks (non-derailment collisions)	Along a shared-use rail corridor close to other rail or highway vehicles (e.g., yards, grade crossings)
7	Drainage problem affecting either the HSR track or adjacent tracks	Along a shared-use rail corridor especially with areas of high precipitation/snow, vegetation, or insufficient drainage systems
8	Evacuation of passengers from trains on adjacent tracks	Along a shared-use rail corridor with multiple tracks
9	Hazardous material transportation on adjacent tracks	Along a shared-use rail corridor with freight trains transporting hazardous materials
10	Fire on adjacent tracks	Along a shared-use rail corridor with freight trains transporting flammable liquids and/or gases and other locations near fuel-based activities (e.g., power stations, gas stations)
11	EMI between trains and wayside equipment on adjacent tracks	Along a shared-use rail corridor where the high-voltage overhead catenary wires present

2.2 Influencing Factors or Precursors of Each Hazard

There are different factors that could affect the individual hazard. Identifying these factors help to quantify and evaluate the risk of the hazard. Identified major factors include track center spacing between HSR tracks and conventional tracks, train speed (the maximum authorized speed for HSR and conventional rail systems), track geometry (curvature, elevation, maintenance standard, etc.), train equipment design, rail infrastructure, and human factors. A specific influencing factor may affect multiple hazards. Table 2.2 summarizes the key influencing factors for each hazard.

Table 2.2 Key Influencing Factors for Each Hazard

	Hazard	Key Influencing Factors
1	Derailment on adjacent tracks	Track center spacing, train speed, human factors, track geometry, type of rail infrastructure, train control systems
2	Shifted load on adjacent tracks	Track center spacing, train speed, human factors, track geometry, train control systems
3	Aerodynamic interaction between trains on adjacent tracks	Track center spacing, train speed, train equipment design, wind condition
4	Ground-borne vibration and its effect on HSR track geometry	Track center spacing, train speed, track geometry, type of rail infrastructure, soil foundation/subgrade characteristics
5	Intrusion of MOW staff and equipment working on adjacent tracks	Track center spacing, train speed, human factors
6	Obstruction hazard resulting from adjacent tracks (non-derailment collisions)	Track center spacing, train speed, human factors, track geometry, train control systems
7	Drainage problem affecting either the HSR track or adjacent tracks	Track center spacing, soil foundation/subgrade characteristics, track geometry, type of rail infrastructure
8	Evacuation of passengers from trains on adjacent tracks	Track center spacing, train equipment design, human factors
9	Hazardous material transportation on adjacent tracks	Track center spacing, train equipment design, hazardous materials traffic volume
10	Fire on adjacent tracks	Track center spacing, train equipment design, human factors, flammable product traffic volume
11	EMI between trains and wayside equipment on adjacent tracks	Train equipment design, type of rail infrastructure, train control systems

2.3 Mitigation Strategies to Address Each Hazard

The ultimate goal of assessing the risk of each hazard is to be able to prevent or reduce the risk of each hazard in the shared-use rail operation. Based on the literature review, identified general locations where each hazard is eminent and the associated influencing factors, several risk mitigation strategies are proposed. Table 2.3 summarizes the potential risk mitigation strategies for each hazard.

Table 2.3 Potential Risk Mitigation Strategies for Each Hazard

	Hazard	Potential Risk Mitigation Strategies
1	Derailment on adjacent tracks	Proper track center spacing, installation of intrusion detection systems, building physical barriers, improved employee training, temporal separation
2	Shifted load on adjacent tracks	Proper track center spacing, installation of intrusion detection systems, building physical barriers, improved employee training on cargo securement, temporal separation
3	Aerodynamic interaction between trains on adjacent tracks	Proper track center spacing, installation of intrusion detection systems, building physical barriers, reduced train speed, temporal separation
4	Ground-borne vibration and its effect on HSR track geometry	Proper track center spacing, reduced train speed
5	Intrusion of MOW staff and equipment working on adjacent tracks	Proper track center spacing, installation of intrusion detection systems, building physical barriers, improved employee training, reduced train speed, temporal separation
6	Obstruction hazard resulting from adjacent tracks (non-derailment collisions)	Proper track center spacing, installation of intrusion detection systems, building physical barriers, improved employee training, grade crossing protection
7	Drainage problem affecting either the HSR track or adjacent tracks	Proper track center spacing, soil improvement, improved drainage
8	Evacuation of passengers from trains on adjacent tracks	Proper track center spacing, installation of intrusion detection systems, building physical barriers, improved employee training on safe passenger evacuation, enhanced rail equipment design
9	Hazardous material transportation on adjacent tracks	Proper track center spacing, building physical barriers, temporal separation, enhanced rail car design to prevent hazardous material release, temporal separation
10	Fire on adjacent tracks	Proper track center spacing, building physical barriers, temporal separation, enhanced rail equipment design
11	EMI between trains and wayside equipment on adjacent tracks	Improved employee training, better rail equipment design to prevent or reduce electromagnetic field effect

3. Train Accident Data Analysis

A thorough analysis of the FRA rail equipment accident/incident database was conducted to identify conventional train accident causes that may be relevant to future HSR operations adjacent to conventional tracks. The identified key accident causes can serve as more detailed, lower-level influencing factors or accident precursors to the high-level ones described in Section 2.2. In addition, results from the train accident data analysis can be used in future risk assessments of HSR operations adjacent to conventional tracks. In particular, the passenger train accident analysis would be applicable to HSR operations adjacent to tracks with conventional passenger train operations. Similarly, the freight train accident analysis would be applicable to HSR operations adjacent to tracks with freight passenger train operations.

3.1 Causal Analysis of Passenger and Freight Train Accident Analyses

Train accident data between 1999 and 2013 from the FRA rail equipment accident/incident database were analyzed to examine the effects of different accident causes on conventional passenger and freight train accidents. The FRA database does not have sufficient information regarding accident locations to identify shared-use corridors. However, the majority of passenger trains run on freight-owned infrastructures, and most of them are on shared trackage. Therefore, it is reasonable to assume that all the mainline passenger train accidents are on shared-use rail corridors. Although not all freight train accidents occur on shared-use rail corridors, due to large sample size of accidents, analyzing all them still help to identify more relevant accident causes (the relatively more frequent and/or more severe causes).

In these analyses the frequency of an accident is represented by the accident rate per unit distance traveled. While several metrics could be used to represent the severity of an accident (e.g., cost, casualty, number of cars derailed), number of cars derailed was selected, as it is expected to affect the cars' dispersion distance away from a track to potentially intrude other tracks on a shared rail corridor. The multiplication of the frequency and severity of an accident was used to represent the risk.

Over the 15-year interval from 1999 to 2013, there were 907 mainline passenger train accidents, including 441 grade crossing accidents, 264 obstruction accidents, 141 derailments, 49 collisions, and 12 miscellaneous accidents. Figure 3.1 shows the mainline passenger train accident rate over the 15-year interval sorted by five types of accidents: grade crossing, derailment, collision, obstruction, and miscellaneous. Over this period, grade crossing accidents have been the most frequent type of passenger train accident, followed by obstructions and then derailments. On freight side, there were 8,947 mainline accidents, including 6,286 derailments, 1,876 grade crossing accidents, 379 collisions, 265 obstructions, and 141 miscellaneous accidents. Figure 3.2 shows mainline freight train accident rate over the 15-year interval sorted by five types of accidents: grade crossing, derailment, collision, obstruction, and miscellaneous. Derailments have been the most frequent accidents, followed by grade crossing accidents and collisions. Passenger train accident rates have been consistently lower than freight train accident rates.

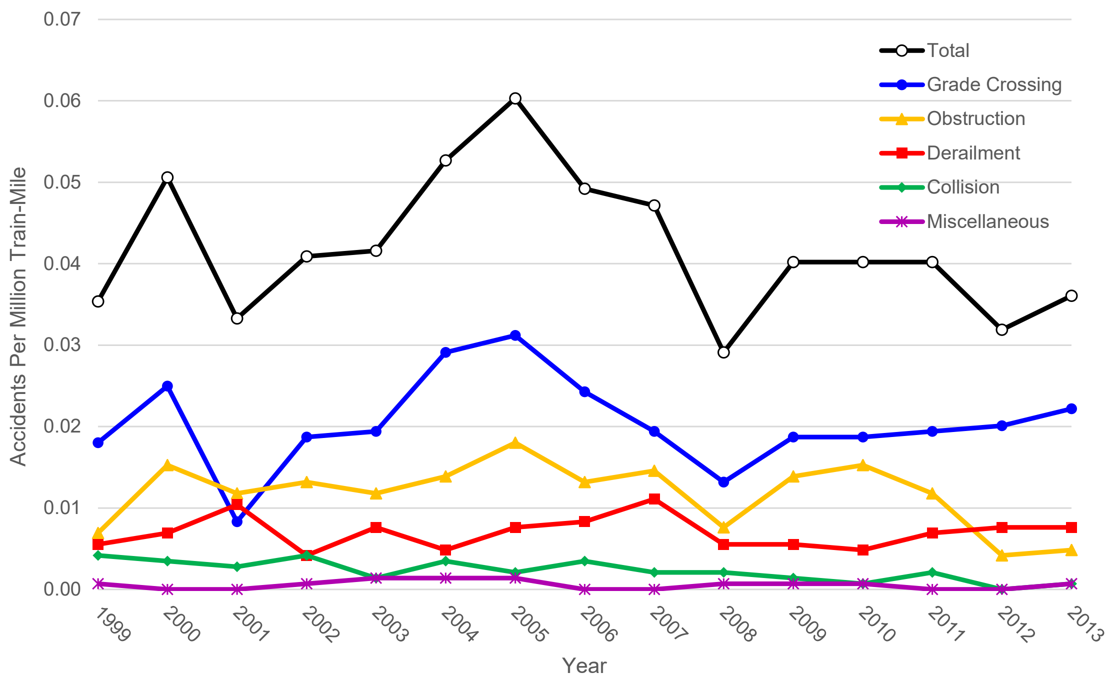

Figure 3.1 Mainline Passenger Train Accident Rates by Type of Accidents, 1999–2013

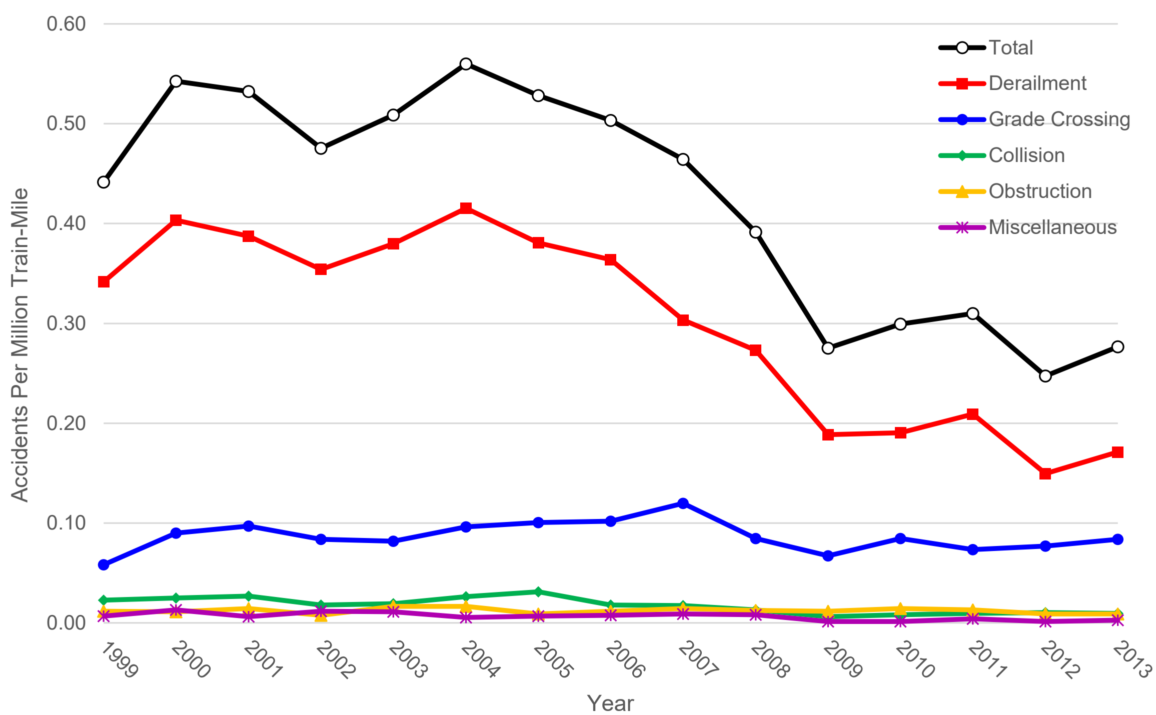

Figure 3.2 Mainline Freight Train Accident Rates by Type of Accidents, 1999–2013

To measure the risk from different types of accidents, researchers plotted the number of accidents per unit train travel to represent the accident frequency versus the average severity of mainline passenger train accidents (Figure 3.3) and freight train accidents (Figure 3.4) by accident type. The graph is divided into four quadrants on the basis of the average frequency and severity along each axis. It enables easy comparison of the relative frequency and severity of different accident types. Accident types in the upper-right quadrant would be the most likely to pose the greatest risk because they are both more frequent and more severe than the average. The data indicate that the types of train accident most likely to result in high-number-of-cars-derailed incidents are derailments and collisions. Although they account for only about 21 percent of all passenger train accidents, derailments and collision combined resulted in about 68 percent of the total number of cars derailed (Table 3.1). For freight train accidents, derailments are both frequent and severe and thus fall in the upper-right quadrant of the graph. Collisions and derailments are still the most severe accidents among all accident types. Although grade crossing accidents are the most common type of accident, they are among the least severe in their consequences. Collisions and derailments are caused by the interaction of two or more trains and motivate concern in shared-use corridors regarding passenger train collisions with a derailed freight train, or vice versa. Therefore, the next section of this report examines mainline passenger and freight derailments and collisions in more detail.

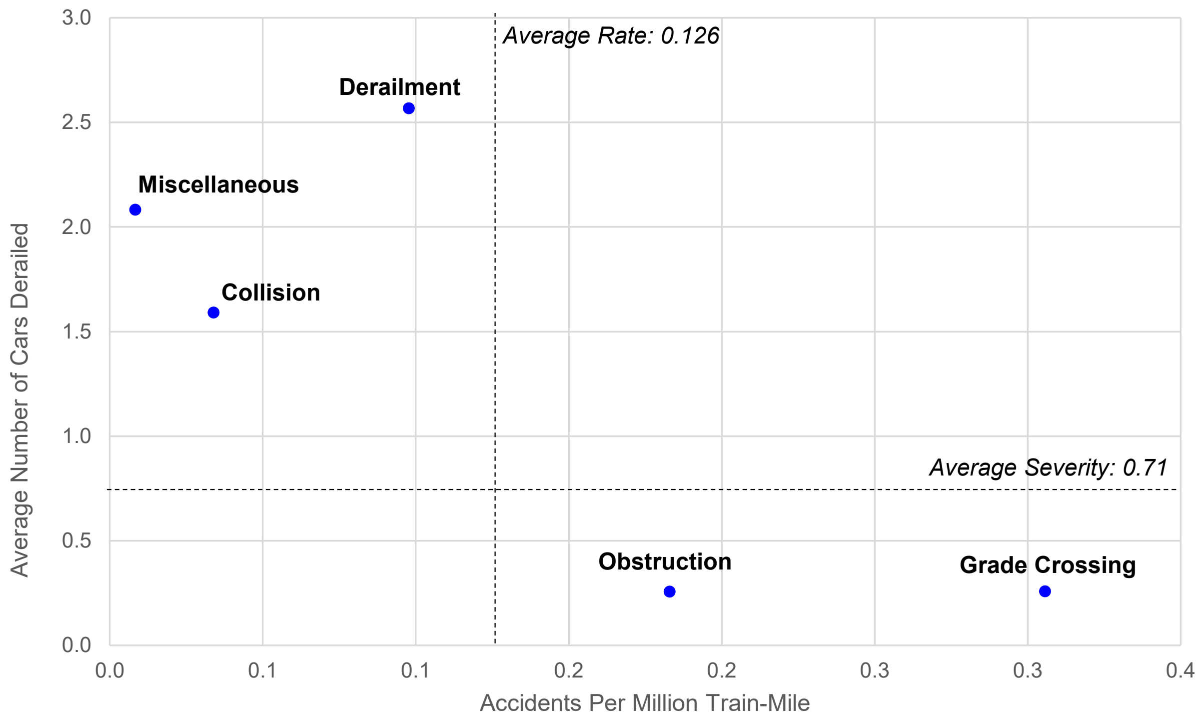

Figure 3.3 Frequency and Severity Graph of Mainline Passenger Train Accidents by Type of Accident, 1999–2013

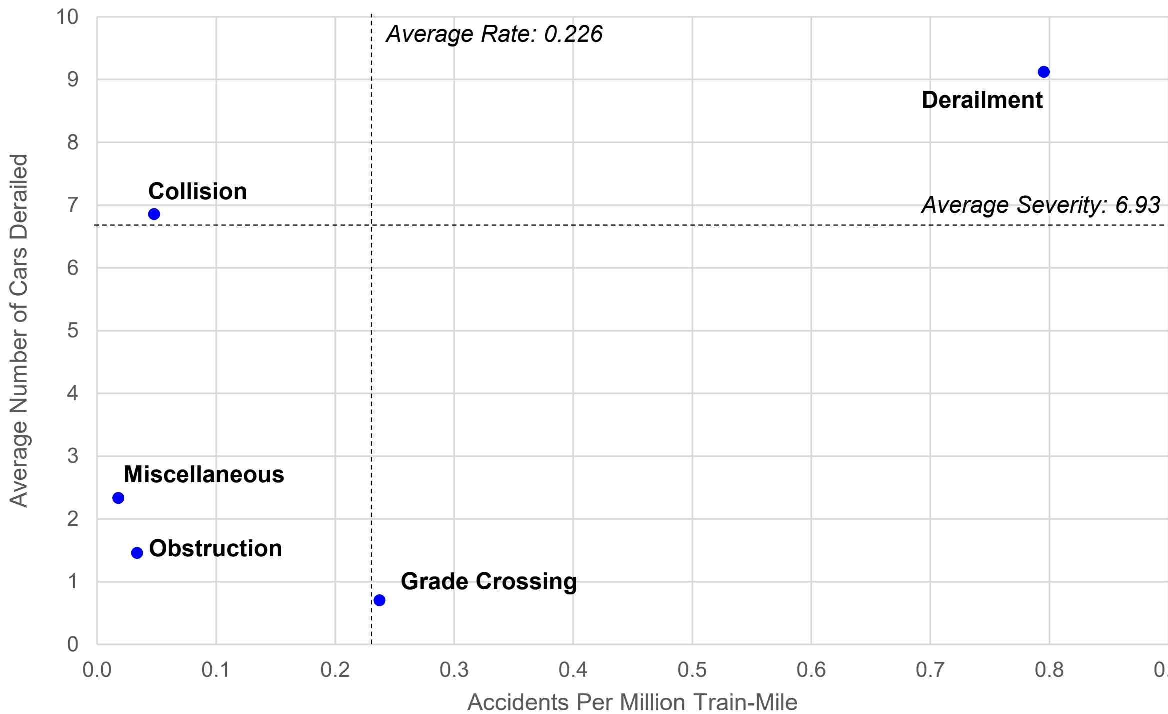

Figure 3.4 Frequency and Severity Graph of Mainline Freight Train Accidents by Type of Accident, 1999–2013

Table 3.1 Mainline Passenger Accident Frequency and Severity by Type of Accident, Sorted by Frequency

	Frequency	Percentage	Average Accident Rate	Total Cars Derailed	Percentage	Average Cars Derailed
Grade Crossing	441	48.6%	0.306	114	17.6%	0.26
Obstruction	264	29.1%	0.183	68	10.5%	0.26
Derailment	141	15.5%	0.098	362	56.0%	2.57
Collision	49	5.4%	0.034	78	12.1%	1.59
Miscellaneous	12	1.3%	0.008	25	3.9%	2.08
Total	907	100.0%	0.629	647	100.0%	0.71

Table 3.2 Mainline Freight Accident Frequency and Severity by Type of Accident, Sorted by Frequency

	Frequency	Percentage	Average Accident Rate	Total Cars Derailed	Percentage	Average Cars Derailed
Derailment	6,286	70.3%	0.795	57,350	92.5%	9.12
Grade Crossing	1,876	21.0%	0.237	1,323	2.1%	0.71
Collision	379	4.2%	0.048	2,600	4.2%	6.86
Obstruction	265	3.0%	0.034	387	0.6%	1.46
Miscellaneous	141	1.6%	0.018	329	0.5%	2.33
Total	8,947	100.0%	1.132	61,989	100.0%	6.93

3.1.1 Passenger Train Derailment and Collision Accident Cause Analysis

FRA train accident cause codes are hierarchically organized and categorized into major cause groups—track, equipment, human factors, signal, and miscellaneous. Each of these major cause groups has subgroups that include individual cause codes of related causes, such as roadbed, track geometry, etc. within the track group, and similar subgroups within the other major cause groups. In this Section, alternative FRA subgroups developed by Arthur D. Little (ADL) are used in which similar cause codes were grouped based on experts' opinions (Arthur D. Little, 1996). Table 3.3 shows the ADL's groupings of FRA accident cause codes.

ADL's groupings enable greater resolution for certain causes. For example, FRA combines broken rails, joint bars, and rail anchors in the same subgroup, whereas the ADL grouping distinguishes between broken rail and joint bar defects. Figure 3.5 shows the frequency and severity graphs by the major accident cause categories, namely infrastructure-related, human factor related, mechanical related, signal and communication related, and miscellaneous. The graph is also divided into four quadrants to enable easy comparison of the relative frequency and severity of different accident cause groups. The infrastructure-related cause category was identified as the most severe group, and the human factor-related cause category had higher frequency but lower severity. Both human factor-related and infrastructure-related accident cause categories consistently represented the most frequent or severe accident cause categories and therefore were analyzed in more detail.

Table 3.3 ADL's Grouping for FRA Accident Cause Group Cause Codes

Cause Group	Description	CM/TM	FRA Cause Codes										
01T	Roadbed Defects	CM	T001	T099									
02T	Non-Traffic, Weather Causes	TM	T002	T401	T402	T403							
03T	Wide Gauge	CM	T110	T111	T112	T113							
04T	Track Geometry (excl. Wide Gauge)	CM	T101	T102	T103	T104	T105	T106	T107	T108	T199		
05T	Buckled Track	CM	T109										
06T	Rail Defects at Bolted Joint	CM	T201	T211									
07T	Joint Bar Defects	CM	T213	T214	T215	T216							
08T	Broken Rails or Welds	CM	T202	T203	T204	T207	T208	T210	T212	T218	T219	T220	T221
09T	Other Rail and Joint Defects	CM	T299										
10T	Turnout Defects - Switches	CM	T307	T308	T309	T310	T311	T312	T313	T314	T315	T319	
11T	Turnout Defects - Frogs	CM	T304	T316	T317	T318							
12T	Misc. Track and Structure Defects	CM	T205	T206	T217	T222	T301	T302	T303	T305	T306	T399	T499
			S001	S002	S003	S004	S005	S006	S007	S008	S009	S010	S011
01S	Signal Failures	TM	S012	S013	S099								
01E	Air Hose Defect (Car)	CM	E00C										
02E	Brake Rigging Defect (Car)	CM	E07C										
03E	Handbrake Defects (Car)	CM	E08C	E0HC									
04E	UDE (Car or Loco)	CM	E05C	E05L									
05E	Other Brake Defect (Car)	CM	E01C	E02C	E03C	E04C	E06C	E09C					
06E	Centerplate/Carbody Defects (Car)	CM	E20C	E21C	E22C	E23C	E24C	E25C	E26C	E27C	E29C		
07E	Coupler Defects (Car)	CM	E30C	E31C	E32C	E33C	E34C	E35C	E36C	E37C	E39C		
08E	Truck Structure Defects (Car)	CM	E44C	E45C									
09E	Sidebearing, Suspension Defects (Car)	CM	E40C	E41C	E42C	E43C	E47C	E48C					
10E	Bearing Failure (Car)	CM	E52C	E53C									
11E	Other Axle/Journal Defects (Car)	CM	E51C	E54C	E55C	E59C							
12E	Broken Wheels (Car)	CM	E60C	E61C	E62C	E63C	E6AC						
13E	Other Wheel Defects (Car)	CM	E64C	E65C	E66C	E67C	E68C	E69C					
14E	TOFC/COFC Defects	CM	E11C	E12C	E13C	E19C							
			E07L	E40L	E41L	E42L	E43L	E44L	E45L	E46L	E47L	E48L	E4TL
			E49L	E51L	E52L	E53L	E54L	E55L	E59L	E60L	E61L	E62L	E63L
15E	Loco Trucks/Bearings/Wheels	CM	E64L	E65L	E66L	E67L	E68L	E6AL	E69L	E70L	E77L		
16E	Loco Electrical and Fires	CM	E71L	E72L	E73L	E74L	E76L						
			E00L	E01L	E02L	E03L	E04L	E06L	E08L	E0HL	E09L	E20L	E21L
			E22L	E23L	E24L	E25L	E26L	E27L	E29L	E30L	E31L	E32L	E33L
17E	All Other Locomotive Defects	CM	E34L	E35L	E36L	E37L	E39L	E79L	E99L				
18E	All Other Car Defects	CM	E49C	E80C	E81C	E82C	E83C	E84C	E85C	E86C	E89C	E99C	
19E	Stiff Truck (Car)	CM	E46C										
20E	Track/Train Interaction (Hunting) (Car)	CM	E4TC										
21E	Current Collection Equipment (Loco)	CM	E75L										
			H510	H511	H512	H513	H514	H515	H516	H517	H518	H519	H520
01H	Brake Operation (Main Line)	TM	H521	H525	H526								
02H	Handbrake Operations	TM	H017	H018	H019	H020	H021	H022	H025	M504			
03H	Brake Operations (Other)	TM	H008	H099									
04H	Employee Physical Condition	TM	H101	H102	H103	H104	H199						
			H201	H202	H203	H204	H205	H206	H207	H208	H209	H215	H216
05H	Failure to Obey/Display Signals	TM	H217	H299									
06H	Radio Communications Error	TM	H210	H211	H212	H405							
			H301	H302	H303	H304	H305	H306	H307	H308	H309	H310	H311
07H	Switching Rules	TM	H312	H313	H314	H315	H399						
08H	Mainline Rules	TM	H401	H402	H403	H404	H406	H499					
			H501	H502	H503	H504	H505	H506	H507	H508	H509	H522	H523
09H	Train Handling (excl. Brakes)	TM	H524	H599									
10H	Train Speed	TM	H601	H602	H603	H604	H605	H606	H699				
11H	Use of Switches	TM	H701	H702	H703	H704	H705	H799					
12H	Misc. Human Factors	TM	H821	H822	H823	H824	H899	H991	H992	H993	H994	H995	H999
01M	Obstructions	TM	M101	M102	M103	M104	M105	M199	M402	M403	M404		
02M	Grade Crossing Collisions	TM	M301	M302	M303	M304	M305	M306	M307	M399			
03M	Lading Problems	CM	M201	M202	M203	M204	M205	M206	M207	M299	M409	M410	
04M	Track-Train Interaction	CM	M405										
05M	Other Miscellaneous	TM	M401	M406	M407	M408	M501	M502	M503	M505	M599		

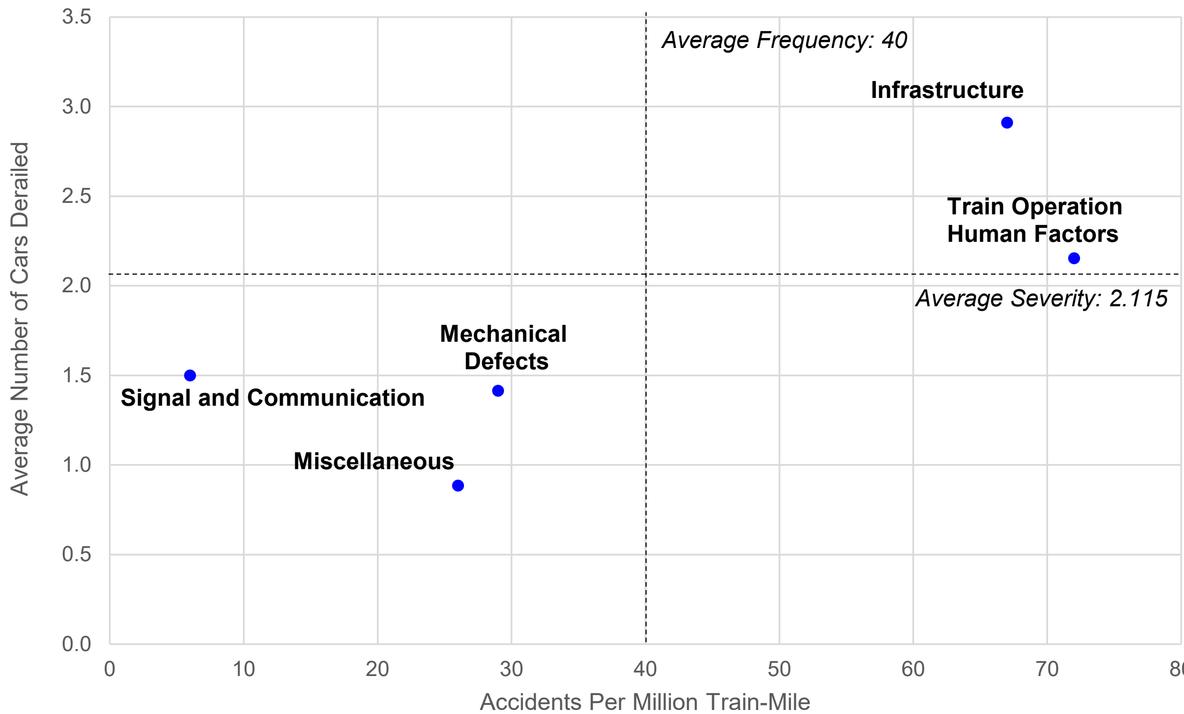

Figure 3.5 Frequency and Severity Graph of Mainline Passenger Derailments and Collisions, 1999–2013, by Accident Cause Category, with Average Cars Derailed as Severity Indicator

In order to gain insights on what specific accident causes would result in high frequency or severity, accident cause categories were broken down to accident cause groups. Table 3.4 shows the accident frequency and severity for individual accident cause groups. The accident cause groups are categorized into infrastructure related (T), human-factor related (H), mechanical related (E), signal and communication related (S), and miscellaneous (M). The risk of each accident cause group was calculated by multiplying its accident rate by its severity. Overall, the top ten accident cause groups with the highest risk are:

- Failure to Obey/Display Signals (05H)
- Wide Gauge (03T)
- Train Speed (10H)
- Turnout Defects–Switches (10T)
- Broken Rails or Welds (08T)
- Use of Switches (11H)
- Joint Bar Defects (07T)
- Other Miscellaneous (05M)
- Misc. Track and Structure Defects (12T)

- Non-Traffic and Weather Causes (02T)

Most of the top ten accident cause groups are infrastructure related or human-factor related. Table 3.5 shows the top ten high-risk accident groups in infrastructure, human factors, and mechanical categories, respectively.

Table 3.4 Passenger Train Derailment and Collision Frequency and Severity by Accident Cause Subgroup, Sorted by Risk

Accident Cause Groups	Number of Accident	Accident Rate (per million train-mile	Number of Cars Derailed	Average Number of Cars Derailed Per Accident	Risk = Rate x Average Number of Cars Derailed
05H Failure to Obey/Display Signals	22	0.0028	60	2.7273	0.0076
03T Wide Gauge	17	0.0022	59	3.4706	0.0075
10H Train Speed	14	0.0018	43	3.0714	0.0054
10T Turnout Defects - Switches	21	0.0027	40	1.9048	0.0051
08T Broken Rails or Welds	7	0.0009	36	5.1429	0.0046
11H Use of Switches	15	0.0019	24	1.6000	0.0030
07T Joint Bar Defects	3	0.0004	22	7.3333	0.0028
05M Other Miscellaneous	11	0.0014	16	1.4545	0.0020
12T Misc. Track and Structure Defects	8	0.0010	14	1.7500	0.0018
02T Non-Traffic, Weather Causes	3	0.0004	13	4.3333	0.0016
07H Switching Rules	7	0.0009	10	1.4286	0.0013
15E Loco Trucks/Bearings/Wheels	6	0.0008	10	1.6667	0.0013
12H Misc. Human Factors	5	0.0006	10	2.0000	0.0013
01S Signal Failures	6	0.0008	9	1.5000	0.0011
08H Mainline Rules	8	0.0010	8	1.0000	0.0010
18E All Other Car Defects	4	0.0005	8	2.0000	0.0010
04T Track Geometry (excl. Wide Gauge)	5	0.0006	6	1.2000	0.0008
13E Other Wheel Defects (Car)	4	0.0005	6	1.5000	0.0008
17E All Other Locomotive Defects	4	0.0005	5	1.2500	0.0006
04M Track-Train Interaction	2	0.0003	5	2.5000	0.0006
11E Other Axle/Journal Defects (Car)	3	0.0004	4	1.3333	0.0005
05T Buckled Track	2	0.0003	4	2.0000	0.0005
16E Loco Electrical and Fires	2	0.0003	4	2.0000	0.0005
14E TOFC/COFC Defects	1	0.0001	4	4.0000	0.0005
03M Lading Problems	3	0.0004	2	0.6667	0.0003
09T Other Rail and Joint Defects	1	0.0001	1	1.0000	0.0001
06E Centerplate/Carbody Defects (Car)	4	0.0005	0	0.0000	0.0000
02H Handbrake Operations	1	0.0001	0	0.0000	0.0000
09E Sidebearing, Suspension Defects (Car)	1	0.0001	0	0.0000	0.0000
01T Roadbed Defects	0	0.0000	0	0.0000	0.0000
06T Rail Defects at Bolted Joint	0	0.0000	0	0.0000	0.0000
11T Turnout Defects - Frogs	0	0.0000	0	0.0000	0.0000
01H Brake Operation (Main Line)	0	0.0000	0	0.0000	0.0000
03H Brake Operations (Other)	0	0.0000	0	0.0000	0.0000
04H Employee Physical Condition	0	0.0000	0	0.0000	0.0000
06H Radio Communications Error	0	0.0000	0	0.0000	0.0000
09H Train Handling (excl. Brakes)	0	0.0000	0	0.0000	0.0000
01E Air Hose Defect (Car)	0	0.0000	0	0.0000	0.0000
02E Brake Rigging Defect (Car)	0	0.0000	0	0.0000	0.0000
03E Handbrake Defects (Car)	0	0.0000	0	0.0000	0.0000
04E UDE (Car or Loco)	0	0.0000	0	0.0000	0.0000
05E Other Brake Defect (Car)	0	0.0000	0	0.0000	0.0000
07E Coupler Defects (Car)	0	0.0000	0	0.0000	0.0000
08E Truck Structure Defects (Car)	0	0.0000	0	0.0000	0.0000
10E Bearing Failure (Car)	0	0.0000	0	0.0000	0.0000
12E Broken Wheels (Car)	0	0.0000	0	0.0000	0.0000
19E Stiff Truck (Car)	0	0.0000	0	0.0000	0.0000
20E Track/Train Interaction (Hunting) (Car)	0	0.0000	0	0.0000	0.0000
21E Current Collection Equipment (Loco)	0	0.0000	0	0.0000	0.0000
Total/Average	**190**	**0.0240**	**423**	**2.2263**	**0.0535**

Table 3.5 Top Ten High-Risk Accident Causes of Mainline Passenger Train Accidents by Accident Cause Categories and Type of Accident, 1999–2013

Accident Cause Groups		Number of Accident	Accident Rate (per million train-mile	Number of Cars Derailed	Average Number of Cars Derailed Per Accident	Risk = Rate x Average Number of Cars Derailed
Infrastructure Related						
03T	Wide Gauge	17	0.0118	59	3.4706	0.0075
10T	Turnout Defects - Switches	21	0.0146	40	1.9048	0.0051
08T	Broken Rails or Welds	7	0.0049	36	5.1429	0.0046
07T	Joint Bar Defects	3	0.0021	22	7.3333	0.0028
12T	Misc. Track and Structure Defects	8	0.0055	14	1.7500	0.0018
02T	Non-Traffic, Weather Causes	3	0.0021	13	4.3333	0.0016
04T	Track Geometry (excl. Wide Gauge)	5	0.0035	6	1.2000	0.0008
05T	Buckled Track	2	0.0014	4	2.0000	0.0005
09T	Other Rail and Joint Defects	1	0.0007	1	1.0000	0.0001
01T	Roadbed Defects	0	0.0000	0	0.0000	0.0000
Human Factor Related						
05H	Failure to Obey/Display Signals	22	0.0152	60	2.7273	0.0076
10H	Train Speed	14	0.0097	43	3.0714	0.0054
11H	Use of Switches	15	0.0104	24	1.6000	0.0030
07H	Switching Rules	7	0.0049	10	1.4286	0.0013
12H	Misc. Human Factors	5	0.0035	10	2.0000	0.0013
08H	Mainline Rules	8	0.0055	8	1.0000	0.0010
02H	Handbrake Operations	1	0.0007	0	0.0000	0.0000
01H	Brake Operation (Main Line)	0	0.0000	0	0.0000	0.0000
03H	Brake Operations (Other)	0	0.0000	0	0.0000	0.0000
04H	Employee Physical Condition	0	0.0000	0	0.0000	0.0000
Mechanical Related						
15E	Loco Trucks/Bearings/Wheels	6	0.0042	10	1.6667	0.0013
18E	All Other Car Defects	4	0.0028	8	2.0000	0.0010
13E	Other Wheel Defects (Car)	4	0.0028	6	1.5000	0.0008
17E	All Other Locomotive Defects	4	0.0028	5	1.2500	0.0006
11E	Other Axle/Journal Defects (Car)	3	0.0021	4	1.3333	0.0005
16E	Loco Electrical and Fires	2	0.0014	4	2.0000	0.0005
14E	TOFC/COFC Defects	1	0.0007	4	4.0000	0.0005
06E	Centerplate/Carbody Defects (Car)	4	0.0028	0	0.0000	0.0000
09E	Sidebearing, Suspension Defects (Car)	1	0.0007	0	0.0000	0.0000
01E	Air Hose Defect (Car)	0	0.0000	0	0.0000	0.0000

3.1.2 Freight Train Derailment and Collision Accident Cause Analysis

The accident causes of freight train derailments and collisions were analyzed in the same way as passenger train derailments and collisions. Figure 3.6 shows the frequency and severity graphs by the major accident cause categories. The graph is also divided into four quadrants to enable easy comparison of the relative frequency and severity of different accident cause groups. The infrastructure-related cause category was identified as the most severe and frequent one. The mechanical-related accident cause category has higher frequency but lower severity.

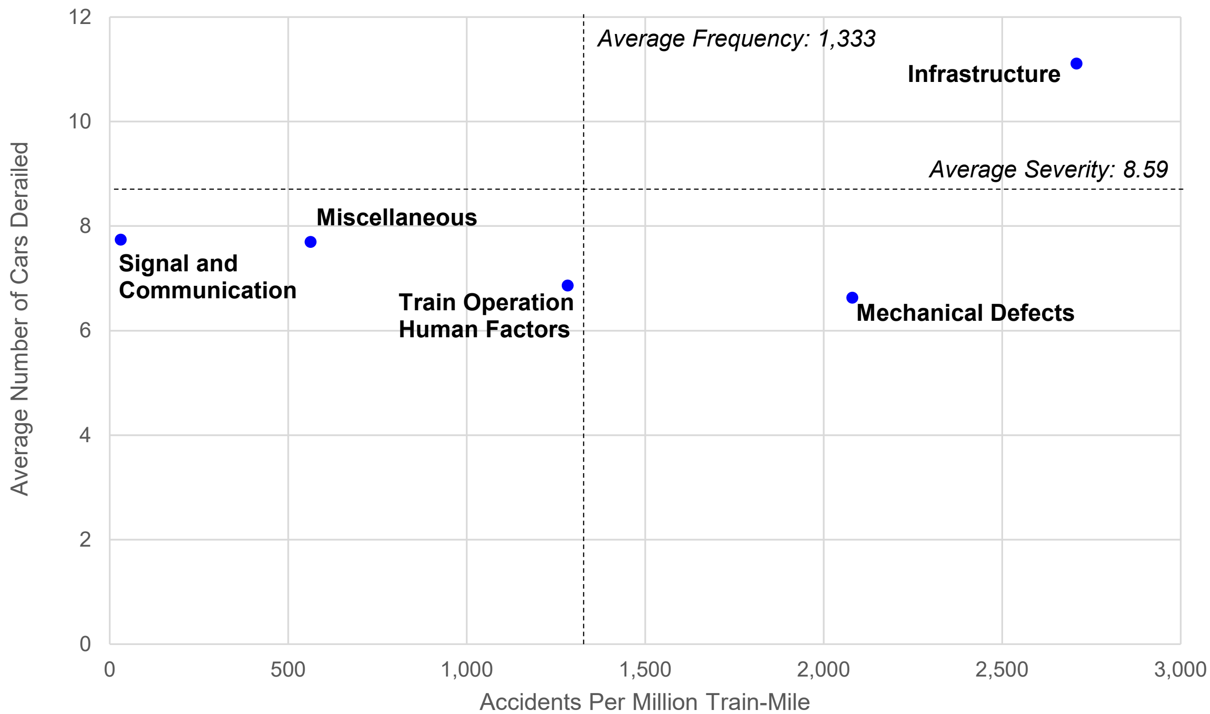

Figure 3.6 Frequency and Severity Graph of Mainline Freight Derailments and Collisions, 1999-2013, by Accident Cause Category, with Average Cars Derailed as Severity Indicator

Table 3.6 shows the accident frequency and severity for individual accident cause groups. The accident cause groups are categorized into infrastructure related (T), human-factor related (H), mechanical related (E), signal and communication related (S), and miscellaneous (M). The risk of each accident cause group was calculated by multiplying its accident rate by its severity. Overall, the top ten accident cause groups with the highest risk are:

- Broken Rails or Welds (08T)
- Buckled Track (05T)
- Track Geometry (excl. Wide Gauge) (04T)
- Wide Gauge (03T)
- Broken Wheels (Car) (12E)
- Bearing Failure (Car) (10E)
- Train Handling (excl. Brakes) (09H)
- Joint Bar Defects (07T)
- Track-Train Interaction (04M)
- Failure to Obey/Display Signals (05H)

Most of the top ten accident cause groups are infrastructure-related and some of them are mechanical-related. Compared to passenger accident causes, more mechanical-related causes are of higher risk in freight train derailments and collisions. Table 3.7 shows the top ten high-risk accident groups in infrastructure, human factors, and mechanical categories, respectively.

Table 3.6 Freight Train Derailment and Collision Frequency and Severity by Accident Cause Subgroup, Sorted by Risk

	Accident Cause Groups	Number of Accident	Accident Rate (per million train-mile	Number of Cars Derailed	Average Number of Cars Derailed Per Accident	Risk = Rate x Average Number of Cars Derailed
08T	Broken Rails or Welds	984	0.1245	12,756	12.9634	1.6138
05T	Buckled Track	238	0.0301	3,081	12.9454	0.3898
04T	Track Geometry (excl. Wide Gauge)	454	0.0574	2,977	6.5573	0.3766
03T	Wide Gauge	286	0.0362	2,691	9.4091	0.3404
12E	Broken Wheels (Car)	312	0.0395	2,480	7.9487	0.3137
10E	Bearing Failure (Car)	384	0.0486	2,399	6.2474	0.3035
09H	Train Handling (excl. Brakes)	297	0.0376	2,170	7.3064	0.2745
07T	Joint Bar Defects	96	0.0121	1,723	17.9479	0.2180
04M	Track-Train Interaction	201	0.0254	1,643	8.1741	0.2079
05H	Failure to Obey/Display Signals	154	0.0195	1,543	10.0195	0.1952
09T	Other Rail and Joint Defects	74	0.0094	1,495	20.2027	0.1891
11E	Other Axle/Journal Defects (Car)	175	0.0221	1,471	8.4057	0.1861
05M	Other Miscellaneous	145	0.0183	1,466	10.1103	0.1855
09E	Sidebearing, Suspension Defects (Car)	178	0.0225	1,273	7.1517	0.1610
01H	Brake Operation (Main Line)	139	0.0176	1,247	8.9712	0.1578
06T	Rail Defects at Bolted Joint	68	0.0086	1,235	18.1618	0.1562
03M	Lading Problems	217	0.0275	1,225	5.6452	0.1550
10T	Turnout Defects - Switches	200	0.0253	1,191	5.9550	0.1507
01T	Roadbed Defects	112	0.0142	1,169	10.4375	0.1479
13E	Other Wheel Defects (Car)	193	0.0244	1,047	5.4249	0.1325
12T	Misc. Track and Structure Defects	113	0.0143	1,029	9.1062	0.1302
07E	Coupler Defects (Car)	176	0.0223	998	5.6705	0.1263
11H	Use of Switches	191	0.0242	936	4.9005	0.1184
10H	Train Speed	144	0.0182	915	6.3542	0.1158
06E	Centerplate/Carbody Defects (Car)	138	0.0175	637	4.6159	0.0806
12H	Misc. Human Factors	73	0.0092	595	8.1507	0.0753
19E	Stiff Truck (Car)	81	0.0102	567	7.0000	0.0717
20E	Track/Train Interaction (Hunting) (Car)	54	0.0068	520	9.6296	0.0658
02T	Non-Traffic, Weather Causes	60	0.0076	508	8.4667	0.0643
07H	Switching Rules	118	0.0149	471	3.9915	0.0596
08E	Truck Structure Defects (Car)	57	0.0072	418	7.3333	0.0529
18E	All Other Car Defects	72	0.0091	413	5.7361	0.0522
08H	Mainline Rules	61	0.0077	377	6.1803	0.0477
15E	Loco Trucks/Bearings/Wheels	64	0.0081	333	5.2031	0.0421
05E	Other Brake Defect (Car)	62	0.0078	327	5.2742	0.0414
02H	Handbrake Operations	70	0.0089	309	4.4143	0.0391
02E	Brake Rigging Defect (Car)	46	0.0058	259	5.6304	0.0328
01S	Signal Failures	31	0.0039	240	7.7419	0.0304
11T	Turnout Defects - Frogs	23	0.0029	239	10.3913	0.0302
17E	All Other Locomotive Defects	25	0.0032	232	9.2800	0.0294
01E	Air Hose Defect (Car)	23	0.0029	198	8.6087	0.0250
16E	Loco Electrical and Fires	25	0.0032	128	5.1200	0.0162
04H	Employee Physical Condition	8	0.0010	95	11.8750	0.0120
04E	UDE (Car or Loco)	10	0.0013	88	8.8000	0.0111
06H	Radio Communications Error	17	0.0022	76	4.4706	0.0096
03H	Brake Operations (Other)	11	0.0014	72	6.5455	0.0091
14E	TOFC/COFC Defects	3	0.0004	3	1.0000	0.0004
03E	Handbrake Defects (Car)	2	0.0003	3	1.5000	0.0004
21E	Current Collection Equipment (Loco)	0	0.0000	0	0.0000	0.0000
	Total/Average	**6,665**	**0.8432**	**57,268**	**8.5923**	**7.2450**

Mechanic Defects

Table 3.7 Top Ten High-Risk Accident Causes of Mainline Freight Train Accidents by Accident Cause Categories and Type of Accident, 1999–2013

Accident Cause Groups		Number of Accident	Accident Rate (per million train-mile	Number of Cars Derailed	Average Number of Cars Derailed Per Accident	Risk = Rate x Average Number of Cars Derailed
Infrastructure Related						
08T	Broken Rails or Welds	984	0.1245	12,756	12.9634	1.6138
05T	Buckled Track	238	0.0301	3,081	12.9454	0.3898
04T	Track Geometry (excl. Wide Gauge)	454	0.0574	2,977	6.5573	0.3766
03T	Wide Gauge	286	0.0362	2,691	9.4091	0.3404
07T	Joint Bar Defects	96	0.0121	1,723	17.9479	0.2180
09T	Other Rail and Joint Defects	74	0.0094	1,495	20.2027	0.1891
06T	Rail Defects at Bolted Joint	68	0.0086	1,235	18.1618	0.1562
10T	Turnout Defects - Switches	200	0.0253	1,191	5.9550	0.1507
01T	Roadbed Defects	112	0.0142	1,169	10.4375	0.1479
12T	Misc. Track and Structure Defects	113	0.0143	1,029	9.1062	0.1302
Human Factor Related						
09H	Train Handling (excl. Brakes)	297	0.0376	2,170	7.3064	0.2745
05H	Failure to Obey/Display Signals	154	0.0195	1,543	10.0195	0.1952
01H	Brake Operation (Main Line)	139	0.0176	1,247	8.9712	0.1578
11H	Use of Switches	191	0.0242	936	4.9005	0.1184
10H	Train Speed	144	0.0182	915	6.3542	0.1158
12H	Misc. Human Factors	73	0.0092	595	8.1507	0.0753
07H	Switching Rules	118	0.0149	471	3.9915	0.0596
08H	Mainline Rules	61	0.0077	377	6.1803	0.0477
02H	Handbrake Operations	70	0.0089	309	4.4143	0.0391
04H	Employee Physical Condition	8	0.0010	95	11.8750	0.0120
Mechanical Related						
12E	Broken Wheels (Car)	312	0.0395	2,480	7.9487	0.3137
10E	Bearing Failure (Car)	384	0.0486	2,399	6.2474	0.3035
11E	Other Axle/Journal Defects (Car)	175	0.0221	1,471	8.4057	0.1861
09E	Sidebearing, Suspension Defects (Car)	178	0.0225	1,273	7.1517	0.1610
13E	Other Wheel Defects (Car)	193	0.0244	1,047	5.4249	0.1325
07E	Coupler Defects (Car)	176	0.0223	998	5.6705	0.1263
06E	Centerplate/Carbody Defects (Car)	138	0.0175	637	4.6159	0.0806
19E	Stiff Truck (Car)	81	0.0102	567	7.0000	0.0717
20E	Track/Train Interaction (Hunting) (Car)	54	0.0068	520	9.6296	0.0658
08E	Truck Structure Defects (Car)	57	0.0072	418	7.3333	0.0529

4. Conclusion

This report is Phase I of the three-part project that defines the scope of the literature review and summarizes the results from the literature review. Locations where each hazard is eminent, influencing factors of each hazard, and potential risk mitigation strategies for each hazard were identified and presented. Causal analysis was conducted for mainline passenger and freight train accidents to understand major factors leading to passenger and freight train accidents and identify accident causes that are more relevant to HSR systems adjacent to and sharing corridors with existing conventional railway operations.

5. References

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

Abbreviations and Acronyms

Abbreviation or Acronym	Name
ADL	Arthur D. Little
FRA	Federal Railroad Administration
GD	Guidance Document
HSR	High-Speed Rail
HF	Human Factors
RailTEC	Rail Transportation and Engineering Center
UI	University of Illinois at Urbana-Champaign