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REPORT 755

Comprehensive Costs of Highway-Rail Grade Crossing Crashes

TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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Field of Transportation Planning—Area of Forecasting

FOREWORD

By Andrew C. Lemer
Staff Officer
Transportation Research Board

NCHRP Report 755: Comprehensive Costs of Highway-Rail Grade Crossing Crashes presents a process for estimating the costs of highway-rail grade crossing crashes. A spreadsheet tool to facilitate use of this cost estimation process was also developed and may be downloaded at http://www.trb.org/main/Blurbs/169061.aspx. Departments of transportation (DOTs) and other public agencies use such estimates in making decisions about investments to install safety devices or reconstruction to provide grade separation of the road and rail line. The report will be helpful to officials of such agencies who must identify and assess the merits of investments proposed to enhance safety at grade crossings.

Most analyses of the need to invest public funds in safety improvements at highway-rail grade crossings focus on preventing fatalities, injuries, and property damage at specific priority locations. However, the comprehensive quantifiable costs of collisions involving a train and one or more motor vehicles at a grade crossing may include substantial property damage incurred by freight shippers as well as the parties to the crash, delivery delay and lost time for traffic that is diverted by the crash, cost of public-service agencies responding to the crash and its aftermath, and more. Little information has been developed about such costs.

Lacking such information, highway and rail system decisionmakers cannot effectively judge the economic benefits of public investments to improve or eliminate grade crossings. While the number of grade crossing collisions is a small fraction of the number of collisions on the roadway system overall, their impacts are disproportionately large. The literature indicates that grade crossing crashes are much more likely to involve a fatality than other highway crashes. In addition, a grade crossing incident will often have other consequences not typically associated with highway crashes, such as damage to rail equipment and infrastructure; injuries to rail employees and passengers; damage to goods; business interruption; and time spent in public hearings following a collision.

The costs are not well documented for several reasons; for example, (1) crash costs are generally incurred by multiple parties who record and report costs differently; (2) concerns for legal liability and litigation risk make railroads reluctant to report publicly their incurred costs of crashes; (3) costs attributable to fatalities, personal injuries, time delays, and other consequences of a crash are not directly observable. Even when costs are observable and reported, wide variance in grade-crossing characteristics—for example, location, geometry, and highway and rail traffic—and the infrequency of grade crossing crashes raise the uncertainty of extrapolations from historic experience to forecasts of potential exposure.

The objectives of this research were to develop (a) a categorization scheme for comprehensively describing costs associated with highway-rail grade crossing crashes; (b) estimates of the cost magnitudes in recent experience; and (c) an analytical framework for forecasting these costs at specific locations, considering the characteristics of a crossing and the rail and highway traffic using it.

A research team led by DecisionTek, LLC, Rockville, MD, conducted the research. The research team reviewed pertinent current literature and practices on measuring and estimating costs of highway-rail crashes and crash-related traffic interruptions. The team used a variety of information sources to consider the full range of costs that may be incurred by railroads, businesses, public agencies, shippers, passengers, and the public at large. Because of the substantial uncertainties in cost reporting, the team relied substantially on publicly available sources such as records maintained by the Federal Rail Administration and Federal Highway Administration.

In addition, the team used recorded costs for fatalities and injuries based on the U.S. Department of Transportation's definition of the value of a statistical life (VSL), a monetary value attributed to each crash fatality. The VSL is established by the U.S.DOT and updated from time to time to reflect current economic conditions. The U.S.DOT issued guidance increasing the VSL as this research project was nearing completion. Because the costs attributed to fatalities typically are large compared with other costs reported for crashes, the primary consequence of an increase in the VSL is seen in the computations related to crash-cost estimation.

This document is written to assist agency staff responsible for identifying and assessing the merits of options to improve safety at highway-rail grade crossings. The report presents the research team's analysis of available information in a framework designed to facilitate estimation of crash costs that may be incurred at a specific grade crossing characterized by particular geometry and traffic. The framework was used to construct a spreadsheet tool, referenced in the report, which may be used to develop crash-cost estimates. The spreadsheet tool may be downloaded from the TRB website at http://www.trb.org/main/Blurbs/169061.aspx.

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Note: Many of the figures and tables in this report have been converted from color to grayscale for printing. The electronic version of the report (posted on the Web at www.trb.org) retains the color versions.

SUMMARY

Comprehensive Costs of Highway-Rail Grade Crossing Crashes

Despite improvements that have reduced the number of highway-rail grade crossing incidents in the past 2 decades, evidence indicates that (a) railroad crossings remain a significant safety hazard, (b) the trends supporting the decline in incidents are unlikely to continue, and (c) solutions that reduce the risk of grade crossing incidents will continue to be costly. Although public funding currently is available for grade crossing enhancements, the funding level is periodically reset, a process whose outcome is ultimately determined by considering tradeoffs and competition with other categories of highway system enhancement.

The persistence of grade crossing safety issues and the necessity of competing for ever-scarcer surface transportation funds suggest the need for refining methods for gauging the costs of highway-rail grade crossing crashes. Crashes between trains and road vehicles typically are more severe and more costly than highway crashes in general. Less than 1% of police-reported highway crashes involve fatalities, compared with roughly 10% of highway-rail crashes (*1*). In addition, the costs of highway-rail crashes can extend well beyond the usual costs of general highway crashes because of (a) damage to railroad equipment and infrastructure; (b) the potential disruption of rail passenger service and the logistics supply chain; and (c) the potential for very rare, catastrophic events, such as multi-passenger casualties or hazardous material (hazmat) spills with major environmental or human health impacts.

Project Objectives

Grade crossing improvements can receive due consideration in transportation investment decision making only when a more credible accounting of comprehensive highway-rail grade crossing crash costs is available. *NCHRP Report 755: Comprehensive Costs of Highway-Rail Grade Crossing Crashes* addresses this need by meeting the following research objectives:

- Developing a comprehensive grade crossing crash taxonomy that includes costs, their contributing factors, and their orders of magnitude. The taxonomy provides the conceptual foundation on which models and tools are subsequently derived.
- Developing an analytic framework that enables the estimation and forecasting of grade crossing crash costs and effectively supports resource allocation decisions. The analytic framework provides a well-defined process for arriving at grade crossing crash cost estimates, thus enhancing existing methods that support resource allocation decisions.
- Explaining how the research findings are readily usable and accessible to the community of practitioners.

Current Practice: Principal Cost Components

A review of the literature identified the principal components of grade crossing crash costs and covered six topics:

1. crash categories,
2. casualty categories,
3. categorization of cost components,
4. direct costs, not property damage,
5. willingness-to-pay (WTP) casualty costs, and
6. property damage costs.

Key findings for each topic include:

- **Crash categories.** The most accepted and widely practiced method of forecasting crashes and crash severity in the United States is that followed by the U.S.DOT Accident Prediction and Severity (APS) model. The APS is employed in FRA's Web-Based Accident Prediction and Severity (WBAPS) system and GradeDec.Net, as well as in several variant models used by states. The general procedure is to calculate predicted crashes and allocate them to severity categories (fatal, injury, and non-casualty—that is, property damage only). In principle, given predicted crashes by severity category, a forecasted average cost per crash would enable a straightforward calculation of crash costs at a specific grade crossing.
- **Casualty categories.** Current practice recognizes two main casualty categories: fatal and (non-fatal) injury. The costs associated with casualties will likely remain the most significant cost components of crashes at grade crossings. Consequently, a key goal of cost estimation is to develop refined estimates of per-crash casualties by severity for both casualty types (fatal and injury). The highway crash literature often uses a six-tiered injury severity scale (the Abbreviated Injury Scale, or AIS); however, for this research project it was proposed to adopt the three-tiered classification of the National Safety Council (NSC) instead. Using the NSC classification enables use of police crash reporting and has been shown to have greater reported accuracy than other methods. Grade crossing crash data further reports casualties by mode (highway, pedestrian, rail passenger, and rail employee), which also can inform the effects and costs of crashes.
- **Categorization of cost components.** Cost categories are itemized by effect and impact. Primary effects occur at the crash site and include casualties (with related costs) and property damage (to highway vehicles, railroad equipment, and infrastructure). Secondary effects are associated with supply chain and business disruptions. Also considered are effects associated with rare catastrophic crashes. Impact describes how each cost component affects society (i.e., directly, indirectly, or intangibly); the process through which the impact is perceived (e.g., through business supply chain disruption); or—in the case of rare catastrophic events—the approach taken to evaluate the cost. Both indirect and intangible costs are captured in the WTP measures for loss of life and injury.
- **Direct costs, not property damage.** These costs, such as emergency medical services (EMS) and insurance, are included in bottom-up tallying of costs and are subsumed and counted in the WTP measures of casualty costs.
- **WTP casualty costs.** Costs associated with loss of life and injury are calculated using WTP measures. These costs are based on estimates of what individuals are willing to pay to reduce the risk of being killed or injured. The costs are inclusive of human capital, lost productivity, and tax effects that are associated with persons being killed or injured in crashes. It is accepted practice to derive WTP measures for casualties as fractions of the value of a statistical life (VSL) and to use the VSL established and periodically updated by

Table S-1. Taxonomy of grade crossing crash cost components.

Effect	Impact	Cost Component
Primary	Direct	Property damage (highway vehicles, railroad equipment and infrastructure) Other direct costs (e.g., EMS, insurance)
	Indirect	Work-related productivity loss Tax loss
	Intangible	Quality of life Pain and suffering Environmental cost
Secondary	Supply chain and business disruption	Rerouting costs Lost sales Prevention costs Inventory spoilage Freight and passenger delays Freight and passenger reliability Increased inventory

Note: The cost components shown here are drawn from Table 16 and Table 17 in Technical Memorandum 1, which has been included as the appendix to this report.

U.S.DOT. VSL estimates are widely regarded as upper-bound estimates of damages associated with loss of life; however, in certain cases, these may be exceeded by settlements or jury awards in civil lawsuits. [Note: In 2013, U.S.DOT issued new guidance on use of the VSL. This information followed the conclusion of the research for NCHRP project 08-85. The current guidance can be found at www.dot.gov by searching for the phrase, "Guidance on Treatment of the Economic Value of a Statistical Life."]
- **Property damage costs.** These costs include the costs of damage to highway vehicles and infrastructure as well as to railroad equipment and infrastructure.

Table S-1 presents a summary taxonomy of highway crash cost components identified through the literature review and grouped by primary and secondary effects. Primary effect costs are largely restricted to the crash site. Secondary effect costs relate to the supply chain and business disruption. Some intangible costs and the majority of secondary costs have been recognized in theory as legitimate crash costs, but generally have not been evaluated in crash cost studies.

Conceptual Framework

The conceptual framework for developing a tool to estimate the full cost of highway-rail grade crossing crashes builds on the previously cited principal components of grade crossing crash costs and embodies the principles of benefit-cost analysis to ensure that (a) costs reflect costs to society, not just out-of-pocket costs or costs particular to stakeholder groups, and (b) costs are mutually exclusive and free of double counting.

The framework for calculating total costs of highway-rail grade crossing crashes also supports resource allocation and infrastructure investment decisions in accordance with federal policy guidelines (e.g., Executive Order 12893, Principles for Federal Infrastructure Investments [1994]).

Given the uniqueness of each grade crossing from spatial, engineering, and traffic perspectives, crashes are predicted on a crossing-by-crossing basis. The prediction of crash occurrence by crash severity type is accomplished using external models including those based on the APS and FRA's GradeDec.Net model. GradeDec.Net adds a number of refinements to the APS approach. The framework set out in *NCHRP Report 755* incorporates features that improve on these models by

- allowing use of additional data granularity and setting densities;
- adding explicit methods for calculating the average cost per crash by crash type;
- adding methods to estimate supply chain costs and other secondary cost impacts; and
- adding methods to estimate costs of potential low-probability catastrophic crashes in which multiple parties are injured or killed.

Estimating Crash Costs

The conceptual framework is supported by a system of equations that practitioners can use to estimate the cost of different types of grade crossing incidents. Figure S-1 presents the cost components and calculations used in the method, which is summarized here and further explained in Chapter 3 of this report. The overall crash cost equation is the sum of primary effect costs and secondary effect costs per crash, multiplied by the predicted

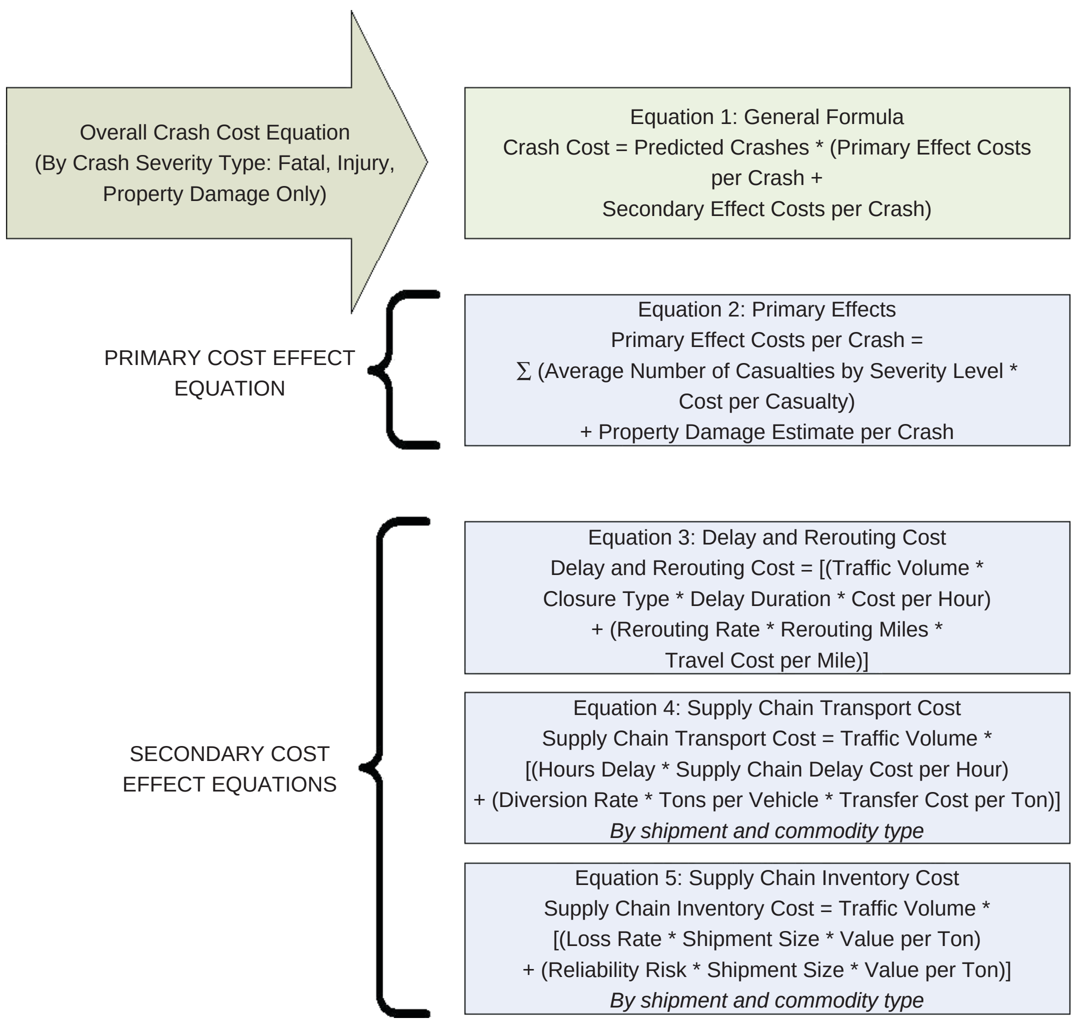


Figure S-1. Method for calculating the full cost of grade crossing incidents.

number of crashes. Equations for primary and secondary costs and their components are calculated separately for each of three incident severity types.

Primary Effect Crash Cost Components

Primary effect crash costs include direct, indirect, and intangible costs associated with property damage, injuries, and fatalities. The FRA grade crossing crash data is a primary source for understanding crashes and their primary effect costs. Information available from the grade crossing data and other FRA safety data includes

- number of crashes;
- casualties and their mode (e.g., highway user, pedestrian, railroad employee, or passenger);
- highway vehicle damage estimates;
- railroad equipment damage estimates; and
- any hazmat breach or spill.

FRA data also includes information on all crossings, including physical characteristics, device type, number of tracks, highway functional class, and traffic by highway and rail modes.

Estimating the costs of casualties in fatal and injury crashes involves three factors:

1. Crash incidence and severity, calculated from a crash prediction model such as GradeDec.Net.
2. Numbers of fatalities and injuries by severity category per crash (although no well-established estimates are available for grade crossing crashes).
3. Unit costs, or the loss value associated with each fatality and injury.

The VSL and the valuations for various levels of injury are available from U.S.DOT; the values of medical, insurance, EMS, and injury avoidance are available from NHTSA.

Two steps are required to estimate property damage costs:

1. Determine predicted crashes by crash severity category.
2. Estimate the average property damage per crash for each crash category.

These costs are estimated from FRA and NTSB data for all crash severity levels. Across all crash severity levels, highway vehicle damage from FRA and NTSB data averaged $8,665 per crash based on 6,038 crashes between 2009 and 2011. Damage to roadways and railroad equipment per crash averaged $8,665 and $67,000, respectively. The average cost of damage per crash increases as the severity level increases.

Secondary Effect Crash Cost Components

Secondary effect costs accrue to delayed travelers and cargo, and to parties beyond the immediate road and rail travelers and service operators. These costs include logistics and supply chain costs, cargo value losses and environmental costs.

Delay and Rerouting Costs. These costs include both vehicle operating costs and the lost value of driver and passenger time caused by closures and detours. Because of a grade crossing incident, closure may occur to the railroad, the highway, or both. The type and duration of the closure depends on the severity of the crash, whether the crash resulted in a hazmat release, the types of vehicles involved, and the extent of damage to the railroad and highway.

Duration of closure is affected not only by the severity of the crash, but also by the length of the train and the volume of traffic on the roadway. No established source provides this information. For NCHRP Project 08-85, the research team conducted a web search and telephone interviews with state highway departments, local public safety departments, state police, and other groups to identify delays experienced at several crash sites and develop averages for closure duration, rerouting distance, and added travel time per person for rail vehicles and roadway vehicles.

The cost of vehicle delay is the added operating expense of running a vehicle for a longer period of time or traveling a greater distance on an alternative route, plus the value of added driver time and passenger time. These costs vary by who is affected (train crew members, and/or vehicle passengers), by trip purpose, train crew and vehicle occupancy, by vehicle operating costs, and by costs associated with local traffic characteristics. Default averages for these factors are available from various publications and economic benefit analysis tools.

Transportation-related Supply Chain Costs. These costs include delivery time delay costs other than those already covered (e.g., tying up inventory stock in transport and idling vehicles), container/mode diversion costs (e.g., offloading and reloading goods to another mode), and penalty fees for late deliveries.

Several sources provide data on traffic volumes by commodity mix and other supply chain factors such as average shipment size, shipping costs, or value of goods shipped:

- For significant highways, FHWA's National Highway Planning Network.
- For the National Highway System (NHS), FHWA's Freight Analysis System. This data can be used to infer information for non-NHS crossings.
- For the railroad industry, the Association of American Railroads (AAR). Financial reports of the Class I railroads are available on the Surface Transportation Board website.
- For county-level estimates of commodity flows, IMPLAN®, TREDIS® or other input-output planning systems are useful (noting that they may yield annual averages that must be supplemented by local information regarding seasonal and time-of-day effects).

Delivery delay rates generally equal one-half the total closure time, plus adjustments for accumulated vehicle queues to be dispersed. This data is *sometimes* available from crash reports recorded by local or state public safety officials, but greater effort is needed to standardize collection of this data. The research team collected delay duration information through case studies conducted for NCHRP Project 08-85.

Supply chain delay costs are derived from the opportunity cost of capital during periods of added transit, as well as the costs of late deliveries (such as overtime pay) or missed deliveries (costs of redelivery). Shipment diversion costs, which generally occur only when there is damage to the track, include (a) the cost of transferring the commodities or goods to different containers or vehicles and (b) the cost of losing the use of the replacement containers or vehicles for other purposes. Estimates of the factors that make up these supply chain costs are available from the TREDIS multi-modal benefit analysis tool.

Inventory-related supply chain costs include spoilage and loss of sales, as well as inventory substitution and stocking costs that result from the uncertainty posed by potential incidents. Inventory costs for cargo replacement occur when shipments are damaged, destroyed, or spoiled. This usually happens when a truck or railcar is substantially damaged, and when the cargo is perishable or involves manufactured goods. The FRA incident database includes information on damage to vehicles and rail cars but does not identify what cargo is being shipped. This information can be estimated through business surveys or using FHWA's Freight Analysis Framework (FAF), which includes regional data on tonnage, mix, and value of freight moving through an area.

Reliability risk relates to the inventory and other costs associated with delayed shipments, such as penalties for late arrivals. To estimate a value for reliability risk, data on the incidence of long delays, the time cost of drawing from inventory to substitute for late deliveries, and when time-sensitive cargos are affected are needed. Sources that can help assemble this data include NTSB and FRA data supplemented with data from local and state highway officials, FHWA's Highway Economic Requirements System (HERS) model, the FAF database, and local officials (for information on specific crashes). The FAF database also provides data on the value per ton for commodities shipped by rail and truck.

Secondary Effect Costs. These costs include two additional categories, indirect costs and intangible costs, not associated with cargo or damage to vehicles or rail equipment. These involve costs related to loss of worker productivity and environmental costs.

Environmental costs include rare incidents of hazmat spills and air pollution from rerouting or idling. No current data sources exist for the cleanup costs of hazmat spills. In most cases, the costs related to air pollution will be small. Based on analysis of data from the 1997 Federal Highway Cost Allocation Study and the *Transportation Energy Data Book,* a typical valuation for air pollution and greenhouse gas emission per vehicle mile is $0.028 for cars and $0.05 for trucks (freight train emissions, based on fuel consumption, are about one-third that of trucks per ton-mile) (*21*).

Rare Catastrophic Crashes. A catastrophic incident is one that includes a degree of fatality, injury, and property damage many times that of a typical rail crossing crash, and may also involve a hazmat spill that requires evacuation of nearby properties and specialized cleanup operations. Catastrophic crashes pose a unique cost estimation challenge because of their high cost and low probability, and have not been automatically included in the conceptual crash cost framework. However, it is helpful to include a brief discussion of these rare crashes and how they could potentially impact the total estimated costs of grade crossing crashes.

Three approaches are available to capture the costs of these incidents:

1. Disregard catastrophic crashes on the basis of their very small risk of occurrence; omit them from the calculation.
2. Consider these incidents as worst case scenarios, include their costs in analyses designed to mitigate such incidents, but do not include them as components of the cost of non-catastrophic crashes.
3. Include a best-guess estimate based on the very large cost of such crashes times the very low probability of such crashes and add this estimate to the aggregate cost of highway-rail grade crossing crashes.

In concurrence with the project panel, the research team adopted the first approach for this study.

Grade Crossing Crash Cost Evaluation Tool

The research team developed a grade crossing crash cost evaluation tool (spreadsheet tool) that implements the findings of *NCHRP Report 755.* The spreadsheet tool is available for download from http://www.trb.org/Main/Blurbs/169061.aspx.

CHAPTER 1

Background

1.1 About NCHRP Project 08-85

NCHRP Project 08-85, "The Comprehensive Costs of Highway-Rail At-Grade Crossing Crashes," was conducted (1) to develop a categorization scheme for comprehensively describing costs associated with highway-rail grade crossing crashes; (2) to obtain estimates of the cost magnitudes in recent experience, and (3) to create an analytical framework for forecasting the grade crossing crash costs, considering the characteristics of a crossing and the rail and highway traffic using it. Costs to be considered included those incurred by railroads, highway agencies, shippers, travelers, businesses, and public service agencies, and other costs occurring as a consequence of a crash and interruption of traffic flows. The model or models developed were to be usable for evaluating the benefits of crossing changes intended to reduce collisions.

1.2 Need for the Research

Highway-rail grade crossings represent a special challenge for transportation professionals. Most crossings are not the result of careful planning; rather, they were created in an ad hoc manner as the two surface transportation systems evolved. By and large, grade crossings are a byproduct of the growth and development patterns of the nineteenth and early twentieth centuries. From a safety perspective, some of the worst grade crossings have no easy solution: Closure is not feasible given access and spatial separation issues, while grade separation options are prohibitively expensive given dense land use. Many forecasts show strong growth in rail movements that, in some areas, will increase existing hazards. New, higher speed rail passenger services are being planned around the country, some of which will leave grade crossings in place as grade crossing elimination required by federal regulation is only for train speeds in excess of 125 mph.

Although grade crossings remain hazardous, recent years have seen a marked decline in crashes nationally, as shown in Table 1.

The national figures also indicate that crash severity has remained about constant, with 10% to 11% of incidents being fatal.

A recent study (Horton 2009) identified five success factors largely responsible for the reduction in crashes, namely: commercial driver safety, locomotive conspicuity, more reliable motor vehicles, sight lines clearance, and the Grade Crossing Maintenance Rule (*2*). These factors accounted for 79% of the reduction in incidents. The Horton study also notes that due to these major factors, crashes have leveled off since 2007. The federal program to eliminate grade crossings through closure also has had an impact. Fewer crossings have reduced total exposure, which explains some of the reduction in crashes at grade crossings over the years.

Despite these improvements, the evidence indicates that railroad crossings remain a significant safety hazard and the trends of the past 20 years will not continue into the future. Moreover, risk-reducing grade crossing solutions will be costly. In the past, grade crossings received dedicated funding through Section 130 of the U.S. Code (23 U.S.C. § 130). Funding for Section 130 continues through the current surface transportation legislation MAP-21 (Moving Ahead for Progress in the 21st Century). However, the highway community anticipates reduced availability of public funding for roads in general, which may be accompanied by reduced availability of dedicated funding for grade crossings.

The persistence of grade crossing safety issues and the necessity of competing for ever-scarcer surface transportation funds suggest the need for refined estimates of the costs of highway-rail grade crossing crashes. Data indicate that highway-rail crashes are more severe and more costly than highway crashes in general. Less than 1% of police-reported highway crashes involve fatalities compared with about 10% of highway-rail crashes (*3*). Yet the costs of these crashes extend well beyond

Table 1. U.S. grade crossing crash trends.

	1989	1994	1999	2004	2009
Total Incidents	6526	4979	3489	3085	1916
Fatal Incidents	648	512	340	322	210
Percent Fatal Incidents	9.93	10.28	9.74	10.44	10.96

Source: FRA Office of Safety (http://safetydata.fra.dot.gov/OfficeofSafety/).

the usual costs of general highway crashes because of (a) damage to railroad equipment and infrastructure, (b) the potential disruption of rail passenger service and the logistics supply chain, (c) the potential for very rare, catastrophic events (i.e., multi-passenger casualties or hazmat spills with major environmental or human health impacts), and (d) many additional cost components, like service disruptions that impact carriers, shippers, and stakeholders both upstream and downstream of the disrupted flow of goods on the rail and highway modes.

Better estimates of the cost of highway-rail grade crossing crashes are needed to inform grade crossing investment decisions.

CHAPTER 2

Research Approach

2.1 Introduction

The research approach for NCHRP Project 08-85 was designed to develop a taxonomy of highway-rail crash costs, construct a modeling framework, and deliver results to practitioners. An overarching objective in developing the research approach was that the research results be practical and useful, and that they be able to truly make a difference in transportation investment and planning. In this context, a balance was struck among preferred theoretical approaches, the limitations of available data, and existing methods and tools. This balance was crucial if the research was to yield practical and usable products, with success being measured by acceptance and widespread use among practitioners. In this chapter, Section 2.2 General Research Approach, discusses the considerations for the overall research design. Section 2.3 Project Tasks, elaborates on the research approach for each task.

2.2 General Research Approach

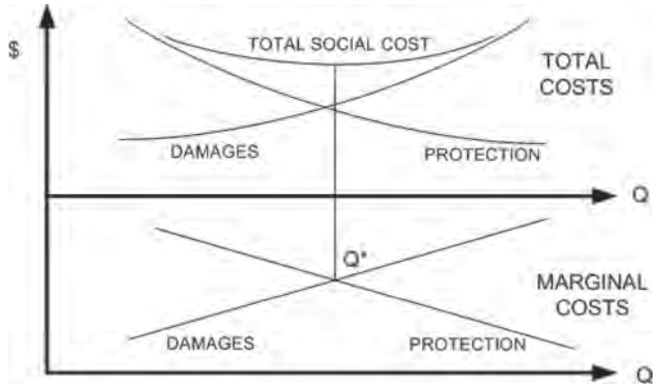
The general research approach centered on the modeling of costs. The research design involved looking at the application and applicability of existing research to crash cost estimation, the comprehensive cost methodology for general highway crashes, the comprehensive costs of grade crossing crashes, and the grade crossing safety evaluation, specifically considering crash severity and the associated costs.

2.2.1 Modeling Costs

Transportation has many stakeholders, and grade crossing crashes impact the costs of each stakeholder to a varying extent. Stakeholders include infrastructure providers (public and private), system users (travelers and carriers), and end users (shippers and the public at large). Cost categories for stakeholders include infrastructure costs, carrier costs, user money costs, user travel time and congestion costs, and costs associated with reliability. Crash costs contain both market and non-market components and are valued economically as social costs. Other costs with non-market components include emissions and noise. The valuation of social costs in transportation continues to evoke strong passions; their overstatement without due regard to true benefits and costs (e.g., harsh environmental standards) has blocked useful projects, while real social costs often have been ignored in financing projects and charging for their use. These passions have caused many researchers to repeatedly offer new definitions for external costs. A consensus definition might be that expressed by Levinson et al. (1996): "Externalities are costs or benefits generated by a system (in this case transportation, including infrastructure and vehicle/carrier operations), and borne in part or in whole by parties outside the system" (*4*).

From an economic standpoint, external costs are true resource costs that are used in making and using transportation services. These costs, including hard-to-measure cost components like life and injury, need to be properly valued and monetized to make proper economic tradeoffs in the analysis of costs and benefits. Individuals and firms strive to maximize benefits and use transportation accordingly, which results in external costs like crashes. Reducing damages requires protection (i.e., defense, abatement, or mitigation). At some point, where marginal costs are equal, the cost of protection outweighs the benefit of reducing residual damages, as illustrated in Figure 1. Note that whether marginal costs of damage and protection are fixed, rising, or declining, and by how much, is an empirical question. Figure 1 is illustrative. The damages and protection curves may not have the exact geometry shown in the figure.

One of the challenges in developing grade crossing crash estimates is to capture broadly all of the costs that derive from a crash. However, care must be taken not to cast the net too broadly. Overstating the costs results in over-investment (i.e., investing beyond the point of economic merit, which in a world of constrained funding means that other, possibly



Source: (*4*).

Figure 1. Minimizing total social costs: damages vs. protection.

more highly valued projects, do not receive the funding they deserve).

2.2.2 Crash Cost Estimation: Applying Existing Research

When examining the literature on crash cost estimation it is important to be mindful of the different purposes for which studies have been conducted. Some policy studies seek to answer the question, What is the national annual cost of highway crashes? These studies produce aggregate-level or national average information that may be of limited use for project-level analysis, but may contain methods or data that are adaptable to the project research.

Other studies focus on estimating an average crash cost, which can then be applied to project-level or strategic-level benefit-cost analysis. Generally, highway analyses apply crash rates and severity allocation formulas for different facility functional classes, and these may vary by traffic volume. The assumption is that for a given facility type and traffic volume the occurrence of crashes and their severity is roughly homogenous.

Highway-rail grade crossing crashes occur in the context of very localized situations. The physical and spatial characteristics of grade crossings and the traffic flows on both highway and rail modes reflect specific, often unique, characteristics. Estimation of crash costs at grade crossings needs to consider these factors, and for crashes where trains strike highway vehicles, train speed also is a factor in determining severity. If the grade crossing comprehensive crash cost will include delay and disruption effects and rare catastrophic events, then the cost estimation methodology will be less able to rely on an average rate and severity composition because the homogeneity assumption fails to hold.

2.2.3 Comprehensive Cost Methodology for General Highway Crashes

The principal means for estimating the cost of crashes is to estimate their damage costs. Crash costs can be categorized into three groups: direct costs, indirect costs, and intangible costs (*5*). For general highway crashes, these costs have been categorized as shown in Table 2.

One comprehensive approach for general highway crash cost estimation is based on valuing years lost to untimely death and injury together with other costs. This approach involves several steps:

1. Convert injuries and fatalities to years of life.
2. Apply an agreed-on or mandated VSL (*6*).
3. Estimate other costs.

In a report to FHWA, Miller et al. describe a year of functional capacity as consisting of several dimensions: mobility, cognitive, self-care, sensory, cosmetic, pain, ability to perform household responsibilities, and ability to perform wage work (*7*). For a specified level of injury, the researchers identify lost hours of functional capacity by category and the functional years lost by degree of injury. Thus, given crash

Table 2. Categorization of general highway crash cost components.

Crash Cost Category	Crash Cost
Direct	Property damage Emergency services, police, and fire Medical (including hospital, rehabilitation, and counseling) Legal Administrative (household help and insurance administration) Travel delay
Indirect	Productivity losses Other associated work-related costs and impositions on family members (e.g., absenteeism and worker substitution of injured and family members) Tax losses
Intangible	Quality of life Pain and suffering

severity levels and a VSL, the lost years and their values can be calculated. Adding other cost values enables the calculation of a crash cost per person or per crash by severity level.

NCHRP Report 755 identifies the most promising approaches to generating comprehensive cost estimates from general highway crashes and develops a validated framework for comprehensive crash cost estimation for grade crossings covering the general highway crash cost components. The research validates these cost categories, determines their relevance and scale in comparison with general highway crashes, and adapts them to the specific requirements of grade crossings.

2.2.4 Comprehensive Costs of Grade Crossing Crashes

The broad categories of crash costs that are unique to highway-rail grade crossing crashes and additive to general highway crashes are

- rail equipment and infrastructure damage and cleanup costs;
- loss of goods and supply chain disruptions (affecting both modes); and
- rare catastrophic events (e.g., those involving multi-passenger casualties or major hazmat spills).

2.2.4.1 Railroad Equipment and Infrastructure

Assessments of rail property damage for major incidents are publicly available from NTSB investigation reports. Some reported damage assessments also appear in FRA Office of Safety Grade Crossing Incident Reports. However, proper damage assessment estimates will include interviews and information obtained directly from the railroads themselves.

One scenario for calculating railroad damages is that, after the clearing of a crash, rail services resume but at restricted speeds (according to specific rules, but often at 15 mph or less) until infrastructure repairs can be scheduled. The infrastructure repairs involve work zone closures or work zone-related speed restrictions or stops, and often create long highway blockages and delays at the grade crossing. The costs of all of these delays and their downstream impacts are crash-related costs.

2.2.4.2 Loss of Goods and Supply Chain Disruptions

Crashes that occur at grade crossings can have a significant downstream impact beyond the direct and indirect costs associated with the losses of cargo, reliability for the rail movement, and direct impacts of the crashes. Methodological and conceptual research exists at the national level on the real costs of incident-induced delays due to crashes for both passenger car and truck movements that may be affected by grade crossing incidents.

For the highway mode, the literature on disruption costs due to crashes is highly developed. Since 1998, when Schweizer et al. (*8*) published the important initial text on the subject, other studies in the United States have focused on the impact of incident-induced delay and reliability cost for both people and goods. The research yields an understanding of key determinants of incident duration, sensitive industries, and potential management approaches.

NCHRP Report 755 builds on the supply chain factors identified in NCHRP Project 8-42 (*9*). That report explicitly models the factors that affect the modal choices of freight shippers. Those factors have been combined with existing research on the cost of supply chain disruption to the highway mode and disruption impact data obtained from the railroads to develop a proposed framework for estimating the disruption costs of grade crossing crashes on the freight rail supply chain.

2.2.4.3 Rare Catastrophic Events

Estimating the costs of rare catastrophic events presents a special challenge. The estimate of the crash cost components due to such events involves multiplying a very small number (the probability of the crash) times a very large number (the damages estimate from the event). The damages estimate from a major crash illustrates its order of magnitude and what could be a "worst case" scenario. A crash cost estimation framework also can develop estimates of relative risk for particular crossings given the presence of aggravating factors and specific traffic mixes. For example, the research would, hypothetically, support statements regarding the relative risk at grade crossings involving hazardous materials.

Maximum cost estimates combined with relative risk estimates could be valuable in supporting grade crossing safety evaluations. The methods discussed below were employed in developing the grade crossing crash cost estimation framework.

2.2.4.4 Grade Crossing Safety Evaluation: Crash Severity and Costs

In developing a framework for estimating the costs of crashes the research team concluded that it is necessary to examine the entire process of grade crossing safety evaluation. Examining costs alone, it becomes necessary to evaluate costs for specific severity categories that best support the evaluation of crash costs. The question then arises whether the safety evaluation process supports the specific crash severity categories of interest. Moreover, it is important to understand the level of precision for incident prediction to know the level of precision that can reasonably be applied to crash severity and cost. For example, if the U.S.DOT's Accident Prediction and Severity (APS) Model is applied without modification to a crossing, then predicted crashes will assume national average exposure (see *10*). However, suppose that specific local data for the crossing indicates that movements of trains and highway traffic are highly correlated during morning peak hours. This suggests that the APS Model would understate predicted incidents because the actual exposure—the probability that a train and highway vehicle will meet at the crossing—is in fact higher than what has been assumed by the model. Similarly, the crash costs per predicted incident would be higher than those predicted by the APS Model, if only from the added travel delay and supply chain disruption components. The research team for NCHRP Project 08-85 concluded that

- the framework for developing highway-rail crash costs must consider how estimates of predicted crashes are developed, and
- a full understanding of the crash prediction and severity estimation process is central to the development of a crash cost estimation and forecasting framework.

The next sections in this chapter describe some current cost estimating methods and the relationships between crash prediction, severity, and costs. Figure 2 shows a preliminary listing of factors at each stage of the process.

2.2.5 Accident Prediction and Severity Model

The APS Model is widely used to assess crash risk at grade crossings and is implemented in the WBAPS system of the FRA Office of Safety. The Rail-Highway Crossing Resource Allocation Procedure, which is based on APS, is used for decision support.

APS contains three models for crash prediction corresponding to three main grade crossing device types: passive, lights, and gates. The models are based on regression analysis of incidents and grade crossing characteristics. Every several years, the FRA Office of Safety updates the normalizing constants that calibrate the APS national grade crossing imputed predicted crashes with actual crashes of recent history. These normalizing constants do not impact predicted crashes uniformly, but their effect is significant: The 2010 update reduced predicted crashes at passive rural crossings with annual average daily traffic (AADT) of 1,000 vehicles and five daily trains by about 30% in comparison with the previous normalizing constants from 2007. Given that the rate of incident decline

Crash Occurrence

- Exposure (product of traffic volumes by mode, times the probability of co-incident arrival of train and highway vehicle at crossing)
- Physical characteristics of roadway and rail (paved/unpaved, through trains, speed, tracks, lanes)
- Type of device (passive, lights, gates with or without supplementary safety measures, other)
- Aggravating factors affecting occurrence (sight distances, grades, alignment)

Crash Severity

- Fatal accident predictive factors (speed, number of tracks, number of through and switch trains, urban/rural)
- Train strikes highway vehicle (TSH) or highway vehicle strikes train (HST)--likely high severity if TSH and highway vehicle is heavy tractor trailer
- Aggravating factors affecting severity (derailment factors, obstructions, proximity to hazards)
- Train speed
- Probability of derailment, severe derailment
- Secondary collision with structure, rolling stock, or other train

Crash Cost

- Train and vehicle type (i.e., severe crash will have higher casualty cost if passenger train or bus is involved)
- Cost of disruption will be a function of time to restore traffic on highway and rail and availability of alternative routes
- Cost of disruption also a function of type of traffic on affected rail and highway lines (i.e., delaying coal trains involves lower cost than delaying intermodal traffic)
- Cost of hazmat spills and other cleanup
- Rail equipment and infrastructure costs
- Magnitude and probability of catastrophic events
- Other costs: EMS, litigation, insurance, etc.

Figure 2. Overview of grade crossing crash prediction, severity, and cost factors.

is expected to moderate, future changes to the normalizing constants and their effects should be less pronounced.

After calculating predicted crashes at a crossing, APS allocates the predicted crashes to categories of severity. Three distinct incident severity categories are ultimately derived: casualty (fatal and injury) and non-casualty. By assigning a cost to each crash severity type, the predicted crash cost for a crossing can be evaluated.

All the data required to populate the APS Model is contained in the FRA National Grade Crossing Inventory (available at http://www.fra.dot/gov). However, the inventory has limitations (i.e., the non-uniform timing of data updates received from the states), so users need to validate the inventory data in their analyses.

The grade crossing crash cost framework provides crash cost estimates for the APS severity categories in local application to each grade crossing. The APS formulas are best-fit, statistically based results from a national sample of grade crossing crashes spanning a number of years. The advantage of this type of method is that it can be applied without bias to any grade crossing anywhere in the United States. However, it has been argued that national average results do not apply well to certain locales (e.g., the Chicago area, which has 1,200 grade crossings in Cook County alone—the highest density of grade crossings in the United States). APS also is limited by reported data, which does not include the time-of-day distribution (i.e., peaking characteristics) of rail and highway traffic, which is critical for arriving at reliable, site-specific exposure estimates. The application of heuristic and other methods to crash cost analysis improves on the results obtained using APS alone.

2.2.5.1 Higher Speed Rail Prediction and Severity Model

One such improvement appeared in an analysis by the Volpe Center (*11*). In this analysis, crash prediction was based on the APS; however, severity was derived using a new method based on a hierarchy of contributing factors. The leading factor was "who struck whom" (i.e., highway vehicle striking train or train striking highway vehicle). In an incident sample of 1975–95, 84% of the time the train strikes the highway vehicle. For the larger category (train strikes highway vehicle), data show that incident outcomes range widely, from the train just nicking the highway vehicle to fatalities on the highway to severe derailment of passenger trains (like the 1999 crash in Bourbonnais, IL). Outcomes for the smaller category (highway vehicle strikes train) were fairly uniform: extensive highway vehicle damage, light casualties, if any, and few additional effects.

An important contribution of the Volpe high speed rail method was its use of the logic that crash severity is proportional to the kinetic energy of a crash, which increases as a square of speed. The Volpe severity analysis model further deviates from the APS Model by breaking out damages to rail and highway modes (*11*).

2.2.5.2 Aggravating Risk Factors

A number of aggravating risk factors have been identified and used to model crash severity (*12*). Factors contributing to possible derailment include track curvature, railroad grade, and special trackwork (turnouts, crossovers, and diamonds in approaches to the grade crossing). Other aggravating factors include obstructions such as embankments, ledge or rock outcroppings, retaining walls, overhead bridge piers and other structures. Proximity to hazards like water or hazmat storage also influence predicted severity of grade crossing incidents.

The aggravating factors model relies on the APS Model but scales the severity outcome upward or downward based on the presence or absence of the aggravating factors.

2.2.5.3 GradeDec.Net Refinements to Crash and Severity Prediction

GradeDec.Net, FRA's web-based grade crossing investment analysis system, has incorporated the APS Model, the Volpe high speed rail model, and the aggravating risk factors model to forecast crashes and their severity at crossings. The following modifications have been made to GradeDec.Net to build on the existing methods.

Time-of-Day Exposure Correlation. Users specify time-of-day distributions for highway traffic (auto, truck, bus) and rail traffic (freight, passenger, and switch). Prediction and severity of crashes is based on more precise estimates of the exposure variable, which accounts for peaking characteristics by mode and traffic segment.

Traffic Reassignment. Crossing closures cause traffic to reroute through other crossings, whereas grade separations tend to draw traffic away from nearby adjacent crossings. These kinds of traffic changes in a rail corridor have an impact on predicted crashes and their severity. GradeDec.Net captures the effects of traffic reassignment due to grade crossing closures and grade separations.

Modeling Travel Delays. GradeDec.Net forecasts travel delays that result from blocked crossings and evaluates time savings benefits from grade separations. This feature is readily modifiable to calculate delays due to crashes.

Allowing for More Robust Base-Alternate Logic Flows. U.S.DOT's Rail-Highway Crossing Resource Allocation Procedure applies relative risk factors when evaluating the effect of a grade crossing device upgrade. This approach is used, rather than just applying the model specific to the new device, because taking the latter approach can lead to anomalies in which a device upgrade actually increases predicted crashes and their severity. However, applying relative risk factors requires that other underlying causal factors (like highway AADT) remain invariant between the base and alternate cases. GradeDec.Net removes this restriction and allows for device upgrades combined with traffic management measures, thus allowing for more types of crash mitigation strategies.

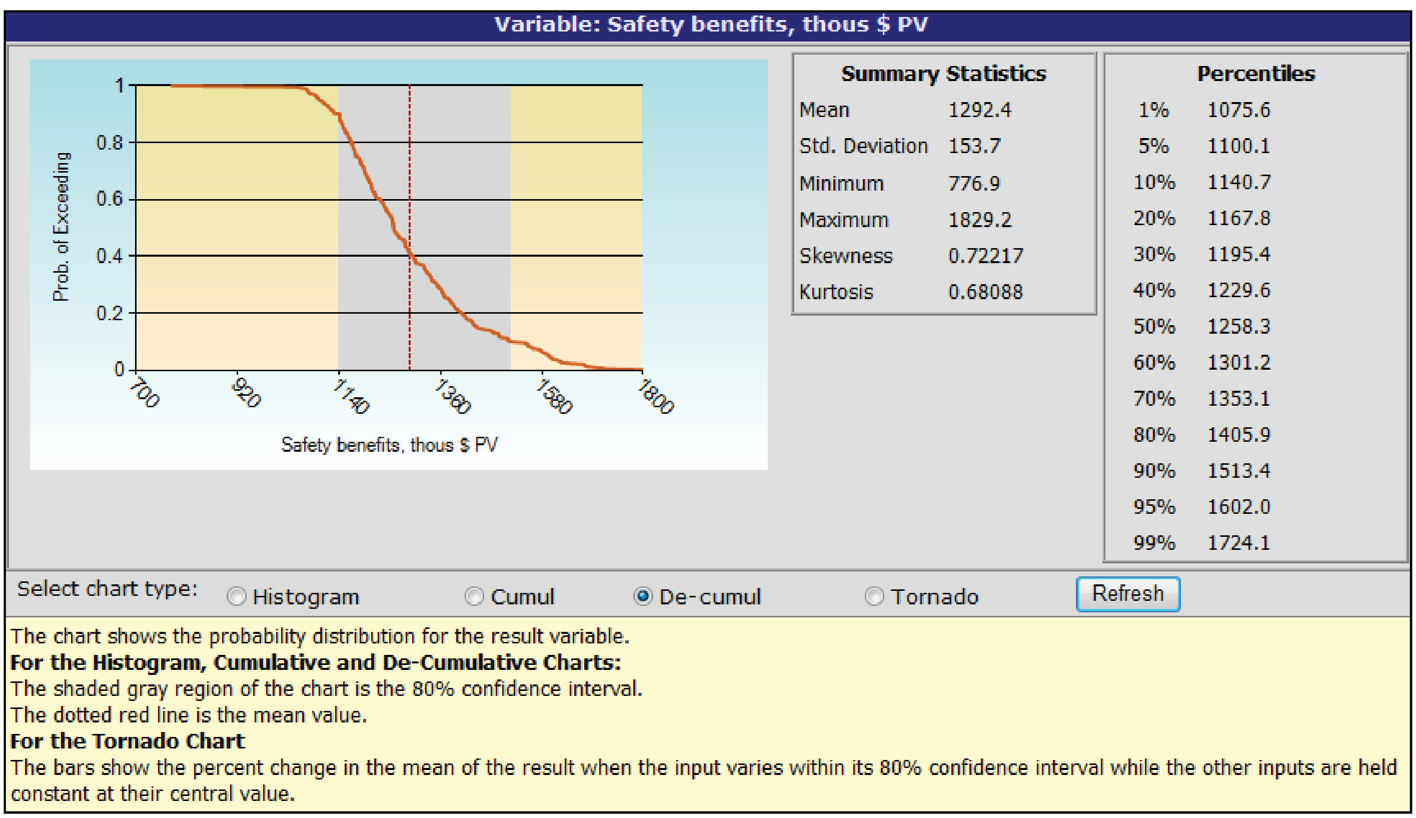
Risk Analysis. One feature in GradeDec.Net that has great promise for crash cost estimation is risk analysis, whereby users set probabilistic ranges for inputs and the results reflect the underlying uncertainty of the inputs. Although continuing research will permit some reduction in uncertainty, risk analysis should remain a component of any forecasting process. The research team proposed that this element be included in the framework for crash cost estimation and that its presence in GradeDec.Net be used to deliver this capability to practitioners. Figure 3 shows a screenshot of risk analysis results from GradeDec.Net.

2.2.6 Alternative Methods for Forecasting Crash Costs

The research approach for NCHRP Project 08-85 recognized that several methods can be employed to develop a crash cost estimation framework. The list is not exhaustive, however. As part of the research approach, all available methods were reviewed, with the intent that the resulting product would employ those methods that have the most merit, from both the theoretical and practical application perspectives. The alternative crash cost-forecasting methods that were considered at the outset included statistical methods, engineering methods, data mining methods, Bayesian reconstruction, and risk analysis methods.

2.2.6.1 Statistical Methods

Statistical methods like the APS Model connect incident costs to causal factors for some sample of data and derive models from the estimated relationships. One limitation of the statistical modeling approach is the general paucity of data (due to crashes—fortunately—being relatively rare occurrences) and the fact that each data point has its own unique circumstances. As would be expected, costs forecast using statistical



Source: GradeDec.Net, FRA.

Figure 3. Sample risk analysis results chart and table from GradeDec.Net.

methods have very high variances. Accordingly, the research team concluded that in developing the crash cost-forecasting framework, statistical methods should be supplemented with ancillary methods to reduce the variance of the outcomes.

2.2.6.2 Engineering Methods

An engineering method (e.g., using a speed-kinetic energy relationship) will typically superimpose a functional form that has logical merit on the objective function, and it will be calibrated to fit some set of data. Engineering methods, as illustrated in the Volpe high speed rail paper (*11*), exhibit significant promise in supporting the crash cost-forecasting framework.

2.2.6.3 Data Mining Methods

In contrast to engineering methods, in which functional forms are imposed, data mining methods assume no structure but follow a process to seek relationships from within the data. One such data mining method—Classification and Regression Tree, or CART—develops logic trees based on a hierarchy of most significant factors. CART could prove useful in a general framework for grade crossing crash cost forecasts.

2.2.6.4 Bayesian Reconstruction

Because crashes that occur at grade crossings are low-probability events, the magnitude of costs (and the probability of any given level of severity in a particular crash) can be derived from a rigorous analysis of crashes that have already occurred. Existing safety research offers Bayesian reconstruction of crashes as a possible methodology for intensively assessing (a) the key events through a crash sequence that lead to the most costly outcomes; (b) the human, physical, and operational characteristics of the crash situation accounting for the events; and (c) the marginal effects that a potential change in the situation may have had on the cost of the crash. Bayesian reconstruction has proven helpful in the transportation literature for modeling the severity of low-probability crash types like pedestrian involvement (*13*), median-crossings (*14*), and the role of particular counter-measures on injury reductions for various crash types (*14*). Given the paucity of data, the approach to crash cost estimation could be informed by Bayesian reconstruction of a sampling of actual crashes, with the findings used in conjunction with conventional statistical and other methods.

2.2.6.5 Risk Analysis Methods

Probabilistic risk analysis can be used to augment the crash cost-forecasting process and permit full information to be used, including uncertainty. Crash cost estimates could be presented as probabilistic ranges or using single qualified values like "the crash cost would exceed 1.5 million dollars with 95% confidence."

2.3 Project Tasks

NCHRP Project 08-85 began with a literature review and survey of current practices of measuring and estimating costs of highway-rail grade crossing crashes and crash-related interruptions in shipments of goods. This research enabled identification of the principal cost components of grade crossing crashes. The next steps were developing a cost-forecasting model framework, collecting data, and estimating grade crossing collision costs. The results of these tasks were reported in Technical Memorandum 1, which is provided as an appendix to this report. Following development of the cost-forecasting model framework with selected data collection, a Webinar workshop was held with the project panel to review the results of the research at that stage. The panel's feedback was used to further refine the cost-forecasting model framework.

2.3.1 Task 1: Literature Review and Survey of Current Practices

The project began with a review of the literature and a survey of current practices for measuring and estimating the costs of highway-rail crashes and for collision-related interruptions in the shipments of goods. The review covered the full range of costs incurred by the many stakeholders in grade crossing crashes, including railroads, businesses, public agencies, shippers, passengers, and the public at large. The availability, accuracy, and reliability of data on collision costs as they may be reported by public agencies, railroads, or other sources also were assessed. The literature review also looked at the models and tools currently in use for forecasting grade crossing collision and service interruption costs.

The findings from the literature review are reported in the appendix to this report (Technical Memorandum 1).

2.3.2 Task 2: Identification of Principal Components

The next task was to identify the principal components of grade crossing collision costs. These components included but were not limited to (a) damages to highway vehicles, trains, and goods carried; (b) investigations by rail carriers and public agencies; (c) business interruptions; (d) lost time and productivity; (e) traffic delays and diversions; (f) cleanup of hazmat spills; (g) repair of damaged infrastructure and rights-of-way; (h) litigation; (i) pollution; and (j) involvement in post-collision hearings and community outreach. Findings from Task 2 also are reported in the appendix (Technical Memorandum 1).

2.3.3 Task 3: Data Collection and Estimation of Grade Crossing Crash Costs

Using the approved cost components from Task 2, the project team collected data and conducted analyses to develop estimates of the magnitude of grade crossing collision costs. In those cases where data was inadequate, the project team identified the research needed to develop meaningful cost estimates.

In coordination with the project panel, the project team performed Task 3 (data collection, cost estimation) after Task 4 (development of the cost-forecasting model framework). This change in sequence enabled more targeted data collection. The Task 3 findings were reported on in a separate document, Technical Memorandum 2, and have been incorporated in detail into Chapter 3, Findings and Applications, in this report.

2.3.4 Task 4: Development of a Cost-Forecasting Model Framework and Webinar

The project team identified alternative approaches to forecasting rail-highway grade crossing collision costs and to developing a framework for a cost-forecasting model or models. The research plan included identifying the key grade crossing characteristics that may affect collision costs and other variables important to forecasting. This task also included defining the steps for model development.

A Webinar workshop was held on October 3, 2012, with the NCHRP Project Panel and other experts to test and refine model approaches and concepts.

2.3.5 Task 5: Model Refinement

Based on the Webinar workshop discussions, the project team refined the modeling approaches and the steps needed for model development. The project team described how cost-forecasting models could be used to enhance federal and state resource allocation and to make decisions to close, grade-separate, or otherwise improve highway-rail grade crossings. The potential benefits of developing these models were also identified.

2.3.6 Task 6: Final Report

The final task was to prepare a final report documenting the research and its results. The final report is published here as *NCHRP Report 755,* along with an appendix containing Technical Memorandum 1. In addition, a grade crossing crash cost evaluation spreadsheet tool (spreadsheet tool) was developed. The spreadsheet tool is available for download from http://www.trb.org/Main/Blurbs/169061.aspx and can also be accessed from www.trb.net by searching for "*NCHRP Report 755.*"

CHAPTER 3

Findings and Applications

3.1 Introduction

3.1.1 Purpose

Project NCHRP 08-85, "The Comprehensive Costs of Highway-Rail At-Grade Crossing Crashes," specified three objectives:

1. Develop a categorization scheme for comprehensively describing costs associated with highway-rail grade crossing crashes.
2. Obtain estimates of the cost magnitudes in recent experience.
3. Create an analytical framework for forecasting grade crossing crash costs, considering the characteristics of a crossing and the rail and highway traffic using it.

The costs to consider were to include those incurred by railroads, highway agencies, shippers, travelers, businesses, public service agencies, and others as a consequence of a collision and interruption of traffic flow. The models were to be usable for evaluating the benefits of crossing changes intended to reduce crashes, and ideally, the model(s) would provide a simplified method of incorporating cost estimates into benefit-cost analyses of highway-rail grade crossing upgrades. In the event that funding for grade crossing improvements were reduced in the future, the comprehensive costs of grade crossing crashes and their use in benefit-cost analyses would support informed decision making in competition for general highway funds.

NCHRP Project 08-85 was conducted to develop a practical framework for estimating comprehensive highway-rail grade crossing crash costs. This chapter presents that conceptual framework and discusses how to estimate costs for the framework and populate the framework with available cost data.

3.1.2 Background

Technical Memorandum 1 (included as the appendix to *NCHRP Report 755*) provides the results of a literature review/survey of current practices and identification of the principal components of grade crossing collision costs. In addition to these research results, the findings included the data collection and estimation of grade crossing collision costs from Task 3 and the development of a cost-forecasting model framework and Webinar workshop as outlined in Task 4. The framework and the initial round of collected data were reviewed at a Webinar held with the project panel in October 2012. Findings from the Webinar are incorporated in *NCHRP Report 755.*

3.1.2.1 Key Findings

This section highlights key findings in the appendix that were significant to the subsequent research. (For additional details, refer to the appendix.)

The appendix to *NCHRP Report 755* identifies and presents the principal components of grade crossing crash costs using a taxonomy that covers

- crash categories,
- casualty severity categories,
- categorization of cost components,
- non-property damage direct cost components,
- casualty costs and WTP measures for loss of life and injury and cost components, and
- property damage costs.

Appendix Section 4.2.2, Crash Categories, notes that the most accepted and widely practiced method of forecasting crashes and severity in the United States is that followed by U.S.DOT's APS Model. APS is employed in FRA's WBAPS, in GradeDec.Net, and in several variant models used by states. The general procedure is to calculate predicted crashes and allocate these to severity categories (fatal, injury, and non-casualty—that is, property damage only). In principle, given predicted crashes by severity category, a forecasted average cost per crash would enable a straightforward calculation of crash costs at a specific grade crossing.

Appendix Section 4.2.3, Casualty Categories, addresses the two main casualty types (fatal and non-fatal injury). The costs associated with casualties will likely remain the most significant cost components of crashes at grade crossings. Consequently, developing refined estimates of per-crash casualties by severity for both crash casualty types will be important for improved cost estimation. Although the highway crash literature often uses a six-tiered injury severity scale (the Abbreviated Injury Scale, or AIS), the research team adopted the three-tier classification of the NSC instead. Use of the NSC classification enables use of police crash reporting and has been shown to have greater reported accuracy than other methods. Grade crossing crash data further reports casualties by mode (highway, pedestrian, rail passenger, and rail employee), which also may be used to inform the effects and costs of crashes.

Appendix Section 4.2.4, Categorization of Cost Components, itemizes the principal cost categories by effect and impact. Primary effects occur at the crash site and include casualties (with related costs) and property damage (to highway vehicles, railroad equipment, and infrastructure). Secondary effects are associated with supply chain and business disruptions. Also considered are effects associated with rare catastrophic crashes. "Impact" describes (a) how the cost component affects society (directly, indirectly, or intangibly), (b) the process through which the impact is perceived (e.g., business supply chain disruption), or (c) the approach taken to evaluate the cost (e.g., in the case of rare catastrophic events). Both indirect and intangible costs are captured in the WTP measures for loss of life and injury.

Appendix Section 4.2.5, Direct Costs Not Property Damage, notes that these costs, like EMS and insurance, are included in bottom-up tallying of costs and are subsumed and counted in the WTP measures of casualty costs.

Appendix Section 4.2.6, Willingness-to-Pay Casualty Costs, notes that the costs associated with loss of life and injury are calculated using WTP measures. These costs are based on estimates of what individuals are willing to pay to reduce the risk of being killed or injured. The costs are inclusive of human capital, lost productivity, and tax effects that are associated with persons being killed or injured in crashes. It is accepted practice to derive WTP measures for casualties as fractions of the VSL and to use the VSL established by the U.S. Department of Transportation. [Note: In 2013, toward the conclusion of the research for NCHRP Project 08-85, U.S.DOT adjusted the VSL to $9.1 million using a base year of 2012. Guidance is available at http://www.dot.gov.] VSL estimates are widely regarded as upper-bound estimates of damages associated with loss of life; however, in certain cases, these may be exceeded by settlements or jury awards in civil lawsuits.

Appendix Section 4.2.7, Property Damage Costs, includes the costs of damage to highway vehicles and infrastructure as well as costs of damage to railroad equipment and infrastructure.

3.1.2.2 Subsequent Research

Findings from the work conducted in Task 3 and Task 4 are presented in the balance of this chapter of *NCHRP Report 755.* The findings follow the taxonomy of costs detailed in the appendix and present data sources, cost estimation methods, and an overall cost-forecasting framework that incorporates feedback and discussions from the Webinar workshop held on October 3, 2012. The intent of the framework is to extend current practices for crash cost estimation to a comprehensive set of cost components, thus providing practitioners a practical and accessible method for estimating grade crossing crash costs.

- Section 3.2 Conceptual Crash Cost Framework defines the processes to calculate crash costs and assign them to categories. The framework integrates with current practices in crash prediction and severity methodologies and is structured to avoid double counting costs.
- Section 3.3 Primary Effect Crash Cost Components describes the direct, indirect, and intangible (non-monetary) cost elements and sources of information for calculating those costs. These include fatality, injury, and property damage costs for both rail and road users.
- Section 3.4 Secondary Effect Crash Cost Components describes the indirect crash cost elements and sources of information for calculating those costs. These elements include supply chain costs, loss of cargo value, and hazmat cleanup costs.
- Section 3.5 The Crash Cost Framework and Rare Catastrophic Crashes describes the methods for calculating the effects of rare catastrophic crash costs. Note: This section is included for discussion purposes only. The preferred approach, per the Webinar consensus, is to disregard these costs.
- Section 3.6 Grade Crossing Crash Cost Evaluation Tool presents the structure of a spreadsheet tool to assess the benefits of grade crossing projects. It incorporates the crash cost calculation elements described in Sections 3.2 through 3.5. The spreadsheet tool is designed to support broader project ranking and policy analysis objectives.

3.2 Conceptual Crash Cost Framework

3.2.1 Introduction

3.2.1.1 Purpose of This Section

This section of Chapter 3 further develops the taxonomy of crash cost components and contributing factors that are described in the appendix. These components and factors ultimately determine the magnitude of crash costs, while indicating the benefits of interventions (projects or policies) that affect them. This conceptual framework presents an overview of the taxonomy and describes the generalized structure for determining crash costs and the integration with external tools needed to estimate crash costs.

The framework builds on principal components of grade crossing crash costs and embodies the principles of benefit-cost analysis to ensure that

- costs reflect costs to society not just out-of-pocket costs or those of a particular stakeholder group, and
- costs are mutually exclusive and free of double counting.

The cost framework is applicable to support resource allocation and infrastructure investment decisions in accordance with federal policy guidelines (e.g., Executive Order 12893).

3.2.2 Overview of Conceptual Crash Cost Framework

The conceptual crash cost framework is illustrated in Figure 4. Scanning from top to bottom, the framework builds on existing external tools that predict the number of crashes by the three severity categories of fatal crashes, injury crashes, and crashes involving only property damage. Given the uniqueness of each grade crossing from spatial, engineering, and traffic perspectives, crashes are predicted on a crossing-by-crossing basis.

The cost framework then determines the cost per crash for each level of severity. Uncertainty can then be considered through risk analysis tools to develop the total cost for grade crossing crashes.

It should be noted that consensus feedback from the Webinar was to disregard the effects of rare catastrophic events. Such effects need not be automatically included in the framework; however, some discussion of costs for rare catastrophic events appears in Section 3.5 and the topic is included in Figure 4. As appropriate or necessary, costs for rare catastrophic events can be factored into the total cost for grade crossing crashes similarly to uncertainty by using risk analysis tools.

3.2.3 Taxonomy of Crash Cost Components

Table 3 summarizes the taxonomy of highway crash cost components. Cost components are grouped into primary and

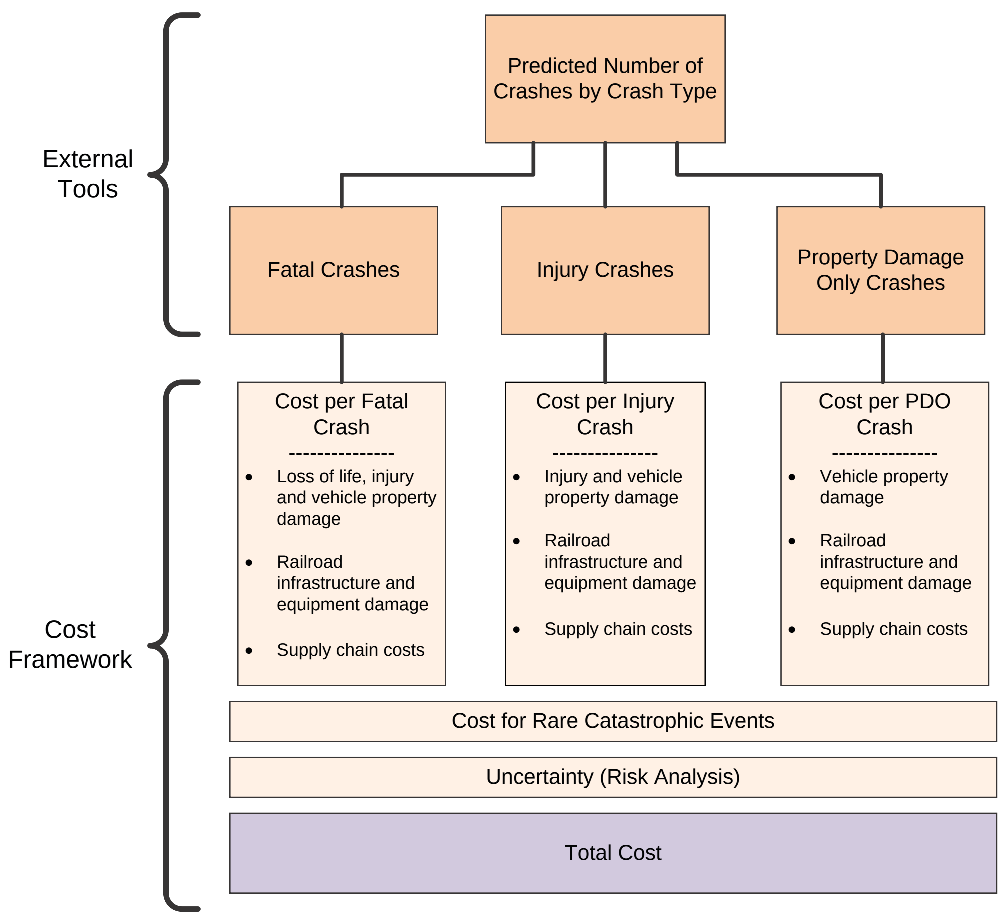


Figure 4. Overview of conceptual crash cost framework.

Table 3. Taxonomy of grade crossing crash cost components.

Effect	Impact	Cost Component
Primary	Direct	Property damage (highway vehicles, railroad equipment and infrastructure) Other direct costs (e.g., EMS, insurance)
	Indirect	Work-related productivity loss Tax loss
	Intangible	Quality of life Pain and suffering Environmental cost
Secondary	Supply Chain and Business Disruption	Rerouting costs Lost sales Prevention costs Inventory spoilage Freight and passenger delays Freight and passenger reliability Increased inventory

Note: The cost components shown here are drawn from Table A-16 and Table A-17 in the appendix.

secondary effects. Primary effects are those effects that are largely restricted to the crash site, and secondary effects are the supply chain and business disruption effects. The "Impact" column refers to the classification of cost components as direct, indirect, and intangible for primary effects, and to supply chain and business disruption for secondary effects.

3.2.3.1 Primary Effect Costs

Primary effect costs include the cost components generally associated with crashes. These include all direct costs, some indirect costs, and some intangible costs. In general, primary effect costs pertain to impacts on users involved in the crash, both on the road and the rail lines. Direct primary effect costs include casualty costs of fatalities and injuries, and property damage to road vehicles, rail cars, and infrastructure. It covers medical costs, including hospital and rehabilitation activities and emergency response services (i.e., police, fire, ambulance, and hazmat cleanup services). In theory, primary effect direct costs also encompass legal costs (including criminal prosecution and insurance claim costs) and administrative costs (e.g., household help and insurance administration). These cost components are subsumed in the WTP valuations of life and injury, which include the intangible costs of lost quality of life and of pain and suffering. Primary effect intangible costs also include the value of impacts on air quality and other environmental quality-of-life impacts for affected persons (e.g., residents near a crash site that suffers some environmental degradation as a result of the crash).

3.2.3.2 Secondary Effect Costs

Secondary effect costs include the business costs associated with supply chain disruption and disrupted travel due to grade crossing crashes. These costs include transportation costs associated with rerouting or diverting shipments and inventory costs associated with delay, loss, or replacement of shipped products.

Service industries also may experience secondary effect costs, as there can be worker productivity losses, employee absenteeism, and worker substitution expenses. Secondary effect costs have been recognized in theory as legitimate crash cost components, but generally have not been evaluated in crash cost studies. The cost framework presented in *NCHRP Report 755* introduces methods to estimate these secondary costs.

3.2.4 Relationship to Existing Methods

The framework specifies that the prediction of crash occurrence by crash severity type is accomplished with external tools.

A widely accepted basis for estimating predicted crashes at grade crossings is U.S.DOT's APS Model (*15*). The APS Model was discussed in Section 2.2.5.

FRA's GradeDec.Net model builds on and adds several refinements to the APS approach, as well as methods for estimating both direct delay costs of queued vehicles (at blocked crossings, not from crashes) and environmental impact. However, existing models for grade crossing crash costs do not encompass supply chain and business disruption costs or the estimated costs of potential low-probability catastrophic crashes in which multiple parties are injured or killed.

The refinements to APS in GradeDec.Net were reviewed in Section 2.2.5. Table 4 summarizes the relationships between existing crash prediction tools and the crash cost framework.

The remainder of this section presents the generalized structure for refined estimates of the cost per crash.

3.2.5 Generalized Structure for Determining Crash Costs

The generalized equation for calculating crash cost is based on the following steps:

Step 1. Predict crashes by crash severity type (from external model, e.g., GradeDec.Net).

Step 2. Estimate casualties by severity type for each crash type (applies to casualty crashes only; fatalities and injury crashes will have different mixes of casualties, which drives the costs for each crash type).

Table 4. Grade crossing crash prediction tools and relationship to the crash cost framework.

Grade Crossing Crash Prediction Tool	Scope and Functionality
APS and WBAPS	• Calculates predicted grade crossing crashes • Covers three severity categories (fatality, injury, and property damage only) • Assigns a cost per crash to each crash severity category to estimate a total crash cost • Contains crash incidence prediction models for three main grade crossing device types (passive, lights, and gates) • Uses independent models for each grade crossing device type, which can lead to insufficient sensitivity to variances in traffic volume, train speeds, and other factors for each type of grade crossing
GradeDec.Net	• Integrates APS models • Enables segmentation of highway and rail traffic into categories (for highway, cars, trucks, and buses; for rail: freight, passenger, and local movements [switch trains]); extends the APS Model by breaking out damages to highway and rail modes • Includes high speed rail model (severity is based on kinetic energy and tracks casualties by mode) • Adds the risk assessment framework developed by the Volpe Center for grade crossing risks with high speed passenger rail • Adds real-world aggravating risk factors, proximity to hazards, geography, and track characteristics (e.g., curvature) • Enables full benefit-cost analysis and risk analysis, and is able to compare alternative grade crossing improvements • Adds methods to estimate direct delay costs of queued vehicles at blocked crossings (not from crashes) • Adds methods for estimating environmental impact
Grade crossing crash cost Framework (NCHRP Project 08-85)	Includes or improves on the listed APS and GradeDec.Net features, including: • Accommodates additional data granularity and setting densities • Adds explicit methods for calculating the average cost per crash by crash type • Adds methods to estimate supply chain costs and other secondary cost impacts • Adds methods to estimate costs of potential low-probability catastrophic crashes in which multiple parties are injured or killed

Step 3. Estimate per-crash casualty costs based on the classification of crash severity and outcomes (i.e., casualties per crash by severity category) and unit costs by injury severity.

Step 4. Estimate property damages (vehicles, rail equipment, and rail infrastructure).

Step 5. Estimate secondary effects (supply chain and business disruptions) by crash severity type.

(The term *crash casualties* refers to individuals injured in a crash; a *casualty crash* is a crash or incident that results in at least one injury or fatality.)

This structure includes all elements of the core calculation process for estimating crash costs (predicted crashes by type, casualties per crash, and unit costs) and is shown by Equation (1).

$$\textit{Crash Cost} = \textit{Predicted Crashes} * (\textit{Primary Effect Costs per Crash} + \textit{Secondary Effect Costs per Crash}) \tag{1}$$

The details of estimating primary and secondary effect costs are presented in the following sections, which enumerate the elements of crash costs and factors affecting their magnitude. In each case, data on actual costs of past crashes is used as a basis for predicting the likely benefits of reducing crash incidence (and severity) in the future.

Remember that even at the same crossing, not all crashes are the same. The probability of a crash with high primary effects and low secondary effects is different from the probability of a crash with high primary and secondary effects. Analysts may wish to consider representative crashes with differing characteristics and apply appropriate weights to arrive at total or average crash costs for a crossing. Careful analysis is required in all cases.

Issues regarding the accuracy of crash cost data, and opportunities for future refinement, are discussed in the report conclusion section.

3.2.6 Specific Concerns

3.2.6.1 Regarding Cost Prediction Accuracy

Because crash cost estimates are to some extent based on historical data, care must be taken to ensure that forecasts reflect any anticipated changes (e.g., longer trains, higher traffic density).

The prediction models based on the APS Model are calibrated every several years so that the model correctly predicts crashes nationwide based on the most recent calibration of model coefficients. User inputs largely determine the future conditions underlying the predictions (e.g., traffic growth, length of trains). These factors impact crash prediction, and for GradeDec.Net, the length of highway delay due to blocked crossings. Unit price factors that directly impact cost should represent analysts' best estimates for the forecast period.

3.2.6.2 Regarding Effects of Crossing Device Type

The APS uses three separate models for the three major groupings of device types: passive (i.e., signage only), flashing lights, and gates and predicts crashes by severity type for each device type. Given a grade crossing crash of a particular severity type, the research team found no evidence of a significant cost difference between crossings with different device types. Differences that may exist are captured by other factors (i.e., device type is strongly correlated with highway AADT and number of highway lanes, and these factors are accounted for when estimating the secondary effects).

3.2.6.3 Comparison of Casualty Costs with Railroad Liabilities for Personal Injury Claims

The methodology for estimating the casualty cost of crashes is based on the WTP method, which applies a VSL measure to each predicted fatality and a percentage for each injury. This measure comprehensively accounts for individual pain, suffering, and loss of quality of life, and is generally considered inclusive and larger than actual out-of-pocket costs that are measured directly.

A comparison was made with the expenditures by Class I railroads on personal injury payments from financial data provided to the Surface Transportation Board. The railroads, for the most part, self-insure for personal injury claims. The total expenses for personal injury payments, including payments for employee injuries and third-party injuries like grade crossing crash victims, was less than $400 million in 2011 for all the Class I railroads combined, based on their submissions of Form R-1. By comparison, there were 251 fatalities in 2011, which at $6.2 million (VSL) per fatality totaled $1.56 billion (not including the cost of injuries). The research concludes that the WTP measure does exceed the actual outlays and other out-of-pocket costs associated with the cost of casualties from grade crossing crashes.

3.3 Primary Effect Crash Cost Components

3.3.1 Introduction

This section describes the data sources and calculations for estimating the primary effect crash cost components. These include direct, indirect, and intangible costs associated with property damage, injury and fatality costs. The cost calculations are specified in a form intended to recognize all relevant cost components, noting that some components are better-supported by existing data than others at this time.

Within this section

- Subsection 3.3.2 describes the general model, data sources for crashes, and refinements to the crash cost framework;
- Subsection 3.3.3 describes methods and data available to estimate costs associated with casualties; and
- Subsection 3.3.4 describes methods and data available to estimate costs associated with property damage.

3.3.2 General Model

In Section 3.2.5 it was noted that the first step in cost estimation is to predict crashes by crash severity type using an external model. The next step is to estimate the primary effect costs.

Primary effect costs are estimated for each crash severity type (fatal, injury, and property damage only). The general model for estimating primary effect costs per crash by crash severity type is shown by Equation (2).

$$\begin{aligned}&\textit{Primary Effect Costs per Crash}\\&\quad=\Sigma\left(\begin{array}{l}\textit{Average Number of Casualties by}\\\textit{Severity Level} * \textit{Cost per Casualty}\end{array}\right)\\&\qquad+\textit{Property Damage Estimate per Crash}\end{aligned}\qquad(2)$$

Costs for crashes involving injuries but no fatalities are estimated following Equation (2) as shown. Cost estimates for crashes involving only property damage follow Equation (2) except that the casualty component is removed. To estimate costs for crashes involving fatalities, Equation (2) is applied as follows:

- The estimate of the casualty cost component equals the sum of the average number of *fatalities* per fatal crash times the VSL plus the average number of non-fatal *injuries* per fatal crash in each of the three severity categories times the cost per injury by severity (estimated as a fraction of VSL).
- The estimate of the property damage component equals the sum of the average property damage per casualty crash for highway vehicles, railroad equipment, and infrastructure.

3.3.2.1 Crash Data

FRA grade crossing crash data is a primary source for understanding crashes and their cost components. Moreover, in developing cost estimates care should be taken that estimates validate reasonably well against the available data.

FRA requires each railroad to report any "impact between railroad on-track equipment and an automobile, bus, truck, motorcycle, bicycle, farm vehicle, or pedestrian at a rail-highway grade crossing"(*16*). Railroad equipment damage estimates are reported on Form 6180.54 (Rail Equipment Accident/Incident). However, there is a minimum reporting threshold—$9,400, in 2011—in railroad damages. Additional incidents are reported on Form 6180.57 (Highway-Rail Accident/Incident), but this form includes only damage to highway vehicles, not railroad equipment. Both sets of collision data are compiled in an FRA annual report that covers crashes at highway-rail grade crossings as well as other types of incidents.

The Materials Transportation Bureau (MTB) of the U.S.DOT Research and Special Programs Administration also collects grade crossing crash data, as all carriers must report to them crashes involving hazmat transport. A carrier must submit a hazmat collision report when hazardous material leads to death, injury requiring hospitalization, property damage exceeding $50,000, or a situation representing danger to life.

The FRA grade crossing data and other FRA safety data make available information about

- number of crashes;
- casualties by mode (highway users, pedestrians, railroad employees or railroad passengers);
- highway vehicle damage estimates;
- railroad equipment damage estimates (for incidents in which damage exceeds the reporting threshold); and
- any hazmat breaches or spills.

Additionally, the FRA National Grade Crossing Inventory contains a wealth of information on all grade crossings in the United States, including physical characteristics, device type, number of tracks, highway functional class, and traffic by highway and rail modes. Generally, the information is more current and complete for the public crossings than for the private crossings. State departments of transportation (state DOTs) provide grade crossing data updates to FRA. Care needs to be taken when using the National Grade Crossing Inventory given the lag time in updates to the data.

3.3.2.2 Casualty Cost

The crash categories used in the framework are: fatal, injury, and non-casualty (property damage only) crashes, with three tiers of injury based on the NSC classification system used for police reporting (A for "severe," B for "other visible [injury]," usually indicating the presence of blood on a victim without loss of consciousness, and C for "complaint of pain").

Fatal crashes, on average, include a number of fatalities and injuries in each of the three injury severity categories. The same is true for injury crashes (except that these do not include fatalities). Each crash type has some extent of property damage. The ability to specify the average number of casualties by type and property damage for each crash type, then to apply unit costs, enables a more precise estimate of crash costs before the framework is extended to include additional cost components. The process for achieving this is described in Section 3.3.3.

The breakout of casualty statistics from the FRA safety data to the NSC categories is not readily accomplished. With some careful analysis and judgment, it is possible to develop estimates and their quality can be improved by comparing with NHTSA analyses of crash severity.

3.3.2.3 Property Damage Cost

Property damage cost extends to the highway vehicle, railroad equipment, and infrastructure. Railroad equipment generally refers to rolling stock (i.e., locomotives and cars). Railroad infrastructure refers to tracks, switches, structures, signals, grade crossing devices, and other wayside equipment. There also may be damage to highway infrastructure, like channeling devices, guard rails, or roadway signals.

3.3.3 Casualty (Fatality and Injury) Costs

Estimating the costs of casualties in fatal and injury crashes follows the general model from Section 3.3.2 and involves three factors: crash incidence and severity, numbers of fatalities and injuries by severity category per crash, and unit costs (i.e., the loss value associated with each fatality and injury).

Table 5. Casualties at grade crossing crashes 2009–2011.

Crash Type	Number of Occurrences	Fatalities	Injuries
Fatal	694	782	320
Injury	1,669	0	2,342
Property Damage Only	3,678	0	0
Total	6,041	782	2,662

Source: FRA Grade Crossing Crash Data, FRA Form 6180.57, 2009–2011.

3.3.3.1 Predicted Crashes by Severity Category

The conceptual framework outlined in this report assumes that the analyst will populate an appropriate model (like GradeDec.Net) with the required data for predicted crashes by severity category. The three categories of crashes are fatal, injury, and property damage only.

3.3.3.2 Average Number of Fatalities and Injuries (by Severity Category) per Crash

The key input for arriving at refined crash cost values for the casualty cost categories is the average number of fatalities and injuries (by severity category) per crash by crash type. Estimates are available for general highway crashes; however, there are no well-established estimates for grade crossing crashes. Historical values for casualties by main crash types in recent years are given in Table 5.

3.3.3.3 Cost per Casualty

The VSL is set by the Office of the Secretary of Transportation (OST) of U.S.DOT (*17*). The valuation for varying injury levels was also established by OST. The collective medical, emergency services, and insurance expense was calculated in a study by NHTSA (*18*). That expense is also included in the total value of injury avoidance. Table 6 summarizes the valuation of injury avoidance by severity level for cost for grade crossing crashes.

Toward the conclusion of the research for NCHRP Project 08-85, the U.S.DOT Undersecretary for Policy issued a memorandum, “Guidance on Treatment of the Economic Value of a Statistical Life in U.S. Department of Transportation Analyses” (see http://www.dot.gov/sites/dot.dev/files/docs/VSL%20Guidance.doc), in which the VSL was increased from $6.2 million (set in July 2011), to $9.1 million. The casualties by injury categories that are based on VSL also were increased proportionately to the increase in VSL. In the crash cost evaluation spreadsheet tool created for this project (available at http://www.trb.org/Main/Blurbs/169061.aspx), the appropriate changes would be made to cells C14 to C17 in the sheet labeled “Casualty Costs.”

Analysis of damage claims for actual crashes tends to support the values shown in Table 6 regarding the magnitude of crash costs. For example, a 2003 collision in Anoka, MN, between a BNSF Railway freight train and a vehicle caused the death of the four people in the vehicle. After 8 years of trials, a settlement of $29.1 million was reached between the families and BNSF. In that case, the settlement amount approaches values based on VSL (see Table 6). However, legal settlements generally should not be considered a reliable basis for establishing crash costs to society, because they can also include punitive judgments (penalties) that would not be applicable for this type of analysis.

Table 6. Valuation of crash casualties as fraction of VSL.

Casualty	Total Value of Injury Avoidance[1,2]	
	Dollars	Fraction of VSL
Fatality (including AIS* Level 6)	$6,200,000	1.000
A—Severe Injury (average of AIS levels 3,4,5)	1,992,000	0.321
B—Moderate Injury (average AIS Level 2)	291,400	0.047
C—Light Injury (average AIS Level 1)	18,600	0.003

Sources:[1] The Blincoe (2002) study for NHTSA, updated to 2011 dollars. [2]Spicer and Miller (2010) study for OST. These two studies are highly comparable in terms of providing very similar total values for the specified types of injuries.

*AIS = Abbreviated Injury Scale. See the appendix (Technical Memorandum 1) Table A-2 for further definition.

Table 7. Highway vehicle property damage at grade crossing crashes, 2009–2011.

Crash Type	Crash Subtype	Number of Occurrences	Average Cost per Crash ($)
Casualty	Fatal	694	$8,483
	Non-Fatal Injury	1,669	11,707
Non-Casualty	Property Damage Only	3,678	7,598
Total		6,041	$8,830

Source: FRA Grade Crossing Crash Data, FRA Form 6180.57, 2009–2011.

Note: For crashes with no reported damage or damage less than $5,000, damage was assumed at $5,000.

3.3.4 Property Damage Costs

Property damage occurs regardless of crash severity. Estimation of property damage costs involves the following two steps:

Step 1. Determine predicted crashes by crash severity category.
Step 2. Estimate the average property damage per crash for each crash category.

Table 7 presents *highway* vehicle property damage data for 2009–2011. Damage to roadway vehicles and other non-railroad property are reported by FRA, based on information from the railroads and state DOTs. Roughly 36% of fatal crashes and 10% of injury crashes report no highway vehicle damage. The property damage estimate for incidents that involve no personal injury or death (averaging $5,000 per crash) is derived from FRA reports but represents the best estimate of the railroads at the time of the incident. Based on crash reporting from FRA Form 6180.57, some reported crashes (including casualty crashes) show no property damage—or some small value in vehicle damage—in the FRA Highway Grade Crossing Accident/Incident database. The framework presented in this report assumes a damage estimate of $5,000 when "no damage" or less than $5,000 damage is reported.

FRA does not evaluate or verify the accuracy of the reported numbers, though it does appear to be a reasonable default value and it is generally consistent with NHTSA data, particularly after considering that nearly all property-only damage crashes are reported at grade crossings, while a significant number of non-injury roadway crashes go unreported altogether.

Table 8 profiles *railroad* property damage data as reported to FRA by railroads. In 2011 railroads were only required to report damage in excess of a threshold of $9,400. Table 8 also shows the damage to highway vehicles in those incidents when rail damage was reported. The average highway vehicle damage in such incidents is about 2.8 times the average damage shown in Table 9, which (as would be expected) indicates that significant damage to rail equipment and infrastructure correlates with crashes involving heavy highway vehicles.

Table 9 shows property damage for highway vehicles, railroad equipment and track according to FRA data, broken out by severity category. The table assumes that the damage to railroad equipment was $7,000 when unreported or reported below the threshold and that infrastructure damage was zero if unreported.

Crash damage valuations in the FRA and NHTSA databases are estimated by on-site representatives (which can include

Table 8. FRA data for grade crossings with reported rail damages, 2009–2011 ($).

	Highway Vehicle Damage	Rail Equipment Damage	Rail Infrastructure Damage
Number of Crashes	539	539	539
Minimum Damage Reported ($Value)	$5,000	$0	$0
Maximum Damage Reported ($Value)	$750,000	$8,554,000	$264,763
Average Damage Across All Crashes ($Value)	$24,700	$67,829	$16,673

Source: FRA, Office of Safety Data.

Notes: Crashes include those where non-zero damages were reported for either rail equipment or rail infrastructure. The smallest non-zero total railroad damage reported for an incident was $8,901. Minimum highway vehicle damage was assumed to be $5,000 and was calculated as such even when unreported or reported as less.

Table 9. Property damage from crashes: highway and railroad equipment, 2009–2011 ($).

Crash Type	Property Damage per Crash		
	Highway Vehicle	Railroad Equipment	Railroad Infrastructure
Fatal	$8,483	$24,328	$2,448
Injury	11,707	17,527	2,332
Property Damage Only	7,598	8,045	923
All Crashes	$8,830	$12,535	$1,487

Sources: FRA Forms 6180.57 and 6180.54.

Notes: Reports from the same crashes were aligned. Minimum highway vehicle damage was assumed to be $5,000 and was calculated as such even when unreported or reported as less. Minimum railroad equipment damage was assumed similarly at $7,000. No minimum damage to railroad infrastructure was assumed.

local law enforcement officers, railroad employees, and federal government employees). The valuations often consist of a visual appraisal performed in a time-sensitive manner. As such, they cannot account for damages that only become apparent after the fact, and the valuations are not verified with any subsequent insurance or repair records. Previous reports have shown large variation in reported costs, as shown in Figure 5. (A logarithmic scale was used to better display the maximum and minimum values in Figure 5.) In addition, analysis by the North Carolina DOT confirmed that damages subsequently claimed by a railroad in legal cases can differ substantially from initial estimates that the railroads supply to FRA at the time of incidents. When this occurs, the railroads generally are unable to illuminate these differences further because they are associated with legal cases.

3.3.5 Effect of Grade Crossing Device Type on Highway Vehicle Damage

Table 10 shows the reported vehicle damage summarized by device type. There does not seem to be a significant difference by device type.

3.4 Secondary Effect Crash Cost Components

This section describes the data sources and methods for estimating secondary effect costs that accrue to delayed travelers and cargo and to parties beyond the immediate road and rail travelers or service operators. These costs include logistics and supply chain costs, cargo value loss, and environmental costs. In developing the conceptual crash cost framework, the research team sought to recognize all relevant cost components, even though data was not available for all cost elements. Section 3.4.1 discusses vehicle delay and rerouting cost, Section 3.4.2 discusses the types of factors affecting supply chain costs elements, and Section 3.4.3 describes other elements that impact the environment and quality of life.

3.4.1 Vehicle Delay and Rerouting Costs

The user cost of vehicle delay is the added vehicle operating cost plus the value of added driver and passenger time caused by waiting in a queue or being rerouted to a longer travel path. Calculating these costs involves three factors (see Equation [3]):

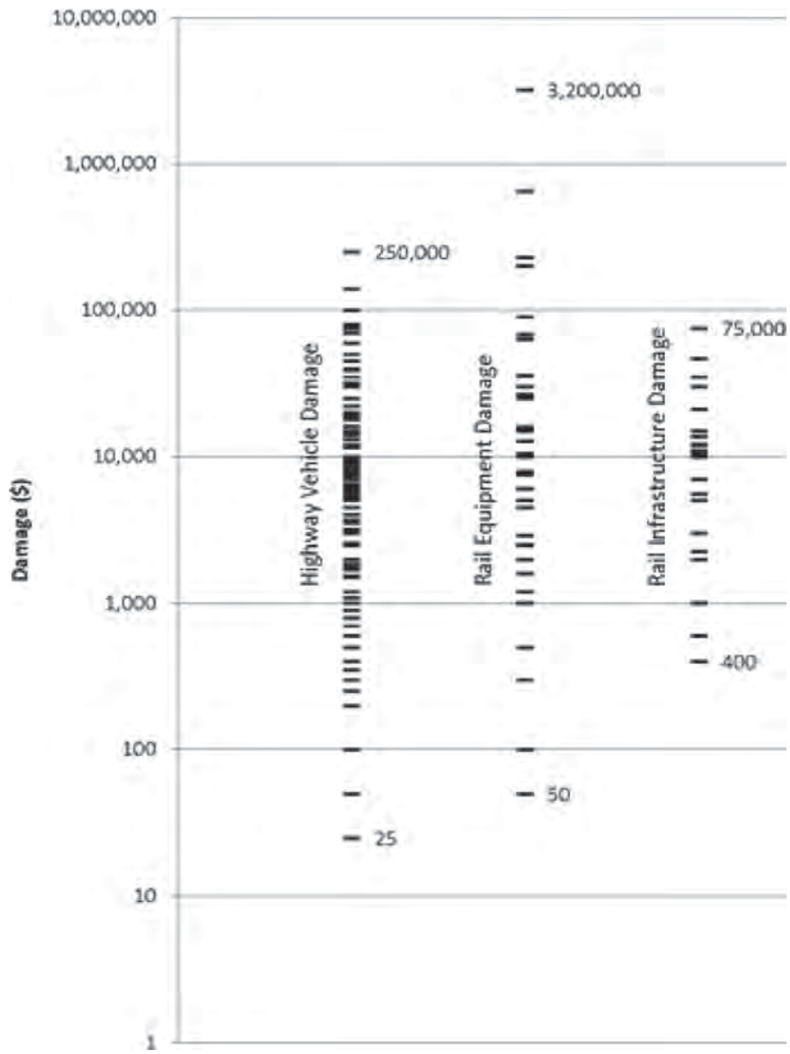
1. The grade crossing setting and the impact of closure on adjacent roadway and rail networks.
2. Closure duration (by closure type: rail line, roadway, or both).
3. Unit costs per hour of delay.

$$\begin{aligned} &\textit{Delay and Rerouting Cost} \\ &\quad = \big[\big(\textit{Traffic Volume} * \textit{Closure Type} * \textit{Delay Duration} \\ &\qquad * \textit{Cost per Hour}\big) + \big(\textit{Rerouting Rate} * \textit{Rerouting Miles} \\ &\qquad * \textit{Travel Cost per Mile}\big)\big] \end{aligned} \tag{3}$$

Figure 6 illustrates the progression of steps for the estimate. Each factor also is discussed in the text.

3.4.1.1 Crash Type and Closure Type

A highway-rail grade crossing crash can close the roadway only, the rail line only, or both. Major determining factors are the nature of the closure, its duration, and the need for (a) emergency services (e.g., ambulance, fire, and spill cleanup); (b) clearance of disabled or damaged vehicles; and (c) crash scene preservation for investigation. As previously discussed, these factors can be tied to the crash type and severity ratings, including the affected vehicle classes (cars, trucks, and/or buses, and trains) and outcome categories (fatality, injury, property damage). In addition, information clarifying that the train struck the highway vehicle–or vice versa–helps determine the nature of the disabled vehicles. Railroad damage outcomes need to be separated from rail



Source: North Carolina DOT.

Figure 5. Distribution and dispersion of cost for rail-highway crashes.

Table 10. Highway vehicle damage for grade crossing crashes, 2009–2011 by device type ($).

Grade Crossing Device Type	Number of Incidents	Average Highway Vehicle Damage ($)
Passive	2,565	$9,036
Lights	998	8,253
Gates	2,478	8,848
All Types	6,041	$8,830

Source: FRA Form 6180.57 Highway-Rail Accident Database.

Notes: Highway vehicle damage for incidents with less than $5,000 reported, assumed at $5,000. For 974 incidents at non-public or currently closed crossings, device type was assumed to be passive.

car derailments and severe derailments (i.e., derailments requiring track repair).

3.4.1.2 Time of Day and Seasonality

Although not mentioned explicitly in the delay cost progression in Figure 6, time of day and seasonality of the crash will be significant factors. Highway traffic flows are rarely uniform during the day. There are commuting peaks and late night hours with minimal traffic. Trains may also follow daily and seasonal patterns. Applications of the crash cost framework should not ignore this important factor.

3.4.1.3 Delay Duration

The length of vehicle delay is determined by the crash-related factors shown in Figure 6 and by the extent of vehicle

Figure 6. Estimation steps for vehicle delay cost.

backup to be cleared, which is a function of roadway volume and train length. In other words, the busier the road and the more trains on the affected line, the greater the expected disruptions to both rail and highway travel. FRA's databases do not indicate line disruption, duration, or the impact of the resulting delays to trains or motorists.

The project team researched the availability of data regarding length of road closures. We found that no single entity collects consistent data on delay duration and rerouting distance for highway-rail grade crossing incidents. Information on where data are kept varies by state; also, some data are not collected or retained by all states. Agencies that collect and keep road closure data may include state DOTs, the highway patrol, state police, departments of public safety, and traffic bureaus. For delay and other grade crossing crash-related data multiple inquiries were made to Class I railroads. The railroads claimed that there were no additional data beyond that available from the FRA sources, or that data were related to ongoing investigations or legal actions they would not discuss. In short, it is difficult to obtain reliable data regarding road closure length.

The project team also conducted a web search for news media articles and NTSB reports for rail crossing crashes that resulted in road closures and reroutings. Case studies obtained from those sources showed that durations of road closures following rail crossing crashes ranged from several hours to several days (*19*). The team then contacted state and local public safety officials for each crash documented in a case, attempting to gather additional information about what roads were closed or impeded, detour routes, and the durations of roadway and railroad closures. The research team found that, while there was no systematic reporting of this information, in many cases local public safety officials (primarily police or sheriff's departments) did have incident reports that listed the time the call came in, and the time the scene was cleared of emergency vehicles. This data provided a window of time for estimating roadway closure duration. However, roads may not remain closed the entire time that emergency vehicles are present on the scene, and some roads may remain closed after emergency vehicles have left. (In some instances track damage may not be repaired for days or even months, requiring trains to travel at reduced speeds until repairs can be made. Only in few cases did the public safety agencies have information on rerouting.)

Table 11 shows average values for closure duration, distance rerouted and average added travel time resulting either waiting for road reopening or shifting to alternative but longer routings. It shows that when an intersection with a grade crossing is closed, the average delay duration is longer for road vehicles than for freight trains, reflecting the fact that road vehicles are more frequently damaged or destroyed than train equipment as a result of those incidents. Crashes involving passenger trains are more rare, but tend to have even longer average delays because of the potential for injury to a larger number of passengers. In those cases, railroad personnel may be present and track may be out of service while state, federal and local agencies develop their incident investigations and reports. This

Table 11. Grade crossing crash effects on closure and rerouting.

Crash Type	**Affected Vehicle Class**	**Closure Duration** (minutes)	**Distance Rerouted** (miles)	**Average Added Travel Time per Person** (minutes)
Fatality	Road Vehicle	765[f]	3[b]	7.2[b]
	Freight Train[e]	284[g]	n/a	n/a
	Passenger Train	1,285[h]	n/a	n/a
Injury	Road Vehicle	125[a]	1.2[b]	3.5[b]
	Freight Train[e]	83[b]	n/a	n/a
	Passenger Train	1,380[c]	2.45[c]	36[c,d]
Property Damage Only	Road Vehicle	n/a	n/a	n/a
	Train	n/a	n/a	n/a

Sources: Web-based news articles, telephone interviews with local and state officials, and Google Earth.

Notes: [a] Based on two observations. [b] Based on six observations. [c] Based on one observation. [d] Based on busing of passengers around crash site for track closure duration. [e] No data available on whether or not trains are delayed until track reopens or are rerouted. [f] Based on seven observations, including one observation involving road closures for a second day to repair track. [g] Based on four observations. [h] Based on three observations, including one involving road closures for a second day to repair tracks.

delay can be more significant than the delay associated with emergency vehicles clearing injured parties and debris from a roadway.

3.4.1.4 Rerouting Distance

Availability of alternative routes depends on local conditions, primarily the density of the area highway network. The closure duration also determines whether an alternative route is designated for traffic movement.

Table 11 also shows typical truck rerouting distances. To estimate distance of rerouting, the team relied on two studies of rerouting patterns (*20*), along with information from online news reports that identified detour routes for specific crash sites and calculations using Google Earth to measure the most likely detour given the specific roads closed. The project team was able to document closure information for seven cases. The table presents values that appear reasonable and provide a basis for calculation that is clearly better than ignoring the entire issue. However there is significant room for greater precision in the future, once data on more cases can be assembled.

The researchers found wide variation among cases, indicating that averages can only provide a guide for estimating costs. For example, in more rural locations, detours may require vehicles to travel miles out of the way. In more urban areas, the higher density of street networks may result in fewer miles of detour but more time lost due to traffic congestion caused by the detour. Average (mean) delay is typically one-half of the closure duration, insofar as affected vehicle trips tend to be evenly dispersed over time. The numbers shown in Table 12 are based on the small number of cases for which such data could be obtained.

Table 12. Factors affecting user cost of grade crossing delay and rerouting.

Category	Behavioral Factor	Road			Rail	
		Car	Truck	Bus	Freight Train	Passenger Train
Value or Cost of Time Delay per Hour	Operating cost per vehicle (idling)[a]	$ 0.94	$ 1.12	$ 1.12	$14.25	$14.25
	Wage rate per crew member[b]	--	$26.89	$26.40	$42.55	$39.86
	Time value per passenger - work travel[c]	$22.90	$22.90	$22.90	--	$62.60
	Time value per passenger - other travel[c]	$16.70	$16.70	$16.70	--	$31.90
Occupancy per Vehicle	Crew size[d]	0.0	1.1	1.0	2	2
	Passenger occupancy[e]	1.5	0	10.5	0	120
Operating Cost per Mile	Operating cost per vehicle mile added for rerouting[f]	$0.59	$1.06	$1.52	$100.88	$100.88
Local Traffic Characteristics	Traffic volume per hour	*	*	*	*	*
	Mix of trip purpose for passengers	*	*	*	*	*

Sources:

a. FHWA's RealCost and *NCHRP Report 133*, adjusted by using the CPI.

b. U.S. Bureau of Labor Statistics National Compensation Survey (May 2011) for applicable transport occupations, with 43.7% added for fringe benefits (national average in those occupations). Adjusted to 2011 dollars using CPI.

c. TIGER [Transportation Investment Generating Economic Recovery] Benefit-Cost Analysis (BCA) Resource Guide: http://www.dot.gov/sites/dot.dev/files/docs/TIGER_BCA_RESOURCE_GUIDE.pdf.

d. Car, bus, and rail modes are drawn from typical values for New York City, San Francisco and Chicago, as reported in Chester, Mikhail, Institute of Transportation Studies, UC Berkeley, 2008. Vehicle occupancy rates are estimated at 1.025 for single-unit trucks, and 1.12 for combination trucks, based on guidance from FHWA's HERS–State Version (see HERS–State Version Technical Report, FHWA, 2005.). The crew size for trucks is a based on average truck mix.

e. Typical passenger loadings for car, bus and rail modes are drawn from typical values for New York City, San Francisco and Chicago, as reported in Chester, Mikhail, Institute of Transportation Studies, UC Berkeley, 2008.

f. Vehicle operating costs per mile for free-flow conditions are defined for cars as an average of small, medium and large cars and Sport Utility Vehicles; source AAA (2011). Vehicle operating costs per mile for trucks were calculated by multiplying estimated gallons per mile (FHWA Highway Statistics Series 2010 Data) by applicable gasoline or diesel prices, and then adding in American Trucking Research Institute (ATRI) 2011 data on costs per mile for truck/trailer lease or purchase payments, repair and maintenance, truck insurance premiums, permits and licenses, tires, and tolls. Diesel prices from the U.S. Energy Information Administration "Weekly Retail Gasoline and Diesel Prices." (See http://www.eia.gov/dnav/pet/pet_pri_gnd_dcus_nus_a.htm). For trains, estimates derived from the January 10, 2013, Association of American Railroads statistics (Source: https://www.aar.org/StatisticsAndPublications/Documents/AAR-Stats-2013-01-10.pdf).

* Indicates data is specific to each local grade crossing. Values for local road traffic volume obtainable from the National Highway Planning Network database. Average trip purpose mix obtainable from the National Household Travel Survey.

-- Indicates not applicable.

3.4.1.5 Unit Cost per Hour and per Mile

The cost of vehicle delay is the added operating expense of running a vehicle for a longer time, or traveling a greater distance for an alternative route, plus the value of added driver time and passenger time. The calculation of these costs depends on the time and distance valuation factors shown in Table 12. It should be noted that vehicle delay costs include direct costs (vehicle operating cost), business operating costs (e.g., commercial vehicle driver time, work-related car travel), and social costs (valuation of car driver and passenger non-work-related time).

The total cost of a delay is the sum of the vehicle delay costs calculated here, plus inventory carrying costs for delayed and spoiled cargo (discussed in Section 3.4.2.2).

3.4.2 Supply Chain Cost Elements

With grade crossing crashes, secondary effects are caused by delay that affect supply chains when freight flows are disrupted. Supply chain operations are affected by grade crossing crashes in two principal cost areas: transportation-related costs and inventory-related costs.

Transportation-related supply chain costs (discussed in Section 3.4.2.1) include:

- **Delivery time delay costs.** These costs include the time cost of tying up additional inventory stock in transportation and idling specialized vessels and vehicles during the delay period. These costs may be partially represented by penalties imposed by shipping companies and consignees. (Note: This is in addition to the added driver and vehicle operating costs included under direct costs.)
- **Container/mode diversion costs.** These costs are the processing costs for unloading and reloading goods into different modes (e.g., rail to truck), different containers, or different railcars. The need to do so may be more pronounced for products that require specialized vessels, such as grain, coal, and liquids.

Inventory-related supply chain costs (discussed in Section 3.4.2.2), include:

- **Spoilage and lost business sales.** These costs include the value of lost sales due to delivery delays and the net cost of damaged or spoiled goods that have to be replaced.
- **Inventory substitution and stocking costs.** These costs include logistics processing costs from the use of inventory safety stocks, "downstream costs" to other modes that become underutilized (e.g., a ship waiting for coal or grain would impose demurrage charges on the contracting shipper).

3.4.2.1 Transportation-Related Supply Chain Costs

This cost category includes only the business costs associated with supply chain disruption not otherwise covered. (The added driver time and vehicle operating costs are included with direct delay costs.) The supply chain delay cost encompasses shipper costs from tying up additional inventory for a period of time, shipper replacement deliveries, and penalty fees to compensate for schedule disruption. Penalty fees include those imposed by shippers on transportation companies or by consignees on shippers. Additional cost is incurred when transferring shipments to alternative trucks, railcars, or trains. Equation (4) reflects these supply chain transportation-related costs.

$$
\begin{aligned}
&\mathit{Supply\ Chain\ Transport\ Cost}_{s,c} = \mathit{Traffic\ Volume}_{s,c} \\
&\quad * \left[\left(\mathit{Hours\ Delay}_{s,c} * \mathit{Supply\ Chain\ Delay\ Cost\ per\ Hour}_{s,c} \right) \right. \\
&\quad + \left(\mathit{Diversion\ Rate}_{s,c} * \mathit{Tons\ per\ Vehicle}_{s,c} \right. \\
&\quad \left. \left. * \mathit{Transfer\ Cost\ per\ Ton}_{s,c} \right) \right] \qquad (4)
\end{aligned}
$$

where "s,c" subscripts refer to combinations of s = shipment type (road, rail) and c = community type.

Figure 7 illustrates the progression of estimation steps.

The nature of these added logistics costs will depend on several factors.

Volume of Freight: Traffic and Commodity Mix. Although the freight volume and traffic/commodity mix are unique to each grade crossing location, data can be obtained from various national databases, including:

- FHWA's National Highway Planning Network (NHPN) database, which provides AADT counts and truck/car splits for significant highway links.
- FHWA's FAF, which provides interregional commodity flow data and assignment of commodities to the NHS. Although a majority of grade crossings are on non-NHS roadways, the NHS could be useful for inference where data are lacking. Alternatively, an analyst could assume that the supply chain effects on very low-volume roads are negligible.

Figure 7. Estimation steps for supply chain transport-related cost.

- IMPLAN®, TREDIS® or other input-output modeling systems can provide county-level estimates of freight commodity mix for in-flows, out-flows, and internal flows.

Time of Day and Seasonality. Although not mentioned explicitly in the supply chain transportation cost progression already discussed, the time of day and seasonality of the crash will be significant factors. Highway traffic flows are rarely uniform during the day. There are commuting peaks and late night hours with minimal traffic. Trains may also follow daily and seasonal patterns. Applying the crash cost framework should not ignore this important factor.

Delivery Delay Rate. The amount of time that a highway-rail crossing is closed is the primary factor affecting freight transit time and delivery delays. (Truck and rail terminal bottlenecks and service schedules also can increase total delivery delay, but are not the primary factor.) In general, the average delay is one-half of the total closure time, plus adjustments for accumulated vehicle queues to be dispersed. Both queue accumulation and dispersion can be modeled using GradeDec.Net.

By contacting various DOTs, Departments of Public Safety, and Safety and Traffic Bureaus in states where grade crossing crashes have occurred in recent years, the research team found that information on road closure time periods is sometimes available in crash reports, but further effort is needed to extract that data. Table 11 summarizes the findings regarding closure duration.

Supply Chain Delay Cost. The carrying cost of in-transit inventory derives from the dollar investment in goods tied up while they are in-transit. Delaying a delivery imposes what economists call an *opportunity cost of capital,* which represents the foregone return on investment during the period of added transit. Additional costs accrue with a late delivery (e.g., overtime pay at the loading dock or just-in-time penalties) or a missed delivery window (e.g., costs of redelivery). Table 13 presents an estimate of these costs.

Shipment Diversion Rate. Typically, shipments are transferred to alternative vehicles (or rail cars are transferred to alternative trains) only when a very serious crash closes the road or rail line for more than 8 hours. That length of closure normally indicates a derailment with damage to trains and/or to tracks. The diversion rate involves (a) the cost of transferring the commodities or goods to a different container or vehicle and (b) the "opportunity cost" of not being able to use the replacement container or vehicle elsewhere.

These costs vary. The average of transfer cost values adopted here is based on the FHWA's Intermodal Transportation and Inventory Cost (ITIC) model, which assumes a $125 loading cost and a half-day driver dwell time (valued at around $100) for a freight vehicle transfer. To that is added the logistics cost of using a new (second) container or vehicle for a day (based on 12 hours of use, including dwell time). The total diversion cost for truck shipments is thus around $750 per diverted truckload (See Table 13).

For many shipments by truck or by rail, an alternative way of considering cargo time delay costs is in terms of cost per container or cost per carload rather than cost per ton. On average, a full container of manufactured goods carries roughly 17.5 tons of product, though that ratio can vary depending on the contents. A rail car can hold 75 tons; though a flatcar with two containers would hold roughly 35 tons, a double-stacked flatcar would hold 70 tons. Of course, some rail cars and truck containers are just empty backhauls. For purposes of federal and statewide policy analysis, however, it can be easier to perform the calculations in terms of tonnage because profiles and forecasts of freight tonnage flows are readily available from the FAF and the U.S.DOT's Commodity Flow Survey, whereas data on container loadings is far less broadly available.

Notice that the values shown in Table 13 reflect typical mixes of commodities traveling by truck or rail. Exceptional cases always occur, however. For example, the Orange Blossom Express that carries refrigerated orange juice and other priority trains that carry perishable foods or time-sensitive packages and shipments can incur a much higher cost per hour of delay. However, these exceptional cases account for a small fraction of the total trains passing through grade crossings across the United States each day. On the other hand, railroads tend to have a tighter linked network with far fewer rerouting options than do trucks, and that factor also can raise the costs of rail-line delays. In addition, intermodal (combination truck/rail) shipping is the fastest growing segment of rail traffic, and a portion of this market growth involves time-sensitive cargo shipping contracts that allow shippers to withhold or reduce payment for late deliveries.

Altogether, it is clear that significant variation in the cost of delay occurs depending on the specific grade crossing site, volume and frequency of trucks and trains, mix of commodities being carried by trucks and trains, and availability of rerouting options for both highway and rail networks. For purposes of statewide and national-level analyses, however, it is reasonable to use the types of average values shown in Table 9 as a "first cut" estimate.

3.4.2.2 Inventory-Related Supply Chain Costs

Grade crossing crashes can have further supply chain effects on manufacturers and shippers beyond the added costs from delivery delay and diversion. Crashes also can affect "inventory carrying costs" if stock is taken from inventory to cover loss and spoilage, or otherwise provide substitute goods.

Table 13. Factors affecting supply chain cost per hour of delay.

Category	Behavioral Factor	Commercial Truck	Freight Rail
Supply Chain Cost	Per cargo ton-hour of delay: commodities[a]	$ 0.75	$0.07
	Per cargo ton-hour of delay: manufactured goods[a]	$ 2.50	$0.20
	Per ton transferred to a new container: manufacturing goods[b]	$34	n/a
Rolling Stock Cost	Transfer of all cargo to a new vehicle (truck or train)[c]	$84.48	$2,682
Volume of Freight	Tons per vehicle (truck or train): commodities[d]	12.8	4,218
	Tons per vehicle (truck or train): mfg. goods[d]	10.3	1,710
Local Factors	Average delivery delay (hours)	*	*
	Incidence of expedited shipments	*	*
	Mix of cargo for freight[e]	*	*

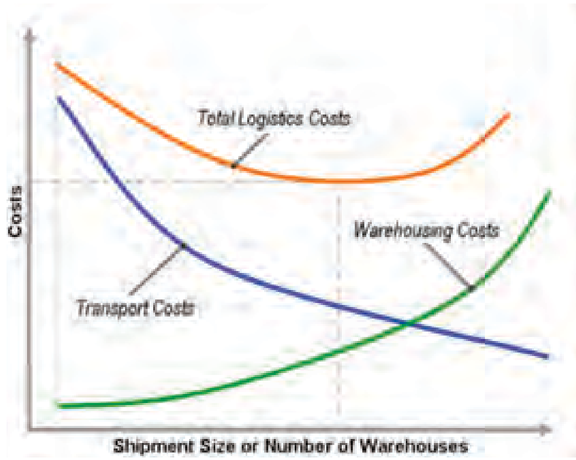
Note: * denotes data specific to each local grade crossing.

Sources: [a] Total supply chain cost includes the opportunity cost of capital tied up in delayed cargo, depreciation due to spoilage and loss of retail value from delayed delivery, and excess labor for warehouse or loading dock workers and just-in-time production loss. Opportunity cost of capital is the value of cargo times rate of return (10% per year or 0.004% per hour of delay). Average value of cargo is $1,440/ton for rail cargo and $3,890/ton for trucked cargo; see Table 15 for specific commodities. The cost of replacing depreciated merchandise or acquiring inventory for immediate delivery is based on cargo value (for perishables and retail goods only); the cost of excess labor cost for shipper or consignee is based on hourly labor cost (applied only for non-retail manufactured goods). Both are adjusted for probability of delivery delayed beyond end of normal workday (12%). Truck cargo mix is from FHWA's FAF: http://www.ops.fhwa.dot.gov/freight/freight_analysis/faf/ and rail cargo mix is from AAR: https://www.aar.org/StatisticsAndPublications/Documents/AAR-Stats-2013-01-10.pdf. The results shown here are conservative, as broader studies by Winston and Shirley for FHWA (The Impact of Congestion on Shippers Inventory Costs, 2004) derive supply chain cost of delay based on a discount rate of 5% of cargo value per day (0.2% per hour) for bulk, 15% (0.6% per hour) for perishables and 10% (0.4% per hour) for other goods. [b] Based on cost of 1.5 hours of labor per ton transferred between vehicles (on-site time plus travel time) See Table 12 for labor cost. [c] Cost of lost revenue associated with tying up a replacement. For truck, based on less than truckload (LTL) truck average revenue of $.0.165 per ton-mile (from Bureau of Transportation Statistics, see https://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/national_transportation_statistics/html/table_03_21.html, with 12.8 tons/truck (see note 4) and avg. 40 miles per hour. For rail, based on Class I railroad revenue of $0.037 per ton-mile and 72,492 net ton-miles per train (source AAR report cited in note a).[d] Truck loading is from the Vehicle Inventory and Use System and updates as reported in the FAF database on tons per truck (payload equivalency by vehicle class). See data tables in: http://ops.fhwa.dot.gov/freight/freight_analysis/faf/faf2_reports/reports9/s501_2_3_tables.htm#_Toc169399555). See breakout by truck type and freight type in Table 3-1 and 3-3 of http://www.ops.fhwa.dot.gov/freight/freight_analysis/faf/faf2_reports/reports7/c3_payload.htm. Note that tons/truck can range from 10 to 18, depending on cargo and load factor (percent full). Data on tons per railroad train is based on overall average of 3,538 tons/train, 57 railroad cars per train, with manufactured goods (typically via TOFC at 30 tons/container) accounting for 25.1% of all cargo. This implies 74 tons per railroad car of non-manufactured goods, though it rises to 100 tons per car and 100 cars per train in the case of coal. Data on overall tons/train and cars/train and cargo mix from the AAR, Class I Railroad Statistics, 2013. See https://www.aar.org/StatisticsAndPublications/Documents/AAR-Stats-2013-01-10.pdf). [e] See [d] above for sources for freight mix.

Tradeoffs in Transportation and Warehousing Costs. To illustrate how inventories are affected, it is useful to take the total logistics cost function and observe how its components are shifted with a crash. The basic tradeoff is between the two broad cost components of transportation and inventory. In Figure 8, those costs are plotted against shipment size and number of warehouses. In the short run, crashes cause transportation costs to increase (e.g., through tied-up capital, expedited shipping costs, penalties, and increased handling costs).

If crash frequency and/or severity increases over the long run, more warehouses (stocking points) will be needed. Adding warehouses/stocking points causes average inventory levels to rise to maintain or meet a given level of customer service. This occurs because of the need for increased inventory by downstream buyers and from adding safety stock in shipper warehouses to hedge against future loss and delivery reliability risks. Thus, grade crossing crashes can ultimately raise both elements of total logistics cost. The inventory cost elements are reflected in Equation (5) as follows:

$$\begin{aligned} &\mathit{Supply\ Chain\ Inventory\ Cost}_{s,c} = \mathit{Traffic\ Volume}_{s,c} \\ &\quad * \left[\left(\mathit{Loss\ Rate}_{s,c} * \mathit{Shipment\ Size}_{s,c} * \mathit{Value\ per\ Ton}_{s,c} \right) \right. \\ &\quad \left. + \left(\mathit{Reliability\ Risk}_{s,c} * \mathit{Shipment\ Size}_{s,c} * \mathit{Value\ per\ Ton}_{s,c} \right) \right] \end{aligned} \tag{5}$$



Total Logistics Cost is a function of transportation costs and inventory costs. This can be written as:

TLC (Q, r : T, ST) = RD_i + ($UCTD_i$/365) + (SD_i/Q) + (QCI/2) + rIC + K(D_i/Q) N(Z)S*1* where:

- TLC = total logistics cost
- R = Rate of transport cost (Origin to Destination)
- D = Annual Demand for some good 'i'
- U = Carrying Cost of In-transit Inventory
- C = Value per Unit
- T = Transit Time of Transportation Alternative
- S = Fixed Ordering Cost per Order
- Q = Order Quantity
- I = Carrying Cost of Warehoused Inventory
- r = Safety Stock
- K = Stockout Cost per Unit
- N(Z) = Unit Loss Integral
- S1 = Std. Deviation of Demand during Transit Time
- ST = Std. Deviation of Demand during Lead Time

Source: Rodrigue, J.-P. et al. (2013), The Geography of Transport Systems. Hofstra University. Department of Global Studies & Geography. http://people.hofstra.edu/geotrans.

Figure 8. Total logistics cost and tradeoffs between transport and warehousing costs.

where "*s, c*" subscripts refer to combinations of:

s = shipment type (road, rail)
c = commodity type

Figure 9 illustrates the progression of estimation steps, followed by discussion of key factors.

Loss Risk. There are inventory costs to replace cargo that is damaged, destroyed, or spoiled. The risk of such loss is a direct function of the severity of the crash, and secondarily of the fragility of the freight. As a general rule, cargo replacement will occur when there is both (a) substantial damage to trucks or rail cars, and (b) affected goods are manufactured products or perishables, versus bulk commodities.

Several information sources exist to help estimate the nature of these risks.

- **Incidence of damage.** Surveys of businesses could support the incidence of damage to trucks and loaded rail cars.
- **Truck damage.** The FRA database of Form 6180.57 (Highway-Rail Grade Crossing Incidents) notes whether trucks were involved and whether there was resulting damage to the vehicle. It does not provide information on whether there was damage to goods being carried.
- **Rail car damage.** The FRA database of Form 6180.54 (Rail Equipment Incidents) notes incidents in which rail cars were damaged and indicates whether or not they were loaded. It does not provide information on what they were carrying or the affected value.

Volume and Value of Cargo. FHWA's FAF provides regional data on the tonnage, mix, and associated value of freight moving through an area. FAF data can be used to estimate the average loading of trucks and rail cars, as well as the expected value of goods they carry. Typical valuations are shown in Table 14 with detailed commodity values by mode shown in Table 15.

Reliability Risk. Inventory costs also are associated with delayed shipments (i.e., on-time delivery reliability). These costs include penalties for late arrivals of schedule-sensitive shipments, replacement costs when substitute inventory is used to replace delayed shipments, and loss of cargo value for shipments that fail to meet arrival deadlines and are not accepted by the consignee. Reliability risk is a direct function of the likelihood of long delays (e.g., a day or longer), and it tends to be concentrated in deliveries of particular types of cargo (e.g., refrigerated and fresh food products, and manufactured goods).

Several sources of information are available to characterize the nature of these risks.

- **Incidence of long delays.** NTSB and FRA data can be mined, supplemented by data from state highway and

Figure 9. Estimation steps for supply chain inventory-related cost.

Table 14. Factors affecting logistics costs.

Category	Behavioral Factor	Commercial Truck	Freight Rail
Time Cost of Capital (per Hour)	Inventory carrying cost: composite[a]	$1.78	–
	Inventory carrying cost: commodities[b]	$0.75	$0.07
	Inventory carrying cost: manufactured goods[b]	$2.50	$0.20
Replacement Value (per Ton)[a]	Value per ton of cargo: coal[c]	$32	$26
	Value per ton of cargo: milled grains[c]	$1,226	$451
	Value per ton of cargo: chemicals[c]	$2,553	$1,124
	Value per ton of cargo: machinery[c]	$7,957	$6,956
	Value per ton of cargo: electronics[c]	$11,553	$8,030
	Value per ton of cargo: pharmaceuticals[c]	$34,135	$31,142
Local Crash Effects	Loss rate (due to damage or spoilage)	*	*
	Reliability factor: replacement rate (non-loss)	*	*
	Cargo mix (for valuing replacement and inventory costs)	*	*

Sources:

a. The inventory carrying cost for a composite of all freight is from the HERS-ST update model documentation.

b. The inventory carrying cost for specific cargo types is based on the HERS model documentation and relative differences in commodity values as shown in Table 15.

c. The inventory carrying cost for specific types of cargo is derived from Table 15.

* indicates data can be specific to each local grade crossing, or profiles may be drawn based on FRA, NTSB, and FAF sources (as noted before).

safety officials, to develop profiles of delay incidence and duration.

- **Time cost of reliability response.** The cost of drawing from inventory to substitute for late shipments is the time cost of additional capital being tied up, plus added driver and vehicle costs. This inventory carrying cost is not the same thing as the time cost of shipment delay, though the two values will tend to be similar in magnitude. Typically, shippers send substitute products in response to shipment delay not to save money but to avoid penalties or the risk of losing a customer. For purposes of this study, therefore the inventory carrying cost of tied-up capital is set as the time cost of delay, as shown in Table 15. The composite value shown in the table is equivalent to the inventory carrying cost assumed in FHWA's HERS model.
- **Time-sensitive cargo.** In rare cases (e.g., delays that last 2 days or longer), any form of cargo may become time-sensitive. For most shorter delays, time sensitivity primarily applies to perishable food products and to manufactured machinery and equipment. To identify crashes in which those types of goods have been affected, data can be obtained from local sources for individual crashes, or the analyst can rely on the FAF database to profile the composition of typical rail and truck shipment in a region.

Time of Day and Seasonality. Although not mentioned explicitly in the supply chain inventory cost progression discussion, the time of day and seasonality of the crash will be significant factors. Highway traffic flows are rarely uniform during the day. There are commuting peaks and late night hours with minimal traffic. Trains may also follow daily and seasonal patterns. Applying the cost framework should not ignore this important factor.

3.4.3 Other Indirect and Intangible Costs

Other indirect and intangible costs are loss of worker productivity and environmental costs.

3.4.3.1 Loss of Worker Productivity

For some sectors of the economy, no tangible goods are being extracted or produced, and no cargo is being shipped. However, crash-related delays experienced by workers who are traveling to work or traveling on the job (for work purposes) still represent a loss of economic productivity. These effects of delay are already captured as part of supply chain delay costs. However, second-round productivity effects may be associated with anticipation of crash-related effects. These effects, over and above the supply chain delay costs, are likely negligible and have been excluded from the crash cost estimation framework developed for *NCHRP Report 755*.

Table 15. Commodity/product values per ton by shipping mode, detailed breakdown.

Commodity or Product	Shipped via Commercial Truck ($)	Shipped via Freight Rail ($)
Live Animals/Fish	1,321	871
Cereal Grains	124	173
Other Agricultural Products	636	405
Animal Feed	363	204
Meat/Seafood	2,811	2,662
Milled Grain Products	1,226	451
Other Foodstuffs	1,054	489
Alcoholic Beverages	1,415	666
Tobacco Products	20,398	8,190
Building Stone	173	43
Natural Sands	13	30
Gravel	10	13
Nonmetallic Minerals	58	52
Metallic Ores	662	104
Coal	32	26
Crude Petroleum	451	451
Gasoline	711	688
Fuel Oils	602	609
Coal—NEC	413	452
Basic Chemicals	700	591
Pharmaceuticals	34,135	31,142
Fertilizers	263	234
Chemical Products	2,553	1,124
Plastics/Rubber	2,826	1,224
Logs/Timber	41	163
Wood Products	566	344
Newsprint/Paper	913	554
Paper Articles	1,363	626
Printed Products	2,762	1,010
Textiles/Leather	8,295	8,333
Non-Metal Mineral Products	165	148
Base Metals	1,347	1,015
Articles-Base Metal	2,580	1,211
Machinery	7,957	6,956
Electronics	11,553	8,030
Motorized Vehicles	6,148	7,165
Transport Equipment	10,956	1,709
Precision Instruments	23,329	22,888
Furniture	4,583	2,521
Misc. Manufactured Products	3,675	2,632
Waste/Scrap	89	176
Mixed Freight	2,861	1,789
Unknown	1,153	1,144

Source: Freight Analysis Framework, 2007 database.

3.4.3.2 Environmental Cost

Two potential environmental costs associated with grade crossing crashes are hazmat spills and air pollution emissions. For hazmat spills, although serious and rare, the costs of cleanup or harm to the environment are not available from current data sources. For air pollution emissions, air quality impact depends on the extent of rerouting or additional motor vehicle idling. In most cases, these impacts are likely to be small. A typical valuation of air pollution and greenhouse gas emissions is $0.028 per vehicle miles of travel for cars, and $0.05 for trucks, based on analysis derived from the Federal Highway Cost Allocation Study and Transportation Energy Data Book (*21*). In general, environmental and other intangible quality-of-life factors are most likely to be applicable in extremely rare cases of catastrophic crashes.

Given that hazmat spills at grade crossings are extremely rare and data do not support credible estimates of costs, and given that regular emission costs from crashes are a negligible cost component, these costs have been excluded from the crash cost estimation framework.

3.5 The Crash Cost Framework and Rare Catastrophic Crashes

Generally speaking, a "catastrophic incident" is one with many casualties, typically having caused a degree of fatality, injury, and property damage that is many times higher than the standard rail crossing crash. Such a situation could occur if:

- a crash involves a loaded bus;
- a major release of toxic inhalable chemicals causes multiple deaths (though no such occurrence has yet occurred at a grade crossing);
- a severe derailment, as might occur if a train crashes with a heavy road vehicle, causes the train to collide with an abutment or with rolling stock on adjacent track; or
- a passenger train running in reverse led by the cab car hits a highway vehicle, causing multiple casualties on the train.

One type of catastrophic event involves hazmat releases or spills. In addition to the higher magnitude of injury and damage costs, such catastrophic events often involve evacuation of local residents from the surrounding area, hazmat emergency response teams, railroad emergency response teams, and other specialized resources to address the situation.

Such incidents pose a unique challenge for cost estimation because of the combination of a very high cost and a very low probably of occurrence. This combination makes a strong case that these types of incidents should be handled separately from other types of grade crossing incidents. Nonetheless, in a general costing framework, several approaches can be taken for dealing with events of this type:

- **"Disregard very small risks" approach.** The analyst can assume that events with a probability below a certain threshold (say, 10^{-9} or one in a billion trips) are "tantamount to statistical noise" and, therefore, cannot be included in calculation of the expected cost of grade crossing crashes.

- **"Mitigation/abatement" approach.** The analyst can quantify the costs of catastrophic crashes, declare these to be "worst case" scenarios, and consider measures to mitigate the relative risk of occurrence or its cost (for example, by reducing the costs of predicted catastrophic crashes in half), and consider the mitigation cost as the relevant crash cost component.
- **"Best-guess" approach.** The analyst can calculate the cost of catastrophic crashes as the projected costs of such crashes (a very large number) times the probability of occurrence (a very small number) and add this amount to the aggregate cost of crashes at a grade crossing. A variant of this approach is to use weighting to average different types of catastrophic events.

Each approach has pros and cons and each has been used in costing hard-to-cost components of transportation projects. The approach recommended by the research team is to allow for case-by-case application of any of the three approaches, depending on the type of catastrophic scenario being contemplated.

During the Webinar, the project panel for NCHRP Project 08-85 discussed the pros and cons of these approaches and concluded that the "disregarding very small risks" approach was the appropriate one. This approach is consistent with that followed by FAA in its evaluation programs.

3.6 Grade Crossing Crash Cost Evaluation Tool

3.6.1 Introduction

The framework and methods for forecasting the comprehensive crash costs at grade crossings described in this report have been gathered in an Excel spreadsheet tool that is available for practitioners. The spreadsheet tool enables practitioners to develop transparent estimates of crash costs based on models, assumptions, and sets of default values that are reflective of the best available data. As needed, users can override default values with those reflecting local conditions that are best-suited for a particular analysis.

3.6.2 Overview of the Spreadsheet Tool

The spreadsheet tool is a stand-alone extension to FRA's GradeDec.Net and takes the principal crash-related outputs of GradeDec.Net (i.e., data about crashes organized by three severity categories–fatality, injury, and property damage only).

For a particular crossing (or collection of crossings), the spreadsheet tool derives costs per crash given the estimated average damages per crash and a list of unit costs for the damages (i.e., injuries by severity category, as well as property damage).

The spreadsheet tool includes a model for estimating property damages associated with each crash type, including rail equipment damages.

The spreadsheet tool also includes a calculator that implements the model for estimating the delays associated with predicted crashes and the costs associated with the delays and rerouting of traffic.

Additionally, the spreadsheet tool incorporates the supply chain cost model that includes the required inputs and the model to calculate the supply chain effects of a crash.

The default setting for the spreadsheet tool is to disregard the costs of catastrophic crashes, but an optional component is included with the spreadsheet that enables users to calculate catastrophic costs in accordance with the three alternative approaches described in Section 3.5.

The spreadsheet tool implements a risk analysis framework similar to that of GradeDec.Net.

3.6.3 Implementation of the Spreadsheet Tool

The spreadsheet tool will be implemented as a web-based application and can be downloaded from http://www.trb.org/Main/Blurbs/169061.aspx.

CHAPTER 4

Conclusions, Recommendations, and Suggested Research

4.1 Conclusions

4.1.1 Value of the Research Product

Crashes at highway-rail grade crossings impose a cost not only on the injured parties but also on the wider population of those who experience traffic delay and diversion for road or rail movements. Yet to date, there has not been an effective way for analysts to estimate a value for that broader impact.

This study has taken an important step toward addressing the issue. It identifies and classifies the various primary and secondary costs imposed by grade crossing crashes and shows how it is possible to calculate dollar values for each of them. It provides formulas, suggested data sources, and a software tool to enable these calculations.

4.1.2 Use of the Findings

The study results show that a highway-rail grade crossing crash can cause five types of costs:

1. casualties to people (fatalities and injuries);
2. damages to both infrastructure and equipment;
3. added operating expenses for vehicles delayed or diverted;
4. supply chain costs associated with handling of delayed or diverted cargo; and
5. opportunity costs for inventory and equipment that is tied up and unable to earn revenue during the period of delay or diversion.

Although data sources for costs associated with casualties and damages (primary impacts) have long been available, this study shows that additional costs represented by added operating expenses, supply chain costs, and opportunity costs (secondary impacts) are also very real and can be calculated using available data (See Section 3.4.2). It also shows that the magnitude of these secondary costs can be significant, in the range of a hundred thousand dollars or so in the case of delays lasting several hours.

However, the study also shows that the magnitude of these costs can vary widely, depending on the actual duration of delay, the extent of local traffic affected, and the mix of rail and truck cargo (which affects the time sensitivity of cargo movements). Averages or typical values can be obtained for each of these factors, but there will always be some cases in which the specific characteristics of local train and truck traffic lead to substantially greater or smaller secondary cost impacts.

It is worth noting that uncertainty regarding traffic mix and time sensitivity is not unique to grade crossing crash costs. This factor is also recognized as a major source of variation in the cost of traffic delays and travel-time variability caused by road traffic congestion at highway bottlenecks. Despite the uncertainty, it is generally better to apply reasonable estimates to calculate such impacts than to totally ignore the issue (which is tantamount to assuming a zero value for delayed car, truck and train movements).

4.1.3 Opportunity for Improvement

This study's methodology involved using experience on incidence and costs of past crashes as a basis for predicting likely incidence and costs for future crashes. The study team concluded that information on casualty and equipment damages from crashes is widely tracked and commonly available, though there will always be some error introduced by the fact that these reported impacts are based on observation and estimation immediately following the crash. Although follow-up and verification several weeks later would be ideal, that is unlikely to occur.

One additional element of information is most critical to calculate secondary costs: information regarding road and rail closures—specifically, information about (a) their incidence, (b) the duration of the closure, and (c) diversion of traffic to alternative routes. The study team found that no single entity collects consistent data on duration of delay and rerouting distance for grade crossing incidents, and there is no systematic reporting of this information. The method used to obtain data for this study involved a combination of web searches, reviews of news media articles, and calls to state and local public safety officials to obtain the desired information. Even these targeted efforts turned up incomplete data (though enough was gathered to at least develop reasonable first estimates of the closure incidence and duration).

Although sufficient information exists to estimate the mix of freight carried by trucks on any given route, no single source is available for identifying the cargo carried by each train involved in an incident. Information about cargo on specific trains is proprietary information held by the railroads. However, it is known that some trains carry perishable goods and time-sensitive shipments, in which cases crashes may result in significant loss of cargo value or associated revenue. On the other hand, some train car movements are empty backhauls with no appreciable value for cargo delay. To develop an overall estimate, it is usually necessary to assume a rail cargo mix based on regional or national averages.

A small fraction of trains carries hazmat cargo that may cause environmental concerns (and potentially add costs associated with local evacuation, spill cleanup, and so forth) if the hazmat cargo is involved in a crash. The very low incidence and very high cost of such incidents makes it problematic to calculate expected values for crashes involving hazmat cargo.

The cost evaluation spreadsheet tool developed for this study is notable in its use of uncertainty or risk analysis. Factoring in uncertainty is particularly valuable for grade crossing analysis, as it shows how crashes can sometimes lead to costs far exceeding the average. The added information can be highly useful for decisions regarding investment in grade crossing improvements and makes the cost evaluation tool particularly useful as a decision support tool.

4.2 Recommendations for Future Research

The study team has developed a computational framework and a crash cost evaluation spreadsheet tool that can be applied to demonstrate and estimate the wider costs of grade crossing crashes and hence the broader benefits of investment to reduce crash incidence. Future research may help to refine the values used in this study, including

- differences in crash incidence and severity rates, between gated and non-gated crossings;
- differences in road and rail closure (incidence and duration), depending on crash severity;
- differences in road or rail traffic diversion (incidence and distance), depending on closure duration and local road or rail network density; and
- refinement of casualty and equipment damage rates and costs, through follow-up verification and its comparison to initial on-site estimates.

Additional research also can improve data resources available for cost estimation. Recommended topics for such research include (a) methods for increased standardization of grade crossing crash reporting and (b) integrating and harmonizing the FRA safety data with state and local crash reporting.

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19. Grade crossing road closures ranged from hours to days, as noted in various NTSB reports and media reports. Examples include crashes in Michigan (www.annarbor.com/news/rawsonville-road-reopened-after-train-vehicle-crash), in Illinois (www.ntsb.gov/doclib/reports/2002/RAR0201.pdf), and in Nevada (www.rgj.com/viewart/20110625/NEWS/110624030/Amtrak-train-crash-Officials-release-name-truck-driver-3-others-killed-wreck).
20. Reports on "Storm Related Closures, I-5 & I-90," conducted by Washington State DOT, and "Investigation of User Costs & Benefits for Winter Road Closures," conducted by the Midwest Transportation Consortium, both contain estimates of the distance and cost of rerouting trucks.
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APPENDIX

Literature Review and Survey of Current Practices (Technical Memorandum 1)

CONTENTS

1 Introduction

Highway-rail grade crossings pose an obvious safety hazard. Crashes cause loss of life, injuries, and property damage; however, no well-established framework exists for estimating their related costs on a per-predicted-crash basis. Moreover, there are no defined methods for estimating the less-apparent cost consequences of grade crossing crashes, such as supply chain disruptions.

Proper costing of grade crossing crashes is imperative for making decisions about allocating resources. The lack of reliable cost estimates prevents decision makers from effectively assessing the benefits of public investments in grade crossings.

The need for reliable cost estimates will become more urgent as funding tightens. Currently, Section 130 of the federal surface transportation bill provides dedicated funding for grade crossing safety improvements. Section 130 is in effect through the end of fiscal year 2014. Beyond that time, reduction or elimination of dedicated federal funding may put grade crossing improvements in competition with other highway projects for resources.

This appendix, titled Technical Memorandum 1 (TM1), describes the research conducted for Tasks 1 and 2 of NCHRP Project 08-85, "The Comprehensive Costs of Highway-Rail At-Grade Crossing Crashes" which sought to develop a practical framework for estimating the costs of such crashes. For Task 1, the research team conducted a review of literature and a survey of current practice. For Task 2, the research team developed a taxonomy of the principal components of grade crossing crash costs.

1.1 Plan of the Report

This report is organized into three main sections: a review of literature, a survey of current practice, and an examination of highway-rail grade crossing crash cost principal components.

1.1.1 Review of Literature

TM1 contains a review of relevant literature on measuring and estimating costs of highway-rail crashes and crash-related interruptions in shipments of goods. It considers the full range of costs incurred by railroads, businesses, public agencies, shippers, passengers, and the public at large. The section assesses the availability, accuracy, and reliability of data on collision costs as they may be reported by public agencies, railroads, or other sources.

1.1.2 Survey of Current Practice

TM1 includes a survey of current practice for assigning costs to grade crossing crashes. It includes analyses that were conducted for the Alameda Corridor East project, the Chicago Region Environmental and Transportation Efficiency (CREATE) plan, the Seattle-area SOUNDER project, and a number of studies including the study of impacts from the Canadian National Railway's acquisition of the Elgin, Joliet and Eastern (EJ&E) Railroad. Also included in the survey is a review of safety for the East Japan Railway and current practice from a number of smaller studies conducted by states, metropolitan planning organizations (MPOs), and local rail authorities in support of resource allocation decisions

1.1.3 Highway-Rail Grade Crossing Crash Cost Principal Components

TM1 identifies the principal components of highway-rail grade crossing crash costs, including but not limited to:

- damage to highway vehicles, trains, and goods carried;
- investigations by rail carriers and public agencies;
- business interruption;

- lost time and productivity;
- traffic delays and diversions;
- cleanup of hazardous materials (hazmat) spills;
- repair of damaged infrastructure and rights-of-way;
- litigation;
- pollution; and
- involvement in post-collision hearings and community outreach.

A crash cost taxonomy is presented for these principal components.

2 Literature Review

2.1 Introduction

2.1.1 Plan of the Literature Review

The literature review contains two principal sections:

- Review of general highway crash cost methodologies
- Discussion of indicators of the relative severity of crash costs at highway-rail grade crossings

The discussion of indicators includes information on damages to railroad equipment and infrastructure and concludes with a review of the effects of disruptions to the regular flow of goods and of the costs of rare catastrophic events.

2.1.1.1 General Highway Crash cost Methodologies

This section considers the principles of general highway crash cost methodologies and examines the principles behind the analysis of highway crash costs.

2.1.1.2 Indicators of Relative Severity of Highway-Rail Crash Costs

The review then seeks indicators that may infer the relative scale of crashes at grade crossings in reference to the components of general highway crashes.

2.1.1.3 Cost of Damage to Railroad Equipment and Infrastructure

Within the section on indicators of relative severity of highway-rail crash costs, the review examines the property damage components of crash costs and the sources of available data.

2.1.1.4 Costs of Supply Chain Disruption

The review examines the costs associated with supply chain disruption and the effects of grade crossing crashes on the supply chain. It also examines the literature on supply chain disruptions and concludes by presenting a model of supply chain costs from the economics literature.

2.1.1.5 Costs of Rare Catastrophic Crashes

The review examines topics associated with possible rare catastrophic crashes at highway-rail grade crossings.

2.1.2 Applicability of Literature Reviewed

Studies on crash cost estimation are conducted for different purposes. Some policy studies seek to answer the question: What is the national annual cost of highway crashes? These studies produce aggregate level or national average information that may be of limited use for project-level analysis but may contain methods or data that are adaptable to project research.

Other studies focus on estimating an average crash cost, which can then be applied to project-level or strategic-level benefit-cost analysis. Generally, highway analyses apply crash rates and severity allocation formulas for different facility functional classes, which may vary by traffic volume. The assumption is that for a given facility type and traffic volume, the occurrence of crashes and their severity are roughly homogenous.

Grade crossings represent localized situations in terms of physical and spatial characteristics and traffic flows on both highway and rail modes. Estimating crash costs at grade crossings requires considering localized factors. When trains strike highway vehicles, train speed is a factor in determining severity. If the comprehensive grade crossing crash cost estimate is to include delay, disruption effects, and rare catastrophic events, then the assumption that occurrence of crashes and their severity are homogeneous fails to hold and the cost estimation methodology will be less able to rely on averages.

2.1.3 Setting the Stage

The research conducted for this project considers scenarios of an established network of public and private road and rail lines. These rail lines pass through and link urban and rural areas and extend across considerable geographic distances. In numerous cases, highways and railroads intersect, forming highway-rail grade crossings.

Real economic resources have been used to create these networks, and the economic value of each component or link in the network depends on both the origins and destinations joined by the network and on the network's extent and design. Economic resources include investments in grade crossing signage, signals, alarms, and barriers.

One approach to economic value is to assess the opportunity cost to the economy should one or several links in the network be closed for a period of time because of a crash or incident. The economic cost of a crash or incident includes the value of all economic resources lost. For example, it includes the loss of life and limb and property damage; the value of all economic resources required to bring the crossing to the state that existed prior to the crash or incident; and the cost to the economy of being unable to use links in the road and rail network during the period of disruption.

Three groups face costs as a result of a grade crossing incident or crash: public and private infrastructure owners, passenger and freight infrastructure users, and participants in the downstream economy that uses transportation services.

2.2 General Highway Crash Costs

2.2.1 Analysis Framework—Welfare Economics and Consumer Surplus

In the general welfare economics framework for estimating the costs and benefits that flow from a transportation project, benefits are estimated as consumer surplus. A common-sense definition traced to the French engineer Dupuit holds that consumer surplus is the difference between the most that a person would pay for a thing less the amount he or she actually pays (*1*, *2*).

Consumer surplus is the area beneath a demand curve where travel (measured as trips) is plotted on the x-axis and is a function of the generalized cost of travel, which is plotted on the y-axis. An individual's demand curve for a good can be interpreted as the most the person will pay for each successive unit of that good. If the good is a trip between an origin and destination in a particular time frame, what is the highest amount the person will pay for the first trip? How much for the second trip and so on?

The individual consumes trips in a given period, thus maximizing consumer surplus as long as the cost per trip remains less than the value to him or her. In Figure A-1, the shaded area of the bars represents consumer surplus to the individual. In the figure, cost per trip is 30 cents.

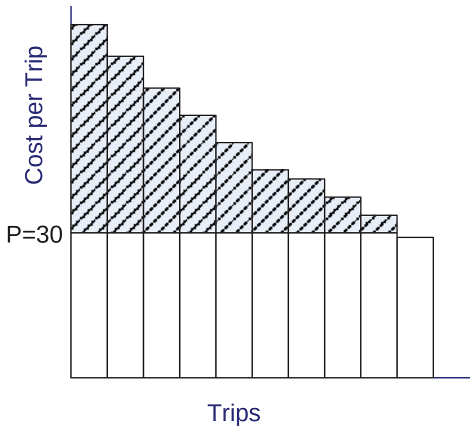


Figure A-1. Illustration of individual consumer surplus.

Under the assumption of perfect divisibility, the individual demand curve shown in Figure A-1 can be aggregated across consumers to a smooth market demand curve, which is a horizontal summation of all the individual demand curves.

A transportation system improvement benefits users by increasing the convenience of travel and decreasing its cost, for example, by reducing travel time or vehicle operating costs. The sum of all cost components of a trip, including hard-to-value components like travel time and safety, makes up the generalized cost of travel.

Safer travel lowers generalized cost for users. Reducing the occurrence or severity of crashes, for example, also reduces the impact to shippers in the case of supply chain disruption. The same is true for hazmat spills or pollution, the consequences of which also incur costs for non-users of the transportation system.

2.2.2 Measuring Costs and Economic Valuation

This section provides a general discussion of the costs of crashes. The section concludes with information specific to rail crashes.

Costs measured need to include all private and social costs plus external costs. Private and social costs are the economic costs of all resources accruing to private-sector and public-sector owners and users. External costs are those costs not borne directly by the users, which include such things as noise and emissions and, more importantly in this case, the costs of crashes to the economy.

The rationale for this approach to costs is the benefit-cost analysis framework. Costs are compared to the benefits from investments for reducing the probability or severity of crashes or incidents. In this framework, the optimal investment would be one that minimizes the sum of crash/incident and prevention costs, where the marginal damage costs would equal the marginal prevention costs.

A cost measure is the product of two components: price and quantity. Generally, the market value determines the price. In replacing a vehicle or repairing a rail car or engine, for example, a wage rate would determine the cost measure. The quantity is often–but not always—a straightforward measure, given the difficulty of measuring indivisibilities and quantities of indirect costs (e.g., productivity losses due to service disruptions and social costs such as severity of an injury and recovery time).

The difference between private and social costs is that the latter include external costs not necessarily considered in private agent decision making yet result in others having to incur real resource costs. External costs include environmental damage from spilled fuel or hazardous materials and crash costs that result in fatalities or injuries or that disrupt the supply chain.

The full social costs of transportation encompass many cost components. A substantial portion of these cost components are recognized and borne by transportation users, such as the costs of vehicles and their operation. Some costs are subjective but still recognized and borne by users, such as the time and effort expended by automobile drivers. Some costs are imposed on society at large, such as the costs of air pollution and contributions to global warming. Some costs are borne partly by users and partly by society, such as the costs of crashes.

As stated, the costing of an externality in general involves two processes: first, measuring the physical production of the externality due to transportation output or incident; and second, providing the economic valuation of the physical impacts. The key concepts and methods involved in such valuation are presented in the next section.

2.2.2.1 Opportunity Cost and Foundations of Valuation Methods

Opportunity cost is the fundamental building block of modern economic analysis. The true economic cost of one unit of some good, X, reflects the cost of opportunities forgone by devoting resources to its production and distribution. This cost measures the economic value of outputs, goods, and services that would have been possible to produce elsewhere with the resources used to produce the last unit of good X. The social opportunity cost of employing a resource for which there is no alternative economic use is thus zero even if its price is positive. An opportunity cost will be different under conditions of full employment than under circumstances involving large quantities of visible or invisible unemployment. Moreover, opportunity cost applies only to small "marginal" changes from equilibrium in systems for which there are multiple equilibria. Likewise, the marginal benefit from consuming good X is the value of the last unit purchased, measured in terms of a real price that reflects the welfare that would have been enjoyed if the requisite expenditure had been devoted to consuming another good or goods.

These concepts may appear circular but that is an artifact of the circular nature of economic systems. Suppliers of some economic goods are consumers of others. The opportunity cost of a good to the producer and the marginal benefit to the consumer are equal when all of the following conditions are met:

- All markets are perfectly competitive.
- Markets are comprehensively established in the sense that all current and future property rights are assigned.
- Marketed goods are exclusive; that is, ownership is singular and well defined, and is transferable, meaning that goods can be bought, sold, or given away.
- The underlying social and legal systems guarantee that property rights are reasonably secure.
- No transaction costs are involved in creating or maintaining any current or future market.
- Information about all current and future markets is perfect and complete.

Under these conditions, the marginal opportunity cost of any good with multiple uses or multiple demanders is equal to its marginal benefit. Marginal opportunity cost and marginal benefit then match the accounting price that can be read from the market, and economic efficiency is assured in the sense that nobody can be made better off without harming someone else.

It is not difficult to think of circumstances in which one or more of these conditions do not hold. This is not news to the economics profession, and much of modern economics has explored how to measure and compare costs and benefits when these conditions break down.

2.2.2.2 Valuing Non-Market Impacts

Another valuation concept is the distinction between "value in exchange" and "value in use." Value in exchange refers to the market price of a good or service. Measuring economic costs makes use of market prices whenever possible, recognizing that it may be necessary to modify observed market prices if there are economic distortions, such as externalities.

All things are not bought and sold in a marketplace, however. Even when they are, other factors come into play. First, the value in exchange is a marginal valuation; that is, markets reveal the value placed on a bit more or a bit less of some product or service. Second, market prices can give rise to paradoxical results. The classic example is the contrast between the price of water and the price of diamond jewelry. Water is indispensable for life, whereas diamond jewelry is purely a luxury; yet diamonds command much higher prices than does water. The value of use for water is far above its value in exchange, which demonstrates the difference between marginal value, or the value of an increment more or less in consumption, and the total value placed on something. In economic terms, the total value is measured by the sum of marginal valuations, or taking the area beneath a demand curve, whereas the market price is only one point on a demand curve.

Transportation services often have valuable attributes that go unpriced in the economic sense. Markets simply do not exist for some attributes and services, such as environmental quality, safety, and human life. The merit of contemplating markets for some services, such as health services, has been questioned even given extensive competition for services and products. For other services, markets that do exist fall short of being comprehensive or complete in the presence of externalities of production or consumption.

Researchers recognize the need to develop alternative means with which to assess the value of transportation services to understand the cost of impacts. They have tried to extend the scope of the economic paradigm to explore implicit and explicit tradeoffs between development and conservation of unpriced resources within the structures of standard decision analytic tools. These tools include cost-benefit analysis, cost-effectiveness analysis, and so on.

To be more specific, economists have built a theory of choice on the notions of consumer sovereignty and rationality. Economists assume that individuals value changes in non-market goods and services as easily as they value changes in market goods and services. The only difference between the two is that markets provide some direct data with which to assess individuals' values of products and services. Nevertheless, individuals should be able to tell researchers what they would be willing to pay for changes in non-market conditions or to accept as compensation for those changes. In fact, willingness to accept (WTA) payment for forgoing a good and willingness to pay (WTP) for a good are the two general yardsticks against which values are judged.

Notice that WTA and WTP are seldom the same for most non-market goods or services. WTA and WTP can be wildly different if there are no perfect substitutes (i.e., when it is impossible to fully compensate individuals unit by unit for their loss). When a perfect substitute does not exist, WTA > WTP. Cummings et al. (1986) reported that it is not uncommon for estimated WTA to be more than 10 times larger than estimated WTP (*3*). This discrepancy might be a result of the method of estimation, but it also reflects that WTA and WTP are different concepts that need not match.

Which measure to use to value a change in, say, environmental quality depends on the implicit assignment of property rights. If the individual is assumed to have a right to a higher level of environmental quality, such as a right to improvement or a right to no deterioration, then WTA is the appropriate basis for valuation. Conversely, if the individual is assumed to have no such a right, then WTP is the appropriate measure. WTA and WTP have analogs in the market context in the concepts of compensating variation and equivalent variation—see, for example, Boardman et al. (*4*). Most of the empirical studies are WTP studies.

2.2.2.3 Valuation Methods for Non-Market Impacts

There are two general approaches for valuing transportation attributes. The first is use of questionnaires and interview techniques to solicit people's valuation of attributes, and the second is empirical analysis of actual decisions that reveal implied valuations.

2.2.2.3.1 Contingent Valuation Methods and Stated Preference: Questionnaires and Interviews

Direct methods of valuation try to judge how individuals value non-market goods by asking those individuals directly. The contingent valuation (CV) method, for example, asks people for their maximum

WTP to effect a positive change in their environment or their minimum WTA to endure a negative change. Davis (*5*) authored one of the earlier papers to report CV results for environmental goods. Comprehensive accounts of these methods appear in Hanley and Spash (*6*), Bateman and Willis (*7*), and Boardman et al. (*4*). CV is a controversial method, and current environmental and resource literature continues to contain paper after paper confronting or uncovering problems of consistency, bias, truth-revelation, embedding, and the like. Nevertheless, CV is one of the most commonly used methods for estimating an economic value for environmental goods (*8*, *9*). Hundreds of CV studies have been completed in the United States and Western Europe (*9*). Hanley et al. (*10*) offer a quick overview of these discussions and a thorough bibliography.

The stated preference (SP) method uses questionnaires to ask people their preference for hypothetical travel cost and time alternatives. The SP method can estimate the influence of otherwise correlated variables, such as journey speed and comfort. The potential shortcoming of SP methods is that they are based on hypothetical choices and interviewers might not give accurate replies, although questionnaire design and administrative procedures can guard against this danger.

2.2.2.3.2 Revealed Preference Methods: Empirical Analysis of Actual Decisions

Indirect methods of valuation, referred to as revealed preference (RP) methods, attempt to measure individuals' value for non-market goods by observing their behavior in related markets. One sort of RP method is hedonic pricing (HP), or hedonic regression, which assumes that people buy goods for various attributes. For example, a house has attributes such as floor area, the number of bathrooms, views, quietness, air quality, and access to schools, hospitals, entertainment, and jobs. By estimating the demand for houses with different sets of attributes, one can apply estimate “pseudo-demand curves” for non-market goods such as noise and air quality. Another RP method is the travel costs method, with which valuation estimates of the multiple criteria on which utility depends can be finessed out of observable behavior.

The HP was first proposed by Lancaster (*11*) and Rosen (*12*). Mendelsohn (*13*) brought it to the fore in measuring the impacts of global change. Consensus has not been reached on the state of the science for these methods. Instead, a growing literature warns of caveats in their application and interpretation, as in the case of health services, or improves their use in consideration of these caveats. Smith (*14*) provided a careful overview of this literature and an assessment of progress over the past 25 years.

Of the direct and indirect approaches, McCubbin and Delucchi (*15*) suggested that the advantage of indirect RP methods is that they are based on actual behavior, while the advantage of direct SP methods is that they specify precisely and explicitly what is to be valued. In recent years, databases have been developed that combine RP and SP methods for the same population. The two methods can complement one another by using SP methods to separate the influence of correlated variables affecting traveler behavior.

2.2.2.4 Valuing Future Goods and Selection of a Discount Rate

Several of the costs explored in *NCHRP Report 755* have longer-term effects, and choosing the proper discounting rate is crucial to forecasting or scenario building. Selection of a discounting rate should take into account six factors:

1. **Impatience or “time preference.**” People tend to prefer current consumption over later consumption.
2. **Economic growth.** If people are richer in the future, a dollar has greater relative value now than later.
3. **Changing relative price.** Certain impacts, such as impacts on human health, may well be valued more highly in the future.
4. **Uncertainty.** Because future consumption is less certain, it is worth less.

5. **Investment opportunities.** People face an opportunity cost of forgone interest when spending dollars now rather than investing them for future use.
6. **Complexity.** Assets and actions may be from the private or public sectors and may take into account both financial and social costs.

Selecting a discount rate allows comparison of costs and values occurring at different times by converting future economic values into their equivalent present values. Formally, the present value of a cost (C_t) that will come due in t years is

$$\frac{C_t}{(1+d)^t}$$

where d is the discount rate. The discount rate is non-negative because resources invested today in physical and human capital usually can be transformed into more resources later on.

In the standard neoclassical formulation, the discount rate d follows $d = \rho + \eta g$, where ρ represents the pure rate of time preference, η the consumption elasticity of marginal utility, and g the growth rate of per capita consumption. The pure rate of time preference ρ varies between 0%, 1%, and 3% per year. A time preference of 0% is taken to be consistent with the principles of sustainability (*16*, *17*), whereas 3% is observed in markets (*18*). The growth rate of per capita consumption is assumed to be equal to the growth rate of per capita income.

Among economists, wide consensus exists that the social discount rate should be positive, but there is less agreement about what this positive rate should be because of various conceptual and methodological issues (*4*). The choice of discount rates will affect any valuation of future damage, and policy analysts and decision makers do not have the luxury of waiting for economists to resolve these issues. Trying to resolve the discount rate debate is well beyond this review's mandate. For the most part, where discount rates arise in empirical studies of the various environmental and social costs, TM1 reports on the rates being used in practice.

2.2.2.5 Measuring the Costs of Crashes

Conceptually, one way to compute the cost of a crash is to sum the cost of its component parts: the number of deaths multiplied by the value of a statistical life (VSL), plus the number of injuries multiplied by the cost of an injury, plus numerous other costs. These other costs include property damage costs, time delay costs from congestion at crash sites, environmental hazard costs, cleanup costs, and investigation costs. Private costs versus social costs also figure in, distinguished mainly by whether the private user of transportation modes or society at large bears the cost of crashes.

In practice, caution is advised when adding up component costs due to the possibility of double counting. For example, some estimates of cost of injury include property damage and time delay. In particular, WTP estimates from CV studies may reflect multiple dimensions or components of costs (*19*). It is also difficult to disentangle the internal and external costs associated with different transportation modes under various insurance systems and infrastructure settings.

Computing the cost of a crash does not require developing new theory or sophisticated econometric methodology, such as hedonic regressions, discrete choice methods of analysis, or computations of dose-response functions. But the lack of academic research into new and novel methods for estimating the costs and economic impacts of injuries and crashes is not surprising, for most academic papers on the cost of crashes stem from government-funded contracts, and the lack of independently investigated research has limited both the quantity of studies and the variation in methodologies employed. Also, investigation into the more theoretical aspects of measuring the impacts of injury on productivity is far from sufficient. Most of the research on crashes pertains to roads.

The next section discusses the usual methods for estimating the cost of crashes. Basically, the cost of a crash is the sum of various component parts. One component is the VSL. Other components are the value of a life-year (VOLY) and the cost of injuries. Estimates of these components are needed as inputs to the subsequent sections that focus on cost of crashes for different modes. Then the section will consider private versus social costs. The main issue is who bears the cost of injuries—the private user of transportation modes or society at large. Subsequent sections in TM1 provide estimates of the cost of road vehicle crashes and the cost of rail crashes. For each mode, the relevant information is reviewed and cost estimates used by government are discussed. External costs that can be identified are discussed last.

2.2.2.6 Methods for Estimating the Costs of Crashes

The usual method of computing the cost of a crash is to sum the cost of its components. Table A-1 shows how cost components can be categorized into three groups: direct costs, indirect costs, and intangible costs. Direct costs pertain to property damage, police and fire department emergency services, medical services, legal services, and travel delays. Indirect costs include productivity losses, other associated work-related costs, costs imposed on family members, and tax losses. Intangible costs include loss of quality of life and pain and suffering.

Table A-1. Categorization of general highway crash cost components.

Category	Cost Component
Direct	Property damage
	Emergency services: police and fire
	Medical: hospital, rehabilitation, and counseling
	Legal and administrative: criminal prosecution, insurance claims and administration, and household help
	Travel delay
Indirect	Productivity losses through reduced participation and ability
	Work-related losses and impositions on family members: absenteeism and workplace substitution for the injured and family members
	Tax losses
Intangible	Quality of life
	Pain and suffering

Source: Adapted from (*20*).

Total costs of crashes should be comprehensive and cover both the private costs to individuals and those costs that are accrued to society at large. To capture all of these costs in a comprehensive manner is expensive and time consuming. Different methods are used for estimating different components. Human capital approaches are used for productivity losses. CV methods, wage-risk studies, jury awards, time tradeoff studies, and consumer market studies are used to measure the intangibles.

2.2.2.6.1 Direct Costs

Direct costs related to crashes include property damage to vehicles and buildings. Crash costs can be substantial in the event of a crash that has environmental or long term/downstream impacts. Police costs generally fit under direct costs, as do medical costs from expenditures on goods and services relating to caring for injured parties. Costs include payments for medical evaluation; transportation, including ambulance; treatment; and rehabilitation. Capital investments in hospitals and buildings represent the opportunity costs of forgone expenditures in other areas of the general economy. In practice, medical prices often do not represent the true economic value of these goods and services. Non-medical care may include such costs as informal care, household help, vocational counseling, and costs of insurance administration, legal services, and court services.

Direct costs can be measured using a top-down approach or a bottom-up approach. The top-down method applies an approach for collecting data without detailed sources. The bottom-up approach allows comparisons at a detailed level of aggregation. The top-down method, also known as the prevalence method, allocates direct costs as a proportion of the total expenditures that accrue to certain subpopulations of the group of interest. These prevalence measures usually are tallied across a consistent indicator and generate an estimate of an average as opposed to a marginal cost. The bottom-up method uses an incidence approach based on the resource costs related to a well-defined population at a fine level of aggregation. The bottom-up method is less likely to minimize distortions caused by the aggregation of data, particularly when substantial gaps may exist between marginal and average costs; however, it does require obtaining a fine level of detail from a data source.

2.2.2.6.2 Indirect Costs

Indirect costs generally involve the output losses that result from an injury at a crash, including morbidity and mortality. Morbidity losses result from changes in worker productivity and workforce participation following an injury. Such losses include unwanted job changes and altered opportunities for advancement and education. The size of morbidity losses relates to the functional impairment that arises from the injury over the short, medium, and long term. However, debate often exists about an individual's level of functional impairment after an injury, its impact on the output of a firm, and the subsequent total economic output. Indirect costs also include absenteeism of injured employees and family members who are providing home care. Loss of home productivity is difficult to measure and often is excluded from studies that focus on injury costs. Another area of debate is the ability of substitute workers to provide output at a similar level to the injured worker.

Three methods are commonly considered for valuing the indirect costs of injuries: the human capital method, the whole economy cost of human capital method, and the friction cost method. Each method takes a different approach to the connection between the injured person and his or her workforce participation.

The human capital method equates the loss of productivity that results from an injury to a contributing member of the economy, including lost productive life years due to fatality, discounted to a present value. This method assumes that loss of productivity reduces both current and future potential production. The method assumes that earnings reflect productivity and that each worker receives the value of output added by the last-hired, at-the-margin, worker. Criticism of this method includes that it undervalues productivity of unemployed persons, elderly persons, and children, and that earnings for some groups are not representative of the relative value of their marginal productivity. To accommodate these criticisms, Landefeld and Sekin (*21*) expanded the human capital approach to include non-labor income and a multiplication for a risk factor, but human capital methods remain ineffective in measuring the intangible costs of injuries.

The whole economy cost of human capital method assumes that the human capital approach is accurate but that loss of future productivity of an injured person has a multiplicative effect in the wider economy. The method assumes that the impact on the productivity of the whole economy will be larger than the lost productivity of the individual worker. The immobility of workers and the loss of some productive members due to injury would lead to increases in wages and is then measured in general equilibrium terms.

The friction cost method assumes that (a) labor is highly mobile; (b) the human capital measure overestimates indirect costs because it captures potential productivity losses, not actual productivity outcomes; and (c) over the long term, unemployed workers substitute for injured workers—although this may take a long period in the case of highly skilled workers. Using the friction cost method, job training costs tend to be large, and the method does not preclude large indirect costs measures.

2.2.2.6.3 Intangible Costs

Intangible costs are the most contentious costs to estimate. Economic theory suggests that individuals are willing to pay to reduce their risk of injury, which would point to using WTP. But measuring WTP is difficult for injuries in a variety of settings. Disagreement also exists on the validity of other methods for estimating intangible costs.

Hedonic regression and CV are accepted ways to capture preferences and can measure total costs or intangible costs alone. CV can measure the WTP for health status indices such as quality-adjusted life years (QALYs) and disability-adjusted life years (DALYs). To define these terms, the QALY is based on the extra years that an intervention adds to someone's life. The DALY is an alternative tool that also measures the quality of life for those years. In general, CV is highly variable in its results because of the flexible nature of the instrument. Other methods include the use of court awards as a proxy for preferences, assuming that they represent the collective view of the intangible costs of injuries and the use of administrative compensations determined by regulatory bodies.

Hybrid measures combine CV with human capital approaches. Miller (*22*) uses this general method, estimating WTP from which the human capital component is subtracted to build decomposed total cost estimates. This hybrid approach highlights the issue of double counting, as it is often difficult to compare across study results or to transform another author's information to a new use. Potentially large overlap exists between the WTP estimates from CV and other costs. Nonetheless, despite existing disagreements about the methods for measuring indirect costs, disregarding them results in misallocation of resources.

2.2.2.7 Social and Private Costs

Some crash cost components are private and borne by the transportation user, and some are borne by the rest of society. Costs not borne by the user are referred to as externalities or uncompensated externalities.

DeSerpa (*23*) is attributed with identifying an externality as "a relevant cost or benefit that individuals fail to consider when making rational decisions." An efficient market assumes the transportation user bears the costs that he or she imposes on society, including crash cost externalities.

Delucchi (*24*) allocates crash costs to categories of monetary and non-monetary costs, private, and social costs. The social costs include lost productivity, vehicle replacement and repair costs, property damage, the social value of life, pain and suffering, and medical costs. However, some costs that are internalized to the user through insurance premiums are not considered externalities. It can also be argued that productivity losses and the pain and suffering of the user and his or her family also are not externalities by assuming that the user knows the risks associated with each possible mode of transportation and accepts those risks when beginning his or her journey.

Crashes result in injuries, which can range from minor to fatal, and property damages, which can range from unreported to massive, as in the case of a high-level environmental hazard due to a train derailment in an urban center. Externalities arise when insurance coverage is insufficient to compensate fully for the crash outcome, whether the costs are related to injury, death, property damage, or environmental hazards. The component of uncompensated costs of crashes that remains as external costs may depend on the nature of regulation and insurance in individual jurisdictions.

Measuring externalities is not a simple task and has only begun to be evaluated in depth in the past 10 years. UNITE (*25*) considers the external cost of crashes separately from the effect that congestion has on the rate of crashes when examining the marginal external cost of crashes. The question of external versus internal costs considers the degree to which the transportation user considers the relevant risks to all participants in the transportation system. The congestion effect suggests that the number of crashes increases at a decreasing rate as traffic volume increases, and that risk is therefore decreasing.

Assigning monetary values for externalities can be difficult, particularly for those of the non-monetary type. Two basic approaches dominate: the damage cost estimate and the prevention cost estimate. The damage cost estimate is most readily applicable, because externalities to transportation are those costs imposed on others by the users of the various modes of transportation. The damage cost estimation process easily assesses market goods, while non-market goods require use of other valuation techniques, such as RP or implied preferences. Non-market valuations decrease the certainty of accurately estimating total social costs of transportation. If the damage estimates are highly uncertain, the prevention method may be more practical.

Delucchi (*24*) estimates that expenditures on externalities are between 0.59% and 2.10% of U.S. gross domestic product (GDP). The average percentage of GDP consumed by externalities in a survey of 17 European Union countries was 2.5%.

Preparation of credible and accurate valuations for all possible transportation modes and circumstances is a formidable task. Determining levels of resources for the task requires political and administrative practicality. The prevention method has been likened to a control cost, which is conjectured to be less consistently applied, possibly reflecting political and strategic influences (*26*).

Adequately estimating the costs of externalities to transportation use is possible by making certain assumptions and collecting proxy variables from other sources. It also requires appropriate defense of the position taken and consideration of the possibility of double counting.

2.2.2.8 Value of a Statistical Life (VSL)

For purposes of economic analysis, VSL costs that are relevant to crashes are social costs that reflect the true and full cost to society. For goods and services that are bought and sold in competitive markets, market prices—adjusted for the distortionary effects of any taxes or subsidies applied to the particular market—are considered good proxies for social costs.

Clearly, no directly observable market exists for saving or losing a life. The value of life is not what an individual would be willing to pay to avoid surrendering his or her own life; that value would likely be infinite. Rather, it is the willingness to pay or to accept compensation for a reduction in the risk of untimely death.

VSL is linked to risk; that is, to the probability of loss of life over some time period. If for a given roadway two fatalities are predicted per year, then a project that reduces the rate to one fatality per year is said to save one statistical life per year. Estimated statistical lives saved are monetized using an accepted VSL.

It has become standard practice in the United States and other countries to value all lives equally with no differentiation by age, income, or other variable. Over the years, researchers have arrived at a range of values for VSL. However, they generally accept that VSL is a policy variable, usually mandated by a government agency and applied uniformly in all analyses.

Note: Toward the conclusion of the research for NCHRP Project 08-85, the U.S.DOT Undersecretary for Policy issued a memorandum, “Guidance on Treatment of the Economic Value of a Statistical Life in U.S. Department of Transportation Analyses” (see http://www.dot.gov/sites/dot.dev/files/docs/VSL%20Guidance.doc), in which the VSL was increased from $6.2 million—which had been set in July 2011 (*27*)—to $9.1 million. The U.S.DOT-issued guidance memo provides further information for valuing injuries by injury level (which is discussed in the next section of TM1).The casualties by injury categories that are based on VSL also increased proportionately to the increase in VSL. In the crash cost evaluation spreadsheet tool created for this project (available at http://www.trb.org/Main/Blurbs/169061.aspx), the appropriate changes would be made to cells C14 to C17 in the sheet labeled “Casualty Costs.”

2.2.2.9 The Value of a Life-Year (VOLY)

The VOLY, taken to be a constant annual sum over a remaining lifespan, has a discounted value equal to the estimated VSL. Put another way, researchers think of the VSL as the discounted value of the remaining life years of the average member of society. A VOLY can be computed from an estimate of the VSL:

$$VOLY = \frac{VSL}{A(n,r)}$$

where A(n, r) is the annuity factor based on the expected number of remaining years of life (n) and the appropriate discount rate (r). For example, Abelson (*28*) suggests the VOLY for use in public policy in Australia equals $95,070, implied by a VSL of $2.201 million, 40 years of life lost, and a discount rate of 3%. Abelson argues that this formula provides a plausible and consistent basis for valuing life years and states of health.

Blomquist et al. (*29*) estimate the VOLY in a study on the implied VSL based on the time required to use seat belts, child restraints, and motorcycle helmets. Their findings for the implied VSL range from $1.3 million for the use of helmets to $5.1 million for child restraints. These findings reflect a valuation of the lives of children above that of the lives of parents. When conducting further examination of their findings, the authors compare the effect of the variable "remaining life years" on VSL. When they control for differing life spans, the difference is reduced. By dividing the VSL for each outcome by the remaining life years (assumed as 73.8 for children and 42.6 for adults) without discounting, the VOLY for adults is $52,000, which is roughly the midpoint of the $39,000 to $70,000 range of VOLY for children. When future life years are discounted, the VOLY difference disappears at a discount rate of 2.5%, a rate likely to be below that normally applied in valuing future life years.

If one assumes that a VOLY is constant and then computes age-adjusted VSLs as the discounted value of future life years, then one will obtain estimates of the VSL that decline with age. However, is the VSL less for an elderly person? Certainly, some evidence that age is a relevant factor is suggested by the behavior of parents purchasing safety equipment for their children, as shown by Blomquist et al. (*29*). But Miller and Guria (*30*) also provide evidence of similar increased valuation for other members of an immediate family, making it difficult to justify the claim that the elderly have a lower VSL than do other age groups.

This issue was examined by Krupnik et al. (*31*) and Alberini and Austin (*32*) in two related studies that examined the impact of age on VSL in both Canada and the United States. Krupnik et al. surveyed 930 Ontarians between the ages of 40 and 75 years to determine any variation in their willingness to pay to reduce mortality risk. The survey used CV, supported by audio-visual aids, to increase risk comprehension and testing for misunderstanding about the probabilities tested. Excluding those individuals who did not understand the probabilities correctly and risk takers, the researchers found the VSL for all remaining subjects was $1.274 million for a 5-in-10,000 reduction in risk and $3.8 million for a 1-in-10,000 reduction in risk. Examining the data more closely for systematic differences due to age and health status, the researchers found values were relatively stable for the study cohort between 40 and 65 years of age. For people more than 70 years of age, the VSL dropped by roughly one-third. The study did not find a significant difference in WTP based on health status alone, but it did find that the WTP for individuals with a prior cancer diagnosis was 60% higher than for individuals without such a diagnosis and that lower mental health scores corresponded with lower WTP estimates.

Alberini et al. (*32*) presented findings for an American cohort following the same study protocol. The major difference in the way the studies were conducted was that the Krupnik et al. (*31*) study required participants to go to a central testing location, which reduced responses by persons with more health challenges, whereas the Alberini et al. study surveyed participants in their homes, including individuals of more varied health levels. A second difference was that the American cohort included more visible minorities. Alberini et al. suggest that the inclusion of more minorities underlies a larger baseline mortality risk in the American cohort. The Canadian cohort's underlying risk was 123 deaths per 1,000 persons, whereas the American cohort's risk was 187 deaths per 1,000 persons. Lastly, the sample size was larger by 270 persons in the American cohort.

The main findings of the American study were similar to the Canadian findings with regard to the magnitude of the WTP. Because the WTP was not proportional to the risk faced, the VSL found for a 1-in-10,000 reduction was larger than the VSL found for a larger risk reduction. The Canadian study also found that health status as measured by the Short Form (SF)-36 did not have a significant impact on the VSL.

However, there were some differences. Most importantly, the American study found no impact of age on the VSL, whereas the Canadian study found a statistically significant difference. Higher incomes led to increased WTP in both studies, but the effect of increased income in America was statistically significant. For chronic conditions, such as high blood pressure, chronic heart disease, and lung disease, WTP was significantly larger for the American cohort, a finding not corroborated by the Canadian study.

These mixed findings do not totally clarify the concern for the practice of discounting future life years, but they offer some support to the use of unadjusted statistical life values in policy by some groups such as EPA.

2.2.2.10 The Cost of Injuries

Non-fatal injuries are the largest cost component of general highway crashes. They are measured in a number of ways. Many studies simply distinguish between minor and serious injuries. The Association for the Advancement of Automotive Medicine has developed a six-point scale called the Abbreviated Injury Scale (AIS), which focuses on the survival threats posed by an injury. Table A-2 shows the six levels of AIS classification with representative states of injury, from 1 for a minor injury, to 6 for an injury that is ultimately fatal.

Table A-2. Selected sample of injuries classified using the abbreviated injury scale.

AIS Code	Injury Severity Level	Selected Injuries
1	Minor	Superficial abrasion or laceration of skin; digit sprain; first-degree burn; head trauma with headache or dizziness but no other neurological signs
2	Moderate	Major abrasion or laceration of skin; cerebral concussion with unconsciousness of less than 15 minutes; finger or toe crush/amputation; closed pelvic fracture with or without dislocation
3	Serious	Major nerve laceration; multiple rib fracture but without flail chest; abdominal organ contusion; hand, foot, or arm crush/amputation
4	Severe	Spleen rupture; leg crush; chest-wall perforation; cerebral concussion with other neurological signs, including unconsciousness for less than 24 hours
5	Critical	Spinal cord injury, with cord transaction; extensive second- or third-degree burns; cerebral concussion with severe neurological signs, including unconsciousness for more than 24 hours
6	Fatal	Injuries that, although not fatal, within the first 30 days after an accident ultimately result in death

Source: *(42).*

Studies note that the basis for the AIS severity level is the extent to which an injury is life-threatening. However, less severe injuries may involve greater pain and suffering, and thus involve greater cost to the individual on a WTP or WTA basis, in contrast with some injuries of a higher AIS level. For example, a Level 2 injury may leave a victim with serious disfigurement or loss of teeth with enduring pain and suffering/quality of life effects. In contrast, a Level 4 injury, such as a chest-wall perforation, could result in a 2-week hospitalization with full recovery and no lasting effects. To address this inconsistency, alternative approaches have been proposed, such as the ABC scale used by the National Safety Council (NSC):

- A—Severe injury
- B—Other visible injury
- C—Complaint of pain

2.2.2.10.1 Academic Studies of the Cost of Injury

The wage-risk study by Dillingham and Miller (*33*) implies a WTP of between $159,502 and $247,856 to avoid 1 impaired work-year. Wages were found to be insensitive to the degree of job-related injury risk—that is, the estimated coefficient on non-fatal risk was statistically insignificant—in Dorman and Hagstrom's (*34*) and Siebert and Wei's (*35*) wage-risk studies. Dillingham et al. (*33*) mention problems in trying to incorporate the multiplicity and severity of different non-fatal risks. One problem is that the choice of risk categories might be arbitrary. For example, the likelihood or severity of a risk category may not be representative for an individual in a specific occupation or industry. The different measures of risk tend to be collinear; that is, it is difficult to untangle the true relationship between each independent variable and the dependent variable. In some studies, injuries are not measured in terms that can be applied to other markets. Hence, empirical results are of limited use.

However, Dillingham et al. (*33*) addressed this problem by assuming that expected impaired years can be applied to non-work-related injuries, and therefore comparable estimates of WTP can be derived for safety for other markets. The study has several limitations. First, the estimates do not include an adjustment for the ex-post compensation of injury costs through public or private transfers. Second, the study assumes that a worklife shortened by a fatal injury was equivalent to one shortened by a permanent and total but non-fatal disability. Third, the individual may self-select into an occupation and level of risk. Fourth, the discount rate may be not appropriate. Finally, results were obtained using a unique set of injury risk data.

The Canadian wage-risk study by Lanoie et al. (*36*) implies a value of a statistical injury of $10,084. Attempting to estimate jointly the effects of non-fatal and fatal risk on workers' wages may not show a significant effect on individual risks because they are likely to be highly correlated, but may result in large standard errors. Estimating the risks independently of each other, however, could result in an upwardly biased estimate (*37*).

The Blomquist et al. paper (*29*) on VSL implied by time costs also includes estimates of the value of moderate-to-serious non-fatal injury. Their paper intends to derive values of reducing the risks of fatal and non-fatal injuries for different road users. Blomquist et al. (*29*) use data from the 1985 U.S.DOT FHWA Nationwide Personal Transportation Study (NPTS) and the 1980 Census of Population and Housing Public Use, and they use values of personal loss from the net benefit equations of Blomquist (*38*). Variables included in the estimations are family income, child age (and number of children under age 16), number of licensed drivers in the household, years of schooling, motorist age, miles driven in the last year, use cost, vehicle weight, vehicle age, and dummy variables for marital status, vehicle-airbag equipped, vehicle-passive-belt equipped, and vehicle-combined-belt equipped. The mean value of a reduction in risk from a fatal injury to a moderate-to-serious non-fatal injury implied by seatbelt use is $183,000; the value of reduction in non-fatal risk implied by child safety equipment is $134,000; and the value of reduction in non-fatal risk implied by motorcycle helmet use is $62,000.

Schwab Christe (*39*) performed a CV survey to determine the costs of road accidents in Switzerland. The survey's goal was to value explicitly the costs of road accidents in human terms and to provide separate estimates of the human costs to victims and to their relatives. Respondents were asked how much they were willing to pay to reduce their own or a relative's risk of becoming victim of a road accident by

50% across a range of injury severity. The severity of non-fatal injury ranged from no hospitalization, which involved some discomfort and sporadic pain for weeks, to an extended hospital stay in which mental faculties were significantly and permanently reduced. To reduce their own risk by 50%, the respondents were willing to pay $431 per year for the least severe injury to $980 per year for the most severe non-fatal injury. To reduce a relative's risk by 50%, the respondents were willing to pay $751 per year for the least severe injury to $1,399 for the most severe non-fatal injury.

Kidholm (*40*) presents results from a CV survey of traffic safety in Denmark. Respondents were asked their WTP to reduce risk by 30% of a slight, serious, and very serious injury, respectively: a fractured wrist, fractured shin, or open fracture of the femoral bone. The mean annual WTP for the 30% risk reductions were $184 to $260 for a slight injury, $247 to $348 for a serious injury, and $328 to$ 482 for a very serious injury.

2.2.2.10.2 Other Estimates of the Cost of Injury

Various bodies have set a value for the cost of an injury for use in evaluating policy decisions. Lawson (*41*) provides an overview of these injury valuations in Canada. In 1989, an injury of an unspecified severity that resulted from a road accident was valued at $3,600. Presumably, that was for an average injury, and its valuation was significantly smaller than the valuation for a minor injury in aviation projects. For aviation accidents in 1989, a minor injury was valued at $18,000 and a major injury at $47,000.

Miller (*23*) developed a comprehensive analysis of non-fatal police-reported motor vehicle crashes to estimate the cost of injury from road accidents for the five non-fatal AIS severity levels. Miller gathered monetary costs from a variety of sources and added an estimation of quality of life lost (QOL) to create comprehensive costs. The technique for developing the QOL losses was based on converting average health ratings by physicians to an estimate of years of functional capacity lost due to injury. The QOL calculation multiplies the value of fatal risk reduction by the ratio of years of functional capacity at risk between fatal and the injury level. From this number is subtracted the monetary component of the estimate, to avoid double counting. In Miller's study, functional capacity loss was defined as impairment along any of seven health dimensions: mobility, cognitive, self-care, sensory, cosmetic, pain, and ability to perform household responsibilities or wage work. Years at risk of different injuries were calculated by estimating the utility loss caused by impairment as rated by a physician, weighting the percentage contribution of each impairment to create a single value for each severity level. The years of functional capacity lost were computed from standard life tables as the percentage of lost time due to impairment multiplied by the expected life years remaining. Each additional injury of AIS Level 2 or greater was treated as a further reduction of life years at risk after calculation of the first or most significant injury reported. AIS Level 1 injuries were only considered as a single loss of utility.

To value injuries at a particular severity, Miller (*23*) took a fraction of the WTP for avoiding a fatality. He used that fraction to represent the WTP for avoiding an injury of a particular severity. He discusses his method in depth. The method is widely accepted if somewhat arbitrary, and the research team is not aware of a superior method.

Spicer and Miller (*42*) recently updated fractions of VSL associated with each injury level on the AIS scale for a report to the NHTSA, as shown in Table A-3.

Table A-3. Relative disutility factor by injury severity level and value of injury prevention.

AIS Level	Severity	Fraction of VSL	Value of Injury Prevention (2010 U.S. dollars)
AIS 1	Minor	0.003	$18,600
AIS 2	Moderate	0.047	$291,400
AIS 3	Serious	0.105	$651,000
AIS 4	Severe	0.266	$1,649,200
AIS 5	Critical	0.593	$3,676,600
AIS 6	Unsurvivable	1.000	$6,200,000

Source: (*42*).

To convert the findings for individual country differences, Miller (*22*) suggests this possibility: multiply the country's reported values for lost wages, household production, and quality of life by the ratio of the per capita income in the country with that of the United States. The conversion would potentially allow development of comprehensive costs using country-specific values for emergency and medical costs, insurance and administration costs, and legal and court costs. These costs may vary significantly between countries, depending on the structure of insurance industries for both transportation and health care. Miller's method for estimating QOL losses is widely accepted but has opponents given its basis outside strong economic theory. Little in theory links functional years lost to total losses in the economy.

Blincoe et al. (*43*), in a study for the National Highway Traffic Safety Administration, broke out component costs from injury-by-injury categories (see Table A-4).

Table A-4. NHTSA unit costs per injury type (2010 U.S. dollars), adjusted to 2011 U.S.DOT VSL.

	PDO	MAIS 0	MAIS 1	MAIS 2	MAIS 3	MAIS 4	MAIS 5	Fatal
Medical	-	1	4,384	28,777	85,631	241,830	612,299	40,693
Emergency services	57	40	179	390	677	1,528	1,568	1,534
Market productivity	-	-	3,222	46,075	131,599	196,032	807,980	1,096,493
HH productivity	86	61	1,054	13,485	38,815	51,586	274,986	352,769
Insurance administration	214	147	1,365	12,725	34,795	59,553	125,601	68,366
Workplace cost	94	63	464	3,597	7,857	8,652	15,085	16,027
Legal costs	-	-	277	9,174	29,114	62,038	147,074	188,111
QALYs	-	-	8,206	167,850	235,939	706,207	2,406,848	4,400,240
Subtotal	**451**	**313**	**19,149**	**282,074**	**564,427**	**1,327,427**	**4,391,440**	**6,164,231**
Travel delay	1,479	1,424	1,432	1,558	1,731	1,839	16,849	16,849
Property damage	2,734	1,877	7,079	7,283	12,523	18,110	17,398	18,920
TOTAL	**4,664**	**3,613**	**27,660**	**290,915**	**578,681**	**1,347,377**	**4,425,687**	**6,200,000**

PDO = Property Damage Only; MAIS = Maximum Injury Severity Level; HH = Household.
*Property damage only: Unit costs in this category are per damaged vehicle; otherwise, unit costs are per injured or deceased person. Source: (*43*).

Dionne et al. (*44*) examined the economic impact of traffic accidents in the trucking industry. In estimating the social cost of traffic accidents, they used the VSL of $1.74 million as presented by Lawson (*45*). For estimating the cost of an injury, Dionne et al. converted a monetary value used by the SAAQ (Quebec's public automobile insurer) for bodily injuries. SAAQ calculates the monetary value of a fatality as $442,575 and the value of an injury as $23,492. Dionne et al. (*44*) used a value of $92,807 for any injury, regardless of severity level, calculated as the monetary cost of injury times the VSL and divided by the lost production due to fatality, for example (20,250 x 1.5 million/381,500)/0.862.

Table A-5 summarizes the estimates of injury costs from several studies, including those discussed in this part of TM1.

Table A-5. Estimates of cost of injury.

Study	Value of Injury (2010 U.S. dollars)	Components Included	Components Excluded
DOT 2002 Study Type: WTP Mode: Road Country: United Kingdom	*Average Value of Injury* Serious injury: $507,067 Slight injury: $39,099 *Average Value of Injury by Vehicle Type, over Fatal, Serious, and Slight* Bus: $76,177 Goods vehicle: $148,059 Car and taxi: $118,924 Motorized two-wheeler: $248,930	• Lost output • Medical and ambulance costs • Human costs based on WTP values, such as grief, pain, and suffering	• Police and legal costs • Congestion • Property damage
Bureau of Transport Economics (BTE)(*46*) Study Type: Accounting Mode: Road Country: Australia	*Value of Road Injury* Serious injury: $619,592 Minor injury: $22,135	• Labor losses in the workplace, households, and community • Medical costs, including emergency, hospital, and rehabilitation • Quality of life losses • Property damage costs • Travel delay costs • Police and fire service costs • Insurance administration costs • Legal costs, including criminal prosecution and insurance claim costs	
Zaloshnja et al. (*47*) Study Type: Accounting Mode: Road Country: United States	*Average Comprehensive Costs per Victim* Bus: Possible injury $61,670, to incapacitating injury $336,672 Large trucks: Possible injury $87,620 to incapacitating injury $619,465	• Medical costs • Emergency costs • Property damage costs • Lost productivity • Costs of pain and suffering • Quality of life reductions • Delay costs	• Police and legal • Congestion • Insurance
Blomquist et al. (*29*) Study Type: Time Costs Mode: Road Country: United States	Car—seatbelt: $196,000 $698,000, $148,000 Car—all child safety equipment: $0.255 million Motorcycle: $0.118 million	Estimations of value of avoiding an injury following time costs	• VSL • VSI • Medical • Police and legal • Congestion • Property damage • Insurance

(continued on next page)

Table A-5. (Continued).

Study	Value of Injury (2010 U.S. dollars)	Components Included	Components Excluded
Schwab Christe (*39*) Study Type: Contingent Valuation Mode: Road Country: Switzerland	*WTP/Year to Reduce Own Injury Risk* Least severe: $820 Most severe: $1,865 *WTP/Year to Reduce Relative's Risk* Least severe: $1,429 Most severe: $2,662	*Human Costs Only* • Loss of life expectancy • Physical and mental suffering of victims and relatives	• Medical • Police and legal • Congestion • Property damage • Insurance
Kidholm (*40*) Study Type: Contingent Valuation Mode: Road Country: Denmark	*For 30% risk reduction* Slight injury: $350 - $495 Serious injury: $470 - $662 Very serious injury: $624 - $917	Unmentioned	Undetermined
Bureau of Transport and Regional Economics (BTRE) (*48*) Study Type: Accounting Mode: Rail Country: Australia	*Value of Rail Injury* Serious injury: $50,070 Minor injury: $3,708	• Labor losses in the workplace, households, and community • Medical costs, including emergency, hospital, and rehabilitation • Quality of life losses • Insurance administration costs	• Property damage costs • Travel delay costs • Police and fire service costs • Legal costs, including criminal prosecution and insurance claim costs
Dillingham and Miller (*33*) Study Type: Wage-Risks Mode: Work Country: United States	*WTP/Avoid Own Worklife Impairment for 1 Year* $303,473 to $471,577	• Pain and suffering • Loss in lifetime earning capacity	• Medical costs • Police and legal • Congestion • Property damage • Insurance
Lanoie et al. (*36*) Study Type: Wage-Risk Mode: Work Country: Canada	$19,186	Unmentioned	Undetermined

2.2.3 Research on Rail Crash Costs

Few studies, if any, try to estimate the specific cost of an injury for rail. The Bureau of Transport and Regional Economics (BTRE) in Australia has produced two reports on transport crashes: *Road Crash Costs in Australia* in 1996 (*46*) and *Rail Accident Costs in Australia* in 2002 (*48*).

Both studies used the average length of hospital stay to classify injuries as serious or minor. They classified an injury as serious if it resulted in hospital admission with an average stay of more than 1 day, and as minor for any lesser injury that required medical attention. In the 2002 study on rail crashes, the average cost of a fatality was $1.013 million; a serious injury was $14,395, and a minor injury, $1,066. The costs included human costs but excluded property damage and other costs. (The costs given are in

2002 U.S. dollars converted from Australian dollars using the yearly average exchange rate of 1.828 AUD to 1 USD.)

The average costs for rail crashes were $0.191 million more than average costs for road crashes. Several factors could have influenced this result:

- The estimation method for rail VSL was adjusted for WTP to avoid pain and suffering but not for road VSL;
- The costs of a fatality are slightly different between road and rail; and
- Some concern exists that the quality of the data used to estimate the rail costs was lower than that available for estimation of road costs.

More notably, though, a large difference exists in the costs of injuries between the two modes. The costs of road injuries are roughly 10 times the costs of rail injuries. The ratio of serious road costs to rail costs is 12.37:1 and the ratio of minor road costs to rail costs is 5.97:1. The divergence can be attributed to several differences in methodology. Although the road cost estimates are comprehensive, the rail costs reported are for human costs only, excluding property and other costs. The rail costs also are estimated for a limited set of crashes and exclude some rail-related crashes, including motor vehicles at grade crossings and attempted suicides.

Dennis (*49*) estimates risk costs for hazardous materials transported by rail. The study predates hazardous materials legislation and regulation which evolved after the year 2000. Moreover, the study is not specific to risks at grade crossings. The relevance of the Dennis study is in the method for deriving costs associated with exposure to risk. Risk costs are incremental costs incurred by railroads as a result of the presence of hazardous materials (Hazmat). Safety measures have increased during recent decades, but at the same time, the amount of hazmat shipped by rail also has increased significantly.

Dennis (*49*) focused on railroad freight transportation of hazmat groups known to have generated substantial risk costs; in other words, on major releases. The intent was to determine the associated risk costs per unit of exposure, expressed as dollars per car-mile of hazmat shipped. The study defined a hazmat incident as any unintentional release of hazardous materials in railroad transportation. In this study, a release was considered major if it included one of the following: at least $100,000 in current U.S. dollar damages, at least one death, or a release of at least 500 gallons of hazardous materials.

The starting point was a list of 669 potential major hazmat releases developed by the Association of American Railroads (AAR), which the federal hazmat law has since superseded. Given that the risk costs depend heavily on the circumstances of the release, AAR developed seven groups, comprising three safety hazard classes, three environmental hazard categories, and a category for all other hazards. The safety hazard classes are poison inhalation hazard, flammable or combustible commodities, and all other commodities. The environmental hazard categories are high, medium, and low. Because most poisonous inhalation commodities evaporate, the environmental hazard is not considered an important characteristic. Table A-6 summarizes the findings.

Table A-6. Risk cost per unit of exposure (1994 U.S. cents per loaded car-mile).

	Environmental Hazard		
Safety Hazard	High	Medium	Low
Poison Inhalation		1.03	
Flammable/Combustible	10.88	2.61	1.33
All Other	28.25	0.69	0.17

Source: (*49*).

2.3 Indicators of Relative Severity of Grade Crossing Crashes vs. General Highway Crashes

The outcomes of grade crossing crashes have significant similarities with general highway crashes. Both can result in fatalities, injuries, and property damage. However, crashes at highway-rail grade crossings tend to be more severe, because the kinetic energy in a collision with the more massive train exceeds that of an average vehicle-vehicle collision. Thus, the injuries that result from a grade crossing crash are likely to be more severe even though the probability of injury from a crash is similar for grade crossing and general highway crashes that are reported. Indeed, the majority of highway crashes are light-damage "fender benders," many of which go unreported.

Other factors may contribute to the severity of grade crossing crashes. In addition to the presence of larger quantities of fuel at a grade crossing crash, there is the possibility that a tanker spill could generate a hazmat release requiring cleanup operations. The possibility of poisonous inhalants being released from a grade crossing crash exists; however, no such crash has occurred.

Section 2.3.1 uses publicly available data to provide a brief comparison of the relative severity of grade crossing and general highway crashes.

2.3.1 Available Crash Data

State departments of transportation (state DOTs) collect detailed data on highway crashes. While this information is not readily available at the national level, some general trends in highway crashes are identifiable using databases maintained by the NHTSA. One of the primary NHTSA databases for highway crash data is the Fatality Analysis Reporting System (FARS), which includes statistics about fatal crashes from all 50 states.

To capture a comprehensive view of highway accidents, NHTSA samples representative data assembled for the National Automotive Sampling System (NASS) from police reports. Although it is not a complete dataset, the NASS reflects the geography, roadway mileage, population, and traffic density of the United States as a whole. NHTSA's annual *Traffic Safety Facts* summarizes highway statistics using a combination of FARS and NASS data.

FRA requires each railroad to report any "impact between railroad on-track equipment and an automobile, bus, truck, motorcycle, bicycle, farm vehicle, or pedestrian at a rail-highway grade crossing" (*50*). FRA compiles an annual report of all collision data and publishes it on its website. Given that this safety database includes information on all railroad incidents regardless of location, it is necessary to separate information on highway-rail crossing crashes from other types of incidents. Two forms provide the relevant data for grade crossing crashes contained in this database:

- Form 6180.54 Rail Equipment Accident/Incident, and
- Form 6180.57 Highway-Rail Accident/Incident.

Additionally, the Materials Transportation Bureau (MTB) of the U.S. Research and Special Programs Administration collects grade crossing crash data from carrier reports of collisions involving hazmat transport. A carrier must submit a hazmat collision report when any of the following events occurs as a direct result of a hazmat release:

- a person is killed,
- a person receives injuries requiring hospitalization,
- estimated carrier or other property damage exceeds $50,000, or
- a situation exists such that a continuing danger to life exists at the scene of the incident.

The federal Transportation Materials Law defines what substances are considered hazardous. One regulation under the law, the Rail Hazmat Routing Rule, addresses a hazmat subset deemed security-sensitive. Security-sensitive hazmat subset includes toxic inhalables, explosives, and radioactive materials. The rule requires that FRA, in conjunction with AAR and the federal Surface Transportation Board (STB), track and ensure that security-sensitive hazmats are not shipped through densely populated areas where a release could result in significant loss of life. Releases of other hazmats are less likely to result in loss of life, but nonetheless could involve significant cleanup costs.

2.3.1.1 Grade Crossing Crash Trends

The current national trends in grade crossing crashes demonstrate a marked decline over the last 20 years, as shown in Table A-7. The national figures also indicate that crash severity has remained approximately constant, with 10% to 11% of incidents being fatal.

Table A-7. U.S. grade crossing crash trends.

	1989	**1994**	**1999**	**2004**	**2009**
Total Incidents	6,526	4,979	3,489	3,085	1,916
Fatal Incidents	648	512	340	322	210
Percent of Fatal Incidents	9.93	10.28	9.74	10.44	10.96

Source: (*51*).

A recent study (*52*) identified five success factors largely responsible for reducing crashes over the last 20 years: commercial driver safety, locomotive conspicuity, more reliable motor vehicles, sight lines clearance, and the “grade crossing maintenance rule.” These factors accounted for 79% of the reduction in incidents. Another factor is the federal program to eliminate grade crossings through closure, which has had a positive impact by reducing the total exposure between rail and highway traffic over the years. The study also notes that incidents due to these major factors have leveled off since 2007. This leveling off indicates that the incident reduction rate of the study period will not continue into the future.

2.3.1.2 Crashes by Severity Type

Crashes are categorized as “non-casualty” or “casualty.” Non-casualty crashes involve property damage only. Casualty crashes are further subdivided into fatal crashes and injury crashes. Fatal crashes result in at least one fatal injury within 30 days of the crash and may have multiple fatalities and non-fatal injuries. Injury crashes are crashes with at least one injury but also may have multiple injuries. All crashes have property damage to some extent.

2.3.1.2.1 Fatalities and Injuries

Highway crashes can involve multiple fatalities and injuries. According to NHTSA’s *Traffic Safety Facts*, in 2009 the average fatality crash involved 1.098 fatalities, or 33,808 fatalities per 30,797 fatality crashes. The average fatality rate for reported highway crashes was approximately 0.006, or 33,808 fatalities per 5,504,797 crashes. Similarly, the average injury rate for every highway crash was 0.403, or 2,217,000 injuries per 5,504,797 crashes.

Using FRA collision data from 2009, Table A-8 compares the number of fatalities and injuries per crash at public and private grade crossings to those on general highways. As the table shows, a grade crossing incident is 20 times more likely to involve a fatality. Thus, the percentage of fatal grade crossing crashes is higher than the percentage of fatal general highway crashes. Moreover, the 2009 FRA data show that the average fatality incident at a public or private grade crossing involved 1.171 fatalities (or 247 fatalities per 211 fatality crashes), compared to 1.098 fatalities for highway crashes. Although Table A-8 shows that the average number of injuries per crash is slightly less at grade crossings than on highways, the data suggest grade crossing crash-related injuries are likely to be more severe. This hypothesis cannot be tested using FRA safety data, however, because the severity of injuries is not recorded.

Table A-8. Crash severity indicators at grade crossings and on highways in general, selected years.

Crash Type	Average Number of Fatalities per Crash			Average Number of Injuries per Crash		
	2000	2005	2009	2000	2005	2009
General Highway	0.007	0.007	0.006	0.500	0.438	0.403
Highway-Rail Grade Crossings	0.121	0.117	0.128	0.348	0.343	0.383

Source: (*52*).

Table A-9 shows the breakdown of injuries between passengers/users by mode and railroad employees.

Table A-9. Breakdown of highway grade crossing casualties for selected years.

	2000			2005			2009		
	Fatalities	Injuries	Casualties	Fatalities	Injuries	Casualties	Fatalities	Injuries	Casualties
Highway Passengers/ Users	99.5%	90.6%	92.9%	99.2%	85.5%	89.0%	99.2%	80.6%	85.3%
Railroad Employees	0.5%	8.6%	6.5%	0.8%	11.4%	8.7%	0.8%	11.2%	8.6%
Train Passengers	0.0%	0.8%	0.6%	0.0%	3.1%	2.3%	0.0%	8.2%	6.2%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Source: (*52*).

2.3.1.2.2 Property Damage

Table A-10 compares the types of vehicles involved in crashes at public and private grade crossings to those on general highways. The use of different vehicle classification systems across the analyzed databases complicates the analysis. For the purposes of this analysis, heavy trucks include “large trucks” in *Traffic Safety Facts* and “truck-trailers” in FRA safety data.

Table A-10. Composition of vehicles by type in crashes on highways compared to grade crossings in selected years.

Type of Vehicle	2000		2005		2009	
	Highway	Grade Crossing	Highway	Grade Crossing	Highway	Grade Crossing
Passenger Car	60%	48%	56%	46%	54%	46%
Heavy Truck	4%	13%	4%	17%	3%	14%
Light Truck	34%	32%	38%	29%	41%	25%
Motorcycle	1%	<1%	1%	<1%	1%	<1%
Bus	1%	<1%	1%	<1%	1%	<1%
Other	0%	7%	0%	8%	0%	15%

Sources: (*52, 53*).

Table A-10 illustrates that heavy trucks are more likely to be involved in grade crossing crashes than in general highway crashes. This reflects a higher percentage of trucks in the traffic mix on routes with grade crossings. It is unclear from the data whether trucks compared to other highway traffic have a higher or lower rate of trespassing at highway-rail intersections with trains present or approaching.

Grade crossing crashes also involved a greater proportion of pedestrians—about 6% of the 15% shown as "Other" in the table—than did general highway crashes. The crashes involving pedestrians had a higher incidence of casualties and little or no property damage. In contrast, grade crossing crashes were less likely to involve passenger cars and light trucks than were general highway crashes.

The greater involvement of heavy trucks indicates that average property damage for vehicles should be greater in grade crossing crashes than in general highway crashes. According to FRA safety data, grade crossing crashes led to $12.1 million in motor vehicle damage, or about $6,300 per incident, in 2009. Data from Form 6180.54 indicates that railroads spent about $17 million annually between 2006 and 2010 to repair damage to locomotives, track, and grade crossing protection equipment because of grade crossing crashes. This corresponds to about $67,500 in rail equipment damage per reported incident, a figure that considers only railroad equipment damage that was reported. The requirement to report applies when damages exceed a threshold (see Table A-11 for the thresholds by year).

Table A-11. Accident/incident reporting thresholds by year for completing a Form 6180.54.

Year	Reporting Threshold
2002	$6,700
2003	$6,700
2004	$6,700
2005	$6,700
2006	$7,700
2007	$8,200
2008	$8,500
2009	$8,900
2010	$9,200
2011	$9,400

Source: (*51*).

If the railroad equipment damage in the non-reported cases was an assumed $2,000 per incident, based on FRA estimates in its regulatory evaluation of emergency notification actions (*54*), then the average railroad equipment damage cost per incident would be about $10,400—or about 1.65 times the average highway vehicle damage cost per incident.

2.3.1.2.3 Hazardous Materials and Other Effects

Unlike other transportation operators, freight railroads have a "common carrier obligation" to carry hazmats. Using data from the 2008 STB Waybill Sample, AAR estimates that approximately 1.7 million hazmat carloads are transported annually by rail in the United States. These shipments account for approximately 5.5% of all rail carloads, which is less than 12% of total car miles. AAR notes that the railroads complete 99.998 percent of rail hazmat shipments without incident; however, there are still potential costs associated with hazmat cleanups at highway-rail grade crossing crashes.

The data indicate that there has never been a security-sensitive hazmat release (e.g., toxic inhalables, explosives, or radioactive materials). Hazmat releases of any type from rail cars at grade crossing crashes are relatively rare. In any given year, there are no more than one or two incidents, with negligible consequence in terms of cleanup costs. It is more common for grade crossing crashes to involve some release of locomotive and highway vehicle fuel, but the data do not indicate that these have resulted in significant cleanup costs.

Liability claims are another major cost associated with grade crossing crashes. According to AAR estimates, liability claims against U.S. railroads have averaged approximately $750 million annually over the last several years. Litigation costs are approximately 15% of the total liability claim.

2.3.2 Grade Crossing Crash Estimation Methodologies

A full understanding of the crash prediction and severity process is central to the development of a crash cost estimation and forecasting framework. This is because comprehensive crash cost estimates should map to a standard taxonomy of crashes. This section reviews existing grade crossing crash prediction and severity methods.

2.3.2.1 DOT Accident Prediction and Severity Model

The DOT Accident Prediction and Severity (APS) model is widely used to assess crash risk at grade crossings. It is implemented in FRA's Office of Safety WBAPS (Web-Based Accident Prediction and Severity) system and incorporated into U.S.DOT's *Rail-Highway Crossing Resource Allocation Procedure* report, which is used for decision support (*55*). APS contains three models for crash prediction that correspond to three main grade crossing device types: passive, lights, and gates. The models are based on regression analysis of incidents and grade crossing characteristics. Every several years, FRA's Office of Safety updates what are called the "normalizing constants" that calibrate the APS national grade crossing imputed predicted crashes with actual crashes of recent history. These normalizing constants do not impact predicted crashes uniformly, but their effect is significant: the 2010 update reduces predicted crashes at passive rural crossings with annual average daily traffic (AADT) of 1,000 vehicles and five daily trains by about 30% in comparison with the previous normalizing constants of 2007. As the rate of incident decline is expected to moderate, future changes to the normalizing constants and their effects should not be as pronounced.

After calculating predicted crashes at a crossing, APS allocates these crashes to severity levels within the casualty (injury and fatal) and non-casualty categories. Three distinct crash severity categories are derived: fatal, injury, and non-injury. Assigning a cost to each crash severity type makes it possible to evaluate the predicted crash cost for a grade crossing.

All the data required to populate the APS Model is in FRA's National Grade Crossing Inventory. However, the inventory data have limitations, such as infrequent updates from the states, so users need to validate the inventory data in their analyses.

The APS formulas are best-fit, statistically based results from a national sample of grade crossing crashes spanning a number of years. The advantage of using the APS Model is that it can be applied without bias to any grade crossing in the United States. However, national average results do not always apply well to certain locales, such as the Chicago area (with 1,200 grade crossings in Cook County alone, the highest density of crossings in the United States). APS also is limited by reported data, which does not include the time-of-day distribution of rail and highway traffic. Time-of-day distribution, which provides peaking characteristics, is critical for arriving at reliable, site-specific exposure estimates. The application of heuristic and other methods to crash cost analysis provide useful extensions of APS.

2.3.2.2 Higher Speed Rail Prediction and Severity Model

One such improvement to the APS appeared in an analysis by the John A. Volpe National Transportation Systems Center (*56*). In this analysis, crash prediction was based on the APS; however, severity was derived through a new method based on a hierarchy of contributing factors. The leading factor was what struck what: highway vehicle into train or train into highway vehicle. For an incident sample (1975–1995), 84% of the time the train struck the highway vehicle. Within this larger category, data showed that incident outcomes ranged widely from just nicking the highway vehicle to fatalities on the highway to severe derailment of passenger trains, such as the 1999 Bourbonnais, IL, crash. The outcomes for the smaller category, including highway vehicles striking trains, were fairly uniform: extensive highway vehicle damage, light casualties, if any, and few additional effects.

An important contribution of the Volpe high-speed rail method was its use of the logic that crash severity is proportional to the kinetic energy of a crash, which increases as a square of speed. The Volpe analysis severity model further deviates from the APS Model by breaking out damages to rail and highway modes.

2.3.2.3 Aggravating Risk Factors

Several aggravating factors have been identified and used to model severity (*57*). Factors contributing to possible derailment include track curvature, railroad grade, and special trackwork, including turnouts, crossovers, and diamonds in approaches to the grade crossing. Other factors include obstructions for collisions, such as embankments, ledge or rock outcroppings, retaining walls, overhead bridge piers, and other structures. Proximity to hazards such as water or hazmat storage also can influence the severity of predicted grade crossing incidents.

The aggravating factors model relies on the APS Model but scales the severity outcome upward or downward based on the presence or absence of the aggravating factors.

2.3.2.4 GradeDec.Net Refinements to Crash and Severity Prediction

GradeDec.Net, FRA's web-based grade crossing investment analysis system, has incorporated the APS Model, the Volpe high-speed rail model, and the aggravating factors model to forecast crashes and their severity at crossings (*58*).

The following additional modifications have been made to GradeDec.Net to build on the existing methods.

2.3.2.4.1 Time-of-Day Exposure Correlation

Users specify time-of-day distributions for highway (auto, truck, bus) and rail traffic (freight, passenger, and switch). Prediction and severity of crashes is based on more precise estimates of the exposure variable, which accounts for peaking characteristics by mode and traffic segment.

2.3.2.4.2 Traffic Reassignment

Crossing closures cause traffic to reroute through other crossings while grade separations tend to draw traffic away from nearby adjacent crossings. These traffic changes in a rail corridor impact predicted crashes and their severity. These capabilities are captured in GradeDec.Net (*58*).

2.3.2.4.3 Modeling of Travel Delay

GradeDec.Net forecasts travel delay due to blocked crossings and evaluates time-savings benefits from grade separations (*58*). This feature is readily modifiable to calculate delay due to crashes.

2.3.2.4.4 Allowing for More Robust Base-Alternate Logic Flows

The U.S.DOT Rail-Highway Crossing Resource Allocation Procedure (*55*) applies relative risk factors when evaluating the effect of a grade crossing device upgrade. This approach is preferable to just applying the model specific to the new device because with the latter approach anomalies arise where a device upgrade could actually increase predicted crashes and their severity. However, applying relative risk factors requires that other underlying causal factors, like highway AADT, must remain invariant between the base and alternate cases. GradeDec.Net removes this restriction and allows for device upgrades combined with traffic management measures, thus allowing for more types of crash mitigation strategies (*59*).

2.3.2.5 Bayesian Reconstruction Methods

Crashes are rare events. One approach to analyzing a rare event is to conduct a probabilistic analysis of the factors that contribute to the event.

To appreciate the range of factors involved, consider the following two examples:

1. The occurrence and severity of any given highway-rail grade crossing collision may vary depending on factors such as the occurrence of a train scheduled at a particular place and time and the probability of a truck arriving at the crossing at that same time, combined with some combination of the following factors:
   - Night-time visibility
   - Sunlight reflections
   - Physical obstruction of warning signs
   - Lighting of warning signs
   - Weather conditions
   - Train speed
   - Car or truck driver speed
   - Driver inattention
   - Malfunction of a warning device
   - Extent to which the warning device has given false warnings in the past, leading it to be ignored

   Each of these factors has its own probability, though many are interrelated, or dependent, so the probabilities are not independent.
2. When a grade crossing collision takes place, its economic cost also may vary, though the factors involved are different from those affecting occurrence. These factors may include the following:
   - Type of train involved in the collision
   - Train length
   - Volume and composition of train passengers or cargo
   - Type of road vehicle involved in the collision
   - Size and composition of road vehicle contents—cargo or passengers
   - Severity of damage or injury to equipment, cargo, and people
   - Length of time for resulting road closure or track closure
   - Volume and mix of motor vehicle traffic and trains that are delayed or rerouted because of the collision.

   Each of these factors also has its own distribution of value and probability function, though some of them are also interrelated. Therefore, these probabilities are also not independent.

Because so many uncertainty factors affect grade crossing crashes, their likelihood and economic effects can be estimated through a process by which the combined uncertainty of component factors are estimated. There are generally two ways to address this matter: modeling of uncertainty probabilities using schemes such as Monte Carlo Estimation, or Bayesian Reconstruction (*59*, *60*).

2.3.2.5.1 Bayesian Framework

The Bayesian framework for probability estimation considers knowledge of prior experiences about the occurrence of situations, such as grade crossing collisions, then allows for probability updating as new relevant data emerges. A Bayesian “network” is a means of estimating the joint probability distribution associated with a string of factors, when each factor has a discrete conditional probability dependent on occurrence of other factors.

Davis (*61*) defines Bayesian reconstruction of highway crashes in the following terms: "Traffic accident reconstruction has been defined as the effort to determine, from whatever evidence is available, how an accident happened. . . . Physical principles can usually be used to develop a structural model of the accident and this model, together with an expert assessment of prior uncertainty regarding the accident's initial conditions, can be represented as a Bayesian network. Posterior probabilities for the accident's initial conditions, given evidence collected at the accident scene, can then be computed by updating the Bayesian network."

2.3.2.5.2 Applications of Bayesian Reconstruction

In practice, Bayesian updating has been applied in studies of a wide range of different types of highway collisions and highway/train collisions. Generally, the intent of these studies is to reduce future crashes by improving the identification of risk conditions and specific factors leading to collisions. Conducting these analyses involves reconstructing the conditions present during prior crashes, building the sequence of events, and then identifying the key factors contributing to the event. Yet while the literature has focused on risk prevention, the same basic methods could also hold for further analysis of external factors affecting severity and economic consequences.

Highway collisions are distinguished by whether the location is a road intersection, rail crossing, or freeway link, and whether the vehicles involved are cars, trucks, or trains. Performing separate studies for each type of crash is necessary because each crash type involves a unique set of contributory factors. Across all types of collisions, though, the common element is that the relative roles of contributory factors are identified and estimated though accident reconstruction using Bayesian updating.

2.3.2.5.3 Application to Highway Crashes

Methodological development of Bayesian analysis for road safety has evolved over time (*62*). Many of the more recent empirical studies of road and highway collisions not involving trains have been coauthored by Davis and others at the University of Minnesota Center for Transportation Studies. Recent studies also have been conducted in the United Kingdom. Topics have included:

- median crossing crashes (*63*),
- car speeding and pedestrian intersection injuries (*64*),
- freeway lane-changing accidents (*65*),
- driver inattention accidents (*66*), and
- crash frequency and severity prediction (*67*).

The World Road Association's *Road Safety Manual*, which provides guidelines on accident prediction models, also provides details on the Bayesian method, starting with data on "the random nature of road accidents" and then offering ways to use observations of newer accidents to improve "the accuracy of the estimated potential" (*68*).

In recent years, Bayesian reconstruction has spread worldwide. Work performed in Thailand illustrates a practical application of this method. Using the Bayesian method, analysts examined the relative roles of contributory factors in road crashes—"the linkage between the causes and consequences"—in terms of risk factors such as absence of street lights, inadequate lane marking, and poor visibility (*69*).

2.3.2.5.4 Application to Grade Crossing Crashes

The same Bayesian reconstruction method has been applied to identify factors leading to crashes at road-rail crossings around the world. Again, it is notable that this literature identifies different types of incidents, each with its own unique set of contributory factors. The literature includes:

- highway-rail grade crossings in Canada (*70*), and
- highway-rail grade crossings in the United Kingdom (*71*).

Several extensions of the Bayesian approach are possible beyond crash reconstruction. One is the work by Washington and Oh (*72*) that identified and rated potential crash-reduction factors rather than observed crash causes. Washington and Oh used a stated preference survey of experts (i.e., prospective data) rather than the crash reconstruction (i.e., retrospective data) generally used for observed crash causes. The experts' collective opinions represented factor ratings associated with hypothetical countermeasures, and they were combined with prior knowledge (via classic Bayesian updating) to obtain best estimates of crash modification factors.

Another line of research focuses on applying Bayesian methods to data about detection and simulation of crash conditions for improvement of crossing safety (*73*, *74*, *75*). Together, these various approaches illustrate the usefulness of the Bayesian approach for estimating occurrences and impacts of low-probability events such as grade crossing crashes.

2.3.3 Damages to Railroad Equipment and Infrastructure

FRA's accident database includes estimated damages to rail equipment and infrastructure, and its grade crossing crash database includes estimated damage to the highway vehicle. Thus, it is possible to assemble statistics concerning the damages incurred by the railroads in grade crossing crashes and to conduct studies regarding the factors that determine the extent of damage.

Some references to equipment and track damage can be found in the literature. A study conducted by Arthur D. Little for U.S.DOT (*76*) investigated the risks associated with high-speed passenger trains operating over freight corridors. This study used FRA databases to plot total property damage as a function of speed in 161 reportable grade crossing crashes involving Amtrak. They concluded that "property damage increases as train speed increases . . . [but] the results can be strongly influenced by one or two extreme cases." The most serious accident caused $750,000 of property damage. The 161 reportable accidents in this study were only 15% of the 1,111 grade crossing crashes involving Amtrak.

A study of private-crossing accidents provided some insight into the damages associated with the most severe grade crossing crashes (*77*). The Volpe Center and FRA conducted a series of public meetings to seek comments concerning safety issues related to private crossings. They also compiled detailed information for nine crossing accidents selected to represent varying levels of severity. The total consequences for these nine accidents included 54 injuries, six fatalities, more than $200,000 in damage to the highway vehicles, $91,000 in damage to railroad infrastructure, and $1.3 million in damages to rail equipment. As with the Arthur D. Little study, the consequences were highly variable. A single crash involving an Amtrak train accounted for the majority of the total damage to railroads: $875,000 of the rail equipment damage and $75,000 for track.

Although few studies have been done, the data are certainly available to support more studies of property damage. Table A-12 and Table A-13 illustrate the kinds of analysis that are possible using FRA databases. The tables show statistics for grade crossing crashes for a Class I North American freight railroad in 2010 and include a few crashes in which trains hit vehicles that were not at grade crossings.

The grade crossing crash database can be used to obtain an estimate of the casualty rates and damages to the highway vehicle, as shown in Table A-12. The grade crossing crash database also can be used to obtain estimates from crashes that have significant property damage. By selecting data from both tables, it is possible to obtain additional useful information, as suggested by Table A-13, which shows that the average railroad damage from reportable grade crossing crashes was about $50,000 for this railroad in 2010. Table A-13 also shows that fewer than half of these reportable crashes resulted in damage to track, while more than half of the reportable crashes involved large trucks. Because the FRA databases have very detailed information concerning the time of day, train speed, accident causes, and many other factors, considerable research could be done to calibrate models of the damages resulting from grade crossing crashes.

While it is possible to be specific or general in selecting crashes from the databases, for this study the data were selected from one Class I railroad to simplify the illustrative analysis. Research could easily include data from the entire industry.

Table A-12. Freight railroad grade crossing crashes in 2010 for a Class I railroad.

Description	Value
Total number of grade crossing crashes	323
Average fatalities per crash	0.096
Average injuries per crash	0.372
Average highway vehicle damage	$5,200

Source: (*52*).

Table A-13. Grade crossing crashes with reportable property damage in 2010 for a Class I railroad.

	All Crashes	Freight Train Crashes	Passenger Train Crashes
Number of reportable grade crossing crashes	22	10	12
Percent of total crashes that are reportable	6.8%		
Average equipment damage (One Class I)	$35,161	$77,354	N.A.
Average track damage	$8,402	$11,520	$5,804
Average other damage (passenger equipment)	$7,080	$0	$13,386
Average total damage	$50,643	$88,874	$18,075
Fatal crashes	5	0	5
Fatalities	7	0	7
Injuries	13	6	7
Crashes with damage to track	10	5	5
Average fatalities per crash	0.318	0.000	0.583
Average injuries per crash	0.591	0.600	0.583
Percent of reportable crashes with track damage	45%	50%	42%
Percent of reportable crashes involving large trucks	45%	60%	33%

Source: (*52*).

2.3.3.1 Analyses Supporting FRA Rulemaking

The analyses FRA prepares in support of proposed rules make up a potential source of information in support of a comprehensive grade crossing crash cost framework.

One function of FRA is to propose regulations that promote safety, both on its own initiative as part of the agency's mandate and as required by specific legislation. As part of the regulatory process, when the agency proposes a new rule or regulation it must also demonstrate through analysis that the projected benefits of the regulation exceed its cost. Also, FRA must show that no specific group of individuals or entities—in this case, small railroads—will be unduly burdened by the proposed rule (referred to as a burden analysis).

In 2011, FRA's Office of Safety Analysis prepared an analysis of benefits and costs for the Notice of Proposed Rulemaking for Emergency Notification System (*78*). This proposed rule will require railroads of a certain size to post signs at grade crossings with a toll-free phone number that highway users and pedestrians can call to notify the railroad in the event of failing grade crossing equipment or grade crossing blockages, such as stuck or trapped vehicles on the railroad tracks. Under the proposed rule, railroads will be required to post signage and set up and maintain the toll-free services.

FRA's analysis identified the affected grade crossings by railroad size classes and then calculated the crash damages from 1999 to 2009 for only those crashes that would have been affected by the proposed rule. That is, the analysis included only crashes where a train collided with a vehicle that was stalled or stopped on the tracks.

The analysis makes excellent use of the available data for its purpose. Given the narrow scope of the crashes considered, however, the findings are of limited usefulness for a comprehensive crash cost estimation framework.

2.3.3.2 AASHTO HiSafe Software

HiSafe Software (*79*) is companion software to Part C of the AASHTO *Highway Safety Manual*. The software includes capabilities for analyzing safety-improvement projects on rural two-lane roads, rural multilane highways, and urban or suburban arterial highways. It also includes the ability to consider safety projects for a number of intersection alternatives.

The software has a number of interesting features, and the methodologies for crash prediction that are implemented in the software are sophisticated; however, the software contains no capability for analysis of the safety impacts of highway-rail grade crossings.

2.3.4 Effects of Delay and Supply Chain Impacts from Grade Crossing Crashes

Current crash cost estimation methodology focuses on the direct effects of the crash (i.e., the damages associated with loss of life, injury, and property damage). When grade crossing crashes cause delays that disrupt freight flows, however, their secondary effects also extend to the business supply chain.

Supply chain analyses can be classified into two categories of relevance for grade crossing crash costs: the impacts of reliability, uncertainty, congestion, and delay on supply chain costs (*80*, *81*, *82*, *83*), and the impacts of costs associated with highway and railroad closures (*84*, *85*, *86*). Business supply chains are critical lifelines that transport goods to customers, retailers, and manufacturing locations. Business practices have focused on optimizing the logistics process to reduce operating costs through more frequent service and lower inventory levels. As a result, businesses depend more on planned schedules and tight delivery windows to sustain goods movement in the production and delivery processes. With disruptions a looming threat, some businesses have developed contingency plans or reactionary adjustments to address delays and other delivery challenges.

Grade crossing crashes are but one potential disrupter of business supply chains. The relevant literature for gauging the effects of grade crossing crashes on business supply chains includes studies that quantify the effects of supply chain disruptions from all causes, not just grade crossing crashes. This report seeks to infer from the studied effects of supply chain disruptions the effect costs associated with grade crossing crashes.

The primary elements of supply chain operations affected by grade crossing crashes include the following:

- Rerouting costs
- Lost sales
- Prevention costs
- Inventory spoilage
- Freight and passenger delays
- Freight and passenger reliability
  - Freight: Warehouse or distribution center rescheduling and cross-docking operations
  - Passengers: Commuting
- Increased inventory

Crash reports do not consider information related to supply chain disruption, but the impact of grade crossing crashes on the supply chain can be extrapolated from data about road closures in any transportation network.

2.3.4.1 Closure Events

Catastrophic events such as severe weather conditions or natural disasters directly impact transportation networks, often suddenly and unpredictably, and can therefore approximate the supply chain effects of grade crossing crashes. Several existing studies provide an outline of a methodology for estimating the economic effects of delay and supply chain disruptions due to a highway closure. The three studies reviewed in NCHRP Project 08-85 provide the bulk of information related to the effects of highway disruptions on supply chains. The studies also illustrate that supply chain impacts are regional in nature and reflect the usage of particular roadways.

2.3.4.1.1 Storm-Related Closures of I-5 and 1-90

The Washington State Department of Transportation (Washington State DOT) conducted a study on storm-related closures of I-5 and 1-90 in response to media inquiries about how much the disruptions cost the state. I-5 was closed for 4 days because of excessive flooding in the region, and I-90 was closed for 5 days because of an avalanche in Snoqualmie Pass (*84*).

The Washington State DOT report estimated the following:

- Rerouting for alternative routes to go around the closed highways cost $800 to $850 per hour, and on average required 8.5 hours to complete the detour.
- Lost sales applied to both businesses and the carriers. Freight carriers were estimated to lose 0.51% of revenues (0.32% for an in-house fleet). Businesses dependent on freight services were estimated to lose 0.05% of revenues, and all other sectors, 0.01% of revenues, or $5k for a $50M sales company.
- Prevention costs to provide carriers with information to find alternative routes or to mitigate the effects of delay were mentioned, but no specific cost was cited.

2.3.4.1.2 Confusion Hill

This study focused on the economic effects of reoccurring landslides around Confusion Hill on US-101 in California’s Northern Mendocino County (*85*). The landslides usually caused 2 to 3 days of full-road closure or 2 to 3 months of one-lane closures. In 2003, the year the study was released, landslides accounted for 10 full-road closures.

The report estimated the following:

- Rerouting trucks and cars along an alternative route cost $238,000 per day in terms of travel delay and vehicle operating costs

- Lost sales were around 25% in the tourism industry, which equated to $13 million per month in tourism-related sales

Because of the frequency of landslides and the recurring need to reroute traffic, plans were being made to develop a new highway that provided a more reliable connection so traffic could bypass the landslide area.

2.3.4.1.3 An Investigation of User Costs and Benefits of Winter Road Closures

This study evaluated information from several different states and interviewed a variety of trucking companies to estimate the costs they incur as a result of highway road closures (*86*). The study did not focus on a particular event, but gathered estimates from other studies as well as the results from surveys conducted by the Midwest Transportation Consortium.

The study concluded that an unexpected delay is much more costly than an expected delay, that the cost of delay is greater for freight than for travelers, and that the cost is greatest for perishable goods. Freight delay was estimated at $144-to-$192 per hour. Late schedule delays, which affect freight reliability, were estimated at $371 per hour (*84*). Impacts on commuting routes were estimated at a median value of time for passenger delays of $20 per hour and for passenger reliability of $19 per hour (*84)*. The study did not estimate costs for inventory spoilage.

The study included interviews with several freight carriers and, based on the responses from one company, the authors concluded the following:

- Rerouting cost from $575 to $600 per truck per day. (Another trucking company interviewed similarly responded that rerouting cost the company $600 to $700 per truck per day and added 5 to 6 hours to each of its transportation employees' schedules to cope with the situation.)
- Lost sales and lost productivity were estimated to cost freight-dependent customers an overage of $600 per late shipment. (Another figure, provided in a study conducted by the Salt Institute and included in the report, estimated that it would cost Iowa $60 million dollars per day if all transportation ceased for one day due to a heavy storm.)

An article regarding a major highway-rail grade crossing collision between a tractor-trailer and Amtrak's *California Zephyr* passenger train provides insights into the secondary effects of the crash (*87*). According to the U.S.DOT crossing inventory, the crossing handles 14 Union Pacific freight trains per day, all of which had to be rerouted because the track was unavailable for passage. NTSB also indicated that their investigators were expected to stay at the scene of the crash for 7 to 10 days. Additionally, the highway remained closed in the area surrounding the crossing for at least 1 day following the crash.

2.3.4.2 Effects of Closure

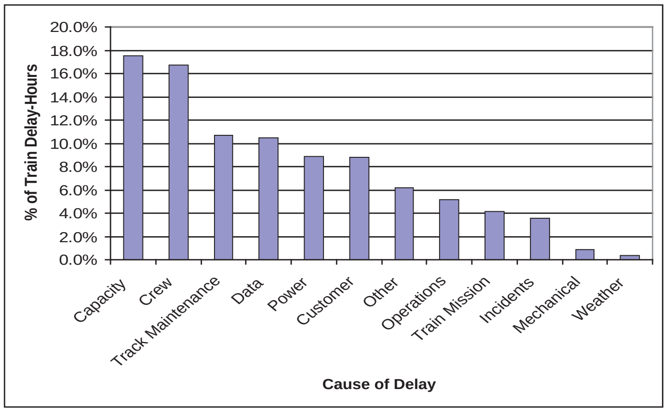
2.3.4.2.1 Duration and Process for Full Service Restoration

Grade crossing crashes can disrupt highway and rail operations. Treating casualties and clearing the track can take many hours, delaying not only trains but also motorists who must wait or detour to other routes. The busier the road—and the more trains on the impacted rail line—the greater the disruptions to both rail and highway travel. FRA databases do not indicate line disruption, its duration, or the extent of the resulting delays to trains or motorists. To supplement the FRA data, Amtrak and its host railroads provide the needed information.

These entities maintain detailed statistics on all train delays; grade crossing crashes are listed within the "trespasser category," the second largest category attributed to third parties, which are organizations other than the host railroad or Amtrak. In the last quarter of 2010, trespasser delays accounted for about 1.5% of total delays to Amtrak trains.

Because Amtrak trains have the highest priority when operating on lines owned by other railroads, Amtrak's data on train delays provide the requisite documentation for the average delay to trains involved in grade crossing crashes. Railroad dispatching centers maintain detailed records of line movements, so it is conceivable that their records could support detailed analysis of all train delays related to a grade crossing crash. However, they do not ordinarily conduct such analyses. Instead, they may maintain summaries of train delays by type of train, region, and type of delay. Figure A-2 shows how one Class I railroad summarizes train delay. In Figure A-2, grade crossing crashes are part of the "incidents" category, which accounted for 3.5% of total train delay during the period shown.

September 1, 2005, to August 31, 2006



Source: (*88*).

Figure A-2. Causes of total train delay on one Class I railroad.

It is possible for railroads to measure and analyze the extent and effects of line blockages that result from grade crossing crashes. For example, East Japan Railways includes the line blockage time in its accident reports and uses this information to calibrate models that estimate the delay to trains and to passengers (*89*).

The North American railroads have developed models to estimate the impacts of line blockages on train performance. At a very detailed level, simulation models can show how a line blockage of any length at any location would affect train service on a specific line. Simulation models can also be executed for an extended time period to estimate the effects of scheduled and unscheduled line blockages (*90*). The execution of these models supports an evaluation of investments or operating strategies aimed at improving train performance.

Analytical models can also estimate the extent of train delay resulting from a line blockage. One approach assumes that trains operate at uniform intervals throughout the day, allowing the use of deterministic queuing models to estimate the extent of delay. The time required to recover from a disruption depends on the duration of the disruption and the level of utilization of the line. For example, a 1-hour disruption when the average utilization is 60% can create a backlog of 0.6 hours by the end of the disruption. By using the 40% excess processing capabilities (100% – 60% = 40%) to assist in alleviating the backlog, 1.5 hours is sufficient time to eliminate a 0.6-hour backlog. As the average level of utilization increases, the time required to alleviate the backlog also increases. If the level is 90%, then only 0.1 hour of processing per hour is available to assist, so a 1-hour disruption requires an additional 9 hours for recovery.

The TRACS model developed by the MIT Rail group incorporated a deterministic queuing model to investigate the costs of track rehabilitation and maintenance. This model demonstrates the relevance of train delay because delay costs often exceeds the maintenance-of-way (MOW) cost for minor repairs. For example, cutting out a broken rail requires several hours and MOW cost of about $2,000. On a busy freight line, a 3-hour delay can affect half a dozen freight trains. The total train delay can easily exceed 10 hours, and the average cost per hour of train delay can exceed $250 per hour, using the hourly rate for rentals of $50 to $100 per locomotive-hour and $0.50 to $1.00 per car-hour. The same analysis used to estimate train delays resulting from MOW work can also be used to estimate delays related to grade crossing crashes.

2.3.4.3 A Model of Supply Chain Costs

The costs associated with disruption of the supply chain can be calculated with the following general model of logistics costs, adapted to disruptions that occur because of grade crossing crashes.

Consider a crash of a given severity that occurs at a grade crossing. All sorts of different costs are associated with such a crash, but the focus here is the supply chain and logistics costs. The costs can be divided into primary and secondary categories. Primary costs are increases to the supply chain costs of goods moving or scheduled to move on the link on which there is a disruption; these goods have to be diverted or simply wait until the link is reopened. The secondary costs are the costs incurred by all other goods moving by rail on adjacent or substitute links/routes. Both primary and secondary costs will increase, however slightly, since a link is out of operation and trains and their cargo must use these substitute links and routes.

Other logistics costs exist. These costs also may be primary or secondary, and these costs can differ by commodity type and shipment characteristics. For example, some goods may require special equipment for reloading because of their density, affecting time and cost. A range of commodities must be moved in special cars (e.g., grain, coal, and liquids under pressure), and shippers often supply specialized cars. Any delay affecting these cars affects the cycle times of moving the commodity from its source (e.g., coal from a mine) to its destination (e.g., a port or power plant). The shipper facing delays on an upcoming shipment incurs direct costs, and the underutilization of other modes incurs downstream costs (e.g., a ship waiting for coal or grain would incur demurrage charges on the contracting shipper).

One approach to developing measures of costs in the supply chain with disruptions is to consider a total logistics cost (TLC) function. There will be two broad categories—transportation costs and inventory costs—and the standard cost function that integrates both of these costs can be written as:

$$TLC\ (Q, r : T, ST) = RD_i + (UCTD_i/365) + (SD_i/Q) + (QCI/2) + rIC + K(D_i/Q)\ N(Z)S\mathit{1}$$

where:

TLC = Total logistics cost

R = Transportation rate per unit between origin and destination

D = Annual demand for some good, “*i*”

U = Carrying cost of in-transit inventory

C = Value per unit

T = Transit time of transportation alternative

S = Fixed ordering cost per order

Q = Order quantity

I = Carrying cost of warehoused inventory

r = Safety stock

K = Stockout cost per unit

N(Z) = Unit loss integral

S*1* = Standard deviation of demand during transit time

ST = Standard deviation of demand during lead time

Figure A-3 illustrates the subcomponents of the transportation costs and inventory costs. These categories indicate that the two key left-side (dependent) variables in any investigation of supply chain disruption are the amount of delay and the extent of its effect on dependability of scheduled delivery.

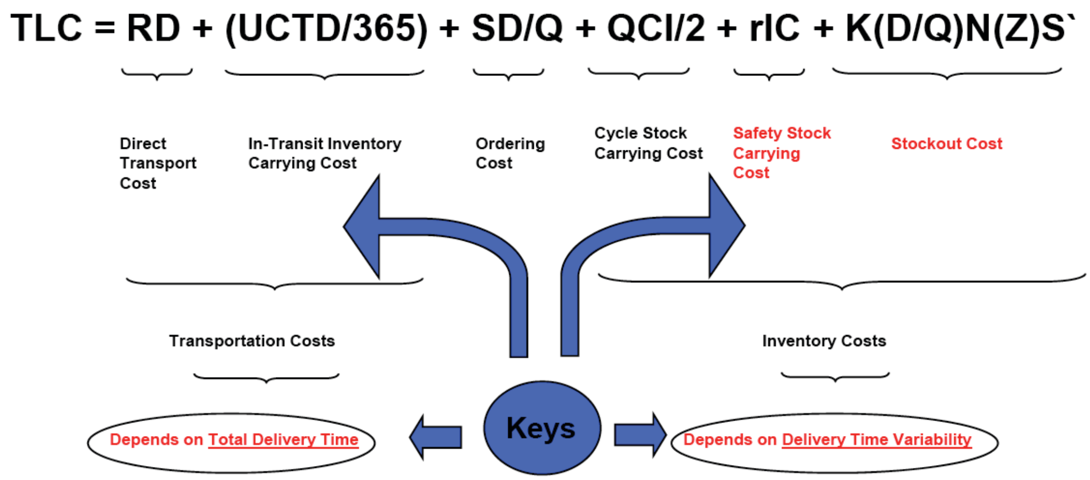


Figure A-3. Total logistics cost model.

TLC behaves in the following ways:

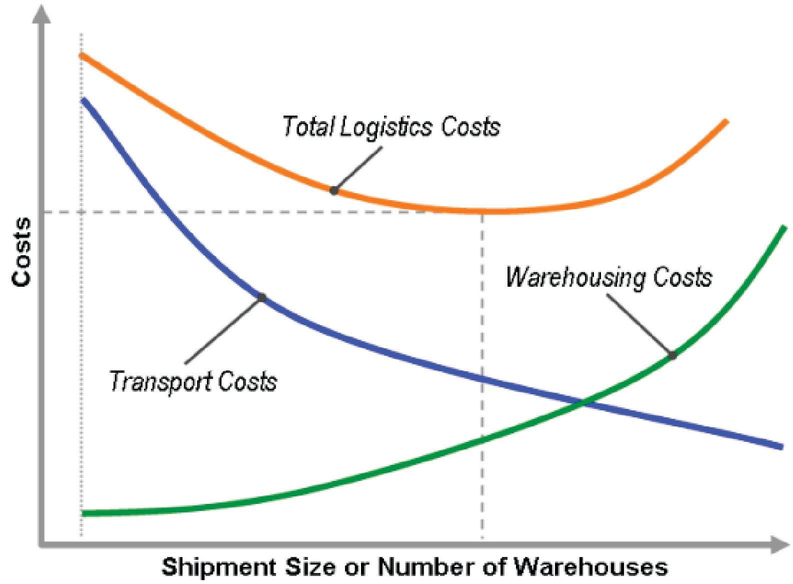
- Increased delay—increases cost of shipping with time in transit and tie-up of capital
- Increased inventory costs—increases direct inventory costs to downstream buyers
- Increased indirect costs from increasing the risk (variability) of supply chain—increases use of resources to reduce risk, and reduces value of supply chain
- Increased costs—reduces responsiveness to markets.

These costs will differ across commodity and shipment characteristics that include the following:

- Origin and destination
- Shipment size
- Annual volume
- Demand per time period
- Unit value
- Required service level (product availability)
- Density
- Perishability (shelf life)
- Fragility
- Packaging and handling characteristics
- Stockout cost.

2.3.4.3.1 Tradeoffs in Transportation and Logistics Costs

It is useful to take the TLC function and illustrate how the component functions might shift with a crash. The basic tradeoff between the two broad components, transportation and inventory costs, is plotted against shipment size/number of warehouses in Figure A-4. Intuitively, one would expect that a crash would increase transport cost, but the impact on TLC actually would show a relative decrease as number of warehouses increases. However, even though unit transport costs decrease with shipment size, aggregate costs will increase, because larger amounts of capital are tied up for a longer period.



Source: Rodrigue, J.-P. et al. (2013), The Geography of Transport Systems. Hofstra University. Department of Global Studies & Geography. http://people.hofstra.edu/geotrans.

Figure A-4. Total logistics costs and tradeoffs.

To better understand the cost tradeoffs, combinations of transportation modes (e.g., rail, truck, and air) can be examined in terms of two key characteristics: speed and reliability. The implicit assumption is that the longer the travel time is, the higher the probability of delay will be. This is not a measure of absolute reliability, which would measure on-time delivery performance for a given mode. A grade crossing crash has several effects:

1. It increases the cost of transportation service; the function shifts up asymmetrically when only rail mode is affected.
2. It makes truck (and perhaps air) transportation more desirable as substitutes.
3. It may increase inventory costs if reliability declines sufficiently that downstream buyers must hold higher safety stock in inventory.

Various other cost considerations arise in the supply chain and would be affected in different ways given grade crossing crash. A crash would reduce customer and transportation service; increase cost of transportation, order processing, and inventory; and increase the total logistics cost (TLC).

The number of stocking points (e.g., warehouses or manufacturing plants, or stockpiles in the case of commodities) is important. The higher the number of stocking points, the lower the costs of a crash. Given that alternative supply routes exist for the delayed product on the train, downstream costs will be mitigated. However, increasing stocking points is costly, requiring more capital and labor. Taking a longer-run view, if grade crossing crashes decline, or their severity declines, it maybe a signal that fewer stocking points are needed to meet a given level of customer service. Therefore, in considering the impact of grade crossing crash effects, a short/intermediate-run view will differ from a longer-run view.

A crash also would affect inventory carrying costs. For a given level of service, average inventory levels would have to go up; TLC would therefore increase. The nature of the product is important in assessing costs of supply train disruptions; commodities would be less affected than consumer durables or perishable products.

Upstream activities also can affect the costs of a grade crossing crash. Generally, scale economies or economies of production runs reduce costs, except that inventory costs increase because there is more to store. This is true for multiple products. A crash that creates delays can increase costs (because delays may reduce the opportunity to take advantage of scale economies) or decrease costs (because with less reliable delivery more inventory is held, and hence production economies improve).

The importance of the upstream impacts of delay is seen in Figure A-5. A reduction in transportation costs means the range of sourcing for supply increases and lower factor prices may be available. The corollary also is true: increasing transportation costs may have the effect of sourcing factors of production (e.g., raw materials) closer to production facilities to ensure reliability. Lower transport costs can reduce overall production costs by consolidating plants; this is a long-run perspective. If delays from crashes are less certain, an opportunity cost is the forgone lower production costs that could have materialized through consolidation.

Infrastructure Benefit	Supply Chain Impact	Supply Chain Benefit Expressed as % of Operating Costs
10% transport cost reduction	Lower material cost by substituting farther, cheaper sources	0.11%
	Consolidate plants due to extended reach	0.24%
	Switch modes and reduce shipment size, decreasing inventory	0.11%
		0.46%
10% capacity increase	Reduce safety stock	0.08%
	Rationalize fleet and warehouse assets	0.06%
		0.14%
10% better in-transit visibility	Gain postponement benefits (cost side only)	0.4%
		0.4%
Secondary effects (Revenue benefits)	Increase service levels	Not quantified
	Convert cost savings to price reductions	Not quantified
	Implement on-demand supply chains	Not quantified
		1.00%

Source: Reproduced by permission, (*91*).

Figure A-5. Supply chain benefits.

2.3.4.3.2 Summary of the Supply Chain Cost Model

The impact on the supply chain of a grade crossing crash occurs in many ways and through many channels. The value of this detailed analysis is to understand the relationships, what may be more important, and where one might look to collect data. The two broad categories of transport and inventory costs can be summarized as delay costs and costs of reliability; therefore, the key variables to measure, taking account of the range of product on the train, would be

- length of delay,
- cost of invested capital,
- inventory cost increase to meet level of service required and increase in safety stock given stock-cycle-carrying and stockout costs, and
- increased shipper costs due to delays and reduction in productivity of invested capital, for example, specialized cars.

2.3.5 Costs of Rare Catastrophic Crashes

Rare catastrophic crashes at grade crossings can be categorized as one of three main types:

1. Multiple fatalities on the highway mode (e.g., a train striking a loaded bus).
2. Multiple fatalities and severe damage on the rail mode (e.g., a passenger train striking a heavy truck, causing severe derailment).
3. Multiple fatalities from the release of poisonous or toxic inhalants (PIH/TIH) (e.g., a crash causing tankers carrying PIH/TIH to severely derail in a populated area. Nothing like this has occurred at a U.S. grade crossing crash, but—as in the 2005 Graniteville, SC, crash that resulted in nine fatalities—there is an extremely small probability it could occur).

In a costing framework four approaches can be used for dealing with these types of events:

1. **Disregard Very Small Risks Approach.** Assume that events with a probability below a certain threshold (say, 10^{-9}) are of no significance or tantamount to statistical noise and, therefore, should be disregarded.
2. **Mitigation/Abatement Approach.** Quantify the costs of catastrophic crashes. Declare these to be worst-case scenarios and consider measures to mitigate the relative risk of occurrence or its cost, say, reduce costs of predicted catastrophic crashes in half, and consider the mitigation cost as the relevant crash cost component.
3. **Best Guess Approach.** Calculate the cost of catastrophic crashes as the projected costs of such crashes, a very large number, times their probability of occurrence, a very small number, and add this amount to the aggregate cost of crashes at a grade crossing.
4. **Weighted Best Guess Approach.** See section 3.3.1.5.1 for a discussion of weighting catastrophic events.

Each approach has pros and cons and each has been used in costing hard-to-cost components of transportation projects.

3 Survey of Current Practices

3.1 Introduction

3.1.1 Plan of the Survey of Current Practices

The survey of current practices contains two principal sections following this introduction: general practices and selected studies and analyses.

3.1.1.1 General Practices

The general practices section reviews whether and how to assign costs to grade crossing crashes in the related work of states and MPOs.

3.1.1.2 Selected Studies and Analyses

The review of selected studies examines the treatment of grade crossing crash costs in those studies. The section concludes with an extensive review of a major study of all the risks affecting railway operations that was conducted by the Massachusetts Institute of Technology (MIT) for East Japan Railways (*108, 109, 110, 111*).

3.2 General Practice

3.2.1 Grade Crossing Crash Costs in Planning and Prioritization

In general, state and local authority involvement in assessing grade crossing improvements consists of three activities:

1. Preparing state rail plans
2. Selecting and prioritizing projects for Section 130 funding
3. MPO activities for local improvements

In these activities, some states rely on measures of *delay* due to crashes, the number of crashes, or occasionally, the severity of crashes, rather than relying on crash costs. Examples of states that use *crash costs* are Illinois and Iowa (as part of their Section 130 funding selection) and California (in its Cal-B/C benefit-cost model). The derivation of the Illinois costs is not fully documented, but the grade crossing crash costs for all three states appear to be adapted from standard highway crash costs using assumptions.

Florida has developed a freight rail investment analysis tool that values highway safety benefits. However, the tool uses an average cost of safety per mile not specific to grade crossings. The North Carolina DOT makes use of GradeDec.Net in its planning of grade crossing improvements. FRA's web-based GradeDec.Net supports grade crossing safety- and benefit-cost analysis on a regional and corridor basis (*59*). Several MPOs use crash cost and severity measures in conjunction with GradeDec.Net.

3.2.1.1 State Rail Plans

States produce periodic state rail plans to guide the development of their passenger and freight rail systems. For example, the California DOT (Caltrans) prepares the California State Rail Plan every 2 years in accordance with Section 14036 of the California Government Code. The federal government added incentives for states to prepare state rail plans as part of the Passenger Rail Improvement and Investment Act of 2008 (PRIIA). Although the federal government had previously authorized funding to improve safety at public grade crossings through Section 130 as early as the 1973 Highway Act, PRIIA established two new federal rail programs: the Capital Assistance to States–Intercity Passenger Rail Service Program and the High-Speed Intercity Passenger Rail Program (HSIPR), and also authorized the appropriation of funding for congestion relief. Without an approved comprehensive state rail plan, state rail projects do not qualify for this federal funding.

Section 303 of PRIIA establishes three primary goals for a state rail plan:

1. To set policy involving freight, passenger, and commuter rail transportation in the state
2. To present priorities and strategies to enhance rail service and benefit the public
3. To serve as the basis for federal and state rail investments within the state

Section 303 also lists elements that must be part of a state rail plan, including the following:

- a description of the public and private benefits of rail capital projects to be undertaken by the state;
- a list of freight and intercity passenger rail capital projects that consider effects on safety, among other issues; and
- a review of publicly funded projects within the state to improve rail transportation safety and security, including all major projects funded under 23 U.S.C. § 130.

In addition to these items, many state rail plans also discuss involvement in the Operation Lifesaver program through which railroads provide grade crossing safety education to local communities.

The federal guidelines for PRIIA-compliant state rail plans are new. A Preliminary National Rail Plan (PNRP) delivered to Congress on October 16, 2009, contained preliminary guidelines for state rail plans. The National Rail Plan Progress Report published in September 2010 did not contain final guidance for state rail plans. FRA subsequently instructed states to prepare state rail plans per the guidelines contained in the PNRP. Although most states have not yet completed new state rail plans that meet the guidelines, California, Michigan, and New York have.

3.2.1.1.1 California

Caltrans prepares a 10-year state rail plan that it updates every 2 years. The latest available California State Rail Plan is the 2007–08 to 2017–18 State Rail Plan, published in March 2008 (*92*). California delayed preparation of the 2009–10 to 2019–20 rail plan pending new federal guidelines from the National Rail Plan. The most recent state rail plan discusses the various funding programs available for funding highway-rail crossing improvements (federal Section 130, California Section 190 and Proposition 1B).

The plan notes that accident history is a factor in project selection but does not reference crash costs. In the section on public benefits, the plan notes that private infrastructure investment reduces congestion, improves safety, reduces freight delays, and reduces shipper costs among other benefits, but it does not quantify crash costs. The plan also references the final report of NCHRP Project 8-36, Task 43, “Return on Investment on Freight Rail Capacity Improvements,” which has a table on case studies that quantify benefits of investing in freight rail.

3.2.1.1.2 Michigan

The most recent Michigan state rail plan (a public review draft dated May 23, 2011) includes a recommended program of priority improvements over the next 20 years (*93*). One goal listed in the plan is to promote rail and highway safety by improving grade crossing surfaces and warning devices and by pursuing road closures and grade separations where appropriate. The plan does not provide a monetized value of safety improvements, although it categorizes projects into “Good,” “Better,” and “Best” investment scenarios given passenger, freight, environmental, and other benefits.

3.2.1.1.3 New York

In June 2009, New York State prepared a draft 20-year state rail plan to meet PRIIA rail planning. The New York State Rail Plan 2009—Strategies for a New Age is the first state rail plan prepared in more than 22 years for New York State (*94*). Goals for the rail system include safety improvements that reduce delays, increase speed, improve reliability and safety, and create increased market demand for passenger rail service. The New York State Rail Plan includes a chapter on rail safety and security that addresses rail safety in three major focus areas: (1) grade crossing safety, (2) rail safety inspections, and (3) Public Transportation Safety Board (PTSB) rail safety activities. The plan does not include an estimate of crash costs. Instead, the rail safety and security chapter discusses funding needs and cost-sharing.

3.2.1.2 Section 130 Funding

Section 130 authorizes the Railway-Highways Crossings Program, a categorical funding program established as part of the Highway Safety Act of 1973. The program provides funding for grade crossing improvement projects that reduce the number and severity of highway crashes by eliminating hazards to vehicles and pedestrians at existing railroad crossings. Under the program, railroad-highway safety projects receive federal funds for up to 90% of total project costs when state or local funds match at least 10% of costs. Activities eligible for Section 130 safety funds include separation or protection of grades at crossings, reconstruction of existing railroad grade crossing structures, relocation of highways to eliminate grade crossings, elimination of hazards and the installation of protective devices at highway-rail crossings, permanent closure of at-grade crossings, and projects to address bicycle safety.

States are free to develop their own methods for measuring safety hazards and for selecting grade crossings and projects to include on their statewide lists. As a result, different formulas are in use for prioritizing highway-rail grade crossings. In general, the methods fall into two categories: hazard indices and crash prediction formulas. Hazard indices rank crossings relative to other crossings using scales of expected crashes or casualties. Crash prediction formulas estimate the absolute number of crashes or casualties for each crossing.

The hazard indices and crash prediction formulas involve the same basic elements, selected in combinations based on the needs of each particular state. These elements include vehicular traffic volume, train volume, a protection factor for crossing controls, frequency of trains, speeds of vehicular and train traffic, number of tracks, type of highway surface, and number of highway travel lanes.

Most methods do not explicitly consider the costs of grade crossing crashes. However, Illinois and Iowa have attempted to include these costs, and California has incorporated grade crossing crash costs in its benefit-cost model (although not for Section 130 project ranking or selection).

The FHWA *Railroad-Highway Grade Crossing Handbook, Revised Second Edition* (*95*) describes several of the accident prediction or hazard index formulas, including the New Hampshire Hazard Index, the U.S.DOT Accident Prediction and Severity (APS) Model, and the accident prediction formula from NCHRP Report 50 (*98*).

The **New Hampshire Hazard Index** (*96*) is a commonly used hazard index calculated using the annual average vehicular traffic, the average daily train traffic, and a protection factor based on the type of traffic-control devices that exist at the railroad-highway crossing. The New Hampshire Index provides an overview of current practice for ranking crossings and calculating exposure. The index is used by New Hampshire, Michigan, and Kansas.

The **FRA Web Accident Prediction System (WBAPS)** (*97*) is a web-based model accessible through the FRA website. WBAPS is intended to alert law enforcement and local officials of the need to improve safety at particular highway-rail crossings. The WBAPS crash prediction formula is based on two independent variables that include basic data about a crossing's physical and operating characteristics along with 5 years of crash history data at the crossing. The data for WBAPS comes from the FRA safety database.

Although WBAPS should not be used to predict collisions at the most dangerous crossings, the system can provide an indication of when a crossing may be more hazardous than others based on data available. FRA intends WBAPS to be one of many tools, including accident prediction or hazard index formulas, which assist states, railroads, and local highway authorities in determining where to focus attention for improving safety. California's benefit-cost model is capable of using WBAPS estimates when evaluating grade separation projects.

The U.S.DOT model has additional equations to predict accident severity for fatalities and injuries (*97*). If a crash occurs, the probability of a fatality depends on factors such as the maximum timetable train speed, through trains per day, switch trains per day, whether the location is an urban or rural crossing, and a formula constant. Similarly, if a crash occurs, the probability of an injury crash depends on the maximum timetable train speed, the number of tracks, whether the location is an urban or rural crossing, and a formula constant.

According to the New York State Rail Plan, at least 20 states (including California, New Mexico, North Carolina, and Virginia) use the U.S.DOT APS Model as part of an in-depth review to prioritize crossing improvements for the Section 130 program. Diagnostic reviews are more detailed, with additional rail-highway crossing data from the field and other available sources to help prioritize the projects.

The **NCHRP Report 50 Accident Prediction Formula** was the precursor to many of the hazard index and crash prediction formulas that states use (*98*). Released in 1968, NCHRP Report 50 introduced this accident prediction model, which is similar to the New Hampshire Hazard Index. The NCHRP Report 50 formula estimates and utilizes train and vehicular traffic and a constant, based on the type of warning device in place.

The **Connecticut Hazard Index** uses a 10-year crash history, vehicular traffic and train volumes, and a protection factor for the different types of crossing control. The index does not estimate crash costs (*99*).

The **Missouri Exposure Index** formula uses the following factors: number and speed of vehicles, number of passenger and freight trains, speed of passenger and freight trains, switching movements, and required and actual sight distance (*99*). Missouri's Exposure Index formula is different for passive and active crossing protection.

In contrast with the methods described so far, the following formulas address the cost of crashes.

The **Illinois Expected Accident Frequency Formula** uses a non-linear regression analysis procedure. Estimates are based on a 10-year crash history, average daily traffic, the number of trains per day, the maximum timetable speed, the number of main and other tracks, the number of highway lanes, the average number of crashes per year, and a warning-devices factor to compute the expected crash frequency. Illinois also estimates benefit-cost ratios for the installation of warning devices at railroad crossings. The user benefits are calculated using NSC estimates of the value of fatalities and injuries per crash, while the cost reflects the device installation and maintenance cost. The Illinois Bureau of Design and Environmental Manual does not cite which NSC estimates are used, but presumably they are the same as those used for highway projects.

Iowa Benefit-Cost Calculations are used to evaluate Section 130 projects (*100*). Beginning in 2006, the Iowa DOT has ranked projects by an exposure index with a benefit-cost calculation, affecting projects with construction starting in 2008. Iowa DOT favored this approach because it distinguished among projects by cost of improvements and severity of crashes at the crossing. Before the change, Iowa DOT gave top priority to projects with a predicted-accident calculation above a certain threshold. The change resulted from a 2006 Iowa DOT review of its procedure for selecting Section 130 projects.

The benefit-cost calculation starts with predicting the number of crashes at a crossing using procedures adapted from GradeDec.Net (*58*). The method takes into account train traffic, AADT counts, time-of-day factors, train-movement factors, roadway and crossing characteristics, and the type of crossing protection. Once the number of crashes is predicted, the method estimates the severity of crashes based on a breakdown by number of fatalities, injuries, and property damage, using procedures adapted from GradeDec.Net.

Iowa DOT adapted its methodology for estimating damage from highway crashes to its estimates for highway grade crashes. It estimates the net societal benefit after applying an effectiveness factor that takes into account the reduction in crashes that are due to the improvement.

To adapt highway crash costs to highway-rail grade crossings, Iowa DOT estimates the numbers of fatal and injury events per type of accident using FRA safety data for Iowa from 1977 to 2004 and calculates a total societal cost for each type of crash. The grade crossing methodology uses the same $1.0 million per fatality value for highway-rail grade crossing crashes that it does for highway crashes. But Iowa DOT assumes that highway-rail crashes are more severe than typical highway crashes and uses twice the typical rate for highway injuries—2 X $160,000 per injury = $320,000 per injury. Property damage in a highway-rail crash is assumed to involve only a single highway vehicle, in contrast to multiple vehicles in a highway crash, but damage is expected to be more severe. Iowa DOT assumes these two factors balance and uses the same property damage rate as it does for a highway intersection crash, which is $26,000 per crash.

The **Cal-B/C Model** is part of a framework that Caltrans uses to conduct benefit-cost assessments of transportation projects (*101*). The framework includes three models that address project-level, corridor-level, and network-level analysis. The project-level tool, Cal-B/C, is a spreadsheet application for assessing a variety of projects across modes. In 2008, the Cal-B/C model was modified to support the analysis of grade separation projects at highway-rail grade crossings for the new $250 million Proposition 1B Highway-Rail Crossing Safety Program. Since its modification, Caltrans has used Cal-B/C to evaluate grade separation projects for the Transportation Investment Generating Economic Recovery (TIGER) Discretionary Grant Program and the TIGER II Discretionary Grant Program. It is expected to be used for future assessments of projects under the State Transportation Improvement Program (STIP), the state's Section 190 Grade Crossing Improvement Program, and federal Section 130 projects.

Cal-B/C estimates two types of crash costs at grade crossings. The first set of costs involves the elimination of crashes at the crossing. For these costs, the model estimates crash rates and severity using the actual 10-year historical data from FRA safety data or predictions from WBAPS. The crash-reduction benefits for most grade separation projects are derived from this first set of costs. The second set of costs is estimated for a less likely benefit, that the grade separation also will change the basic configuration of the highway and lower the overall crash rate near the crossing. For these costs, the model uses its standard highway crash methodology and monetization factors.

To monetize crash costs at the crossing, Cal-B/C uses the average incidence of fatalities and injuries per crash from FRA historical data for California. Cal-B/C treats modes equally, so the model uses the same values per event to monetize crash costs at the crossing as it does for other highway, rail, or transit projects. Currently, the resulting values are $4.1 million for each fatality and $74,500 for each injury in 2007 dollars.

Given that information on injury severity at grade crossings is not available, the injury value is estimated from California highway severity statistics. California uses the same ABC scale as the NSC:

- A: Severe injury
- B: Other visible injury
- C: Complaint of pain

The aggregate injury value for grade crossings is estimated using the relative occurrence of A and B injuries in highway crashes, assuming that highway-rail grade crashes are more severe and C injuries are less likely in these crashes. These assumptions result in a higher average cost per injury for grade crossings than for highways, $74,500 versus $45,800. The same values are used in Cal-B/C for transit crashes involving heavy rail, light rail, or buses.

Cal-B/C estimates the same value of property damage for grade crossing crashes as it does for commuter rail and heavy rail crashes. This value is estimated from data reported in the FTA *Transit Safety and Security Statistics and Analysis Annual Report* (information available at http://transit-safety.fta.dot.gov/Data/SAMIS.aspx). This value may not be representative of the costs associated with passenger or freight rail crashes.

Cal-B/C does not estimate any benefits due to the elimination of delays associated with grade crossing crashes. Crashes at grade crossings typically close the railway and the highway, causing large delays for both facilities. The cost of the delay to freight railroads varies considerably depending on the type of freight being transported along the rail corridor. Because it is difficult to obtain information on the type of freight and the closure duration of average crashes, Cal-B/C ignores any benefits accruing from preventing their occurrence.

The **Florida DOT Freight Rail Investment Software** is part of a framework that Florida DOT recently developed for evaluating how private freight investments generate public benefits. Florida DOT developed an Excel-based model called the Capital Budget Model Decision Support System. The software can calculate a benefit-cost ratio that includes these benefits from investments:

- Avoided highway maintenance costs
- Minimized shipper logistics costs
- Decreased highway delays at rail-highway grade crossings
- Development of new or retained jobs
- Increased taxes from industrial development
- Improved highway safety
- Improved environmental quality

The highway safety benefits are valued using a standard cost per vehicle-mile traveled of $0.091 in 2006 dollars. This cost was derived from NHTSA statistics.

3.3 Selected Studies and Analyses

3.3.1 Case Studies: At-Grade Separation Projects

A few large projects have been undertaken recently that include the elimination of at-grade rail crossings with the joint objectives of reducing traffic delays and increasing safety. Studies related to these projects have varying degrees of detail on the economic impacts of grade separation. Some studies make nothing more than a mention of the potential for reduced accidents while others present calculations for the probability of an incident and the resulting costs in terms of life and property damage. While these studies do not directly identify supply chain costs and the larger economic impacts, they provide insights that can assist in the derivation of such predictions.

3.3.1.1 Alameda Corridor East

The Alameda Corridor East (ACE) project was created by the San Gabriel Valley Council of Governments to reduce rail traffic along the 70 miles of railroad in the valley. Specifically, the project includes 20 grade separations and 39 crossing safety improvements. The stated goals were increasing safety, reducing traffic, and expanding trade.

The San Gabriel Council of Governments conducted a major feasibility study in 1996 that examined 55 grade crossings along the corridor. It primarily focused on vehicular delay resulting from the crossings and did not specifically address collisions. The report mentioned that safety was a general objective, although historical data showed a low frequency of crashes; hence, crashes were not a targeted research area.

The ACE project was further analyzed in the T Corporation study ACE Phase II Grade Separation Traffic Study and Concept Plans (*102*). This study outlined general delay costs from rail-highway grade crossings but did not investigate crash costs or crash prediction. KOA used Webster's widely accepted model of uniform delay (*103*); however, KOA argued that crossings next to other intersections with traffic signals experience more severe compounded delays. Hence, the study implemented a separate methodology for cases in which delays are calculated as a function of vehicle arrival rates, queue duration, and blockages.

On a separate note, as part of the project, the California Public Utilities Commission developed an index to prioritize grade crossings in need of improvements based on traffic volume, crash history, speed limits, types of vehicles that use the crossings, and crossing geometrics.

3.3.1.2 CN Acquisition of EJ&E

A 2008 report prepared by the Economic Development Research Group and Carl Martland, *Regional Economic Benefits from CN's Acquisition of the EJ&E* addressed the motor vehicle delay impacts of rail grade crossings in metro Chicago (*104*). The report drew on a draft environmental impact statement (EIS) by the STB that collected and computed information on vehicle traffic and rail traffic at crossings to determine existing delay time of each crossing. Valuing 1 hour of delay at $20, the Economic Development Research Group and Martland calculated the net effect of vehicle delay resulting from the rerouting of trains under the acquisition, and from this, the total annual value. Specifically, the report determined that rerouting trains would save 107 hours per day, which equated to $781,907 per year. These 107 hours represented 0.97% of total at-grade rail crossing delay in the Chicago metro region, according to the Illinois Commerce Commission.

For the impact of crashes, the report also alluded to the draft EIS for CN's acquisition of the EJ&E, which utilized a methodology from the FRA report summary of the *DOT Rail-Highway Crossing Resource Allocation Procedure-Revised* (*55*) to assess crash risk. Using these formulas, crash predictions were calculated under the then-current and proposed scenarios. The end result was a net decrease of 0.95 crashes. If those crashes were fatal, this represented a value of $3.47 million. The lower bounds were $2,800 for property damage and $211,000 for non-fatal personal injury.

3.3.1.3 CREATE Plan

The Chicago Region Environmental and Transportation Efficiency (CREATE) Program Final Feasibility Plan will eliminate 25 highway-rail crossings (*105*). The present value of the reduction in motorist delays is listed as $72 million. Additionally, rerouting of trains that traverse another 163 crossings will save another $130 million while leaving the crossings physically unchanged. Using data from 1977 to 2001, the plan lists the present value of preventing grade crossing crashes is $32 million through 2042. (The plan lists the amounts without explanation as to how the numbers were calculated.)

3.3.1.4 SOUNDER Project

This Seattle-area project's focus was to develop a commuter rail system. The draft EIS for the project included a brief mention of highway-rail grade crossings, but it concluded that there will be no significant impact in terms of delay because the trains were shorter and quicker than freight trains. The EIS included no mention of crashes or the potential safety effect of increased exposure because of higher train volumes at grade crossings (*106*).

3.3.1.5 The East Japan Railways Study of Global Risks

Over a period of more than 10 years beginning in 1994, the Safety Research Laboratory of the East Japan Railways (JR East) funded a series of research projects at MIT to investigate ways to understand and reduce the overall risks associated with their railway operations. The studies addressed what JR East termed global risk, which is the combination of all the types of risk that affect railway operations summed over all the segments of its network. The research team used probabilistic risk assessment (PRA), a technique that has long been used by railways around the world in safety research (*107*). PRA views risk as the product of two factors: the probability of an accident and its expected consequences. Global risks estimates sum all types of accidents and all types of consequences, using appropriate weights to reflect the perceived importance of different types of accidents or consequences.

The first phase of the research addressed risks in terms of major categories of accidents, listed in terms of increasing frequency but diminishing severity (*108*):

- Accidents caused by earthquakes and other natural disasters
- Collisions and derailments caused by human error or equipment failure
- Grade crossing crashes

The initial research phase produced a comprehensive estimate of the risks associated with each type of accident and an estimate of the expected numbers of accidents, fatal accidents, and fatalities associated with those accidents. This phase also included extensive analysis of grade crossing crashes on JR East (*109*, *110*).

JR East used these results to focus its safety research on the most critical areas. For example, past experience showed that earthquakes could cause a break in the Shinkansen, a network of high-speed rail lines operated by four companies. Although the earthquakes had occurred early in the morning before trains were running, had they taken place during rush hour, they could have caused a catastrophic derailment. To reduce this risk, JR East undertook a program to strengthen its infrastructure and to enhance its early warning system to enable trains to stop more quickly after the first indication of a major earthquake.

Estimating global risk requires comparing different kinds of consequences, including fatalities and serious injuries to employees and passengers, property damage, and delays to and cancelation of trains. Before the start of its research collaboration with MIT, JR East had used weights to compare the severity of the different consequences, although its primary concern was reducing the expected number of fatalities and avoiding fatal accidents altogether. However, as the research progressed, JR East asked whether greater weight should be given to fatalities in catastrophic accidents than to fatalities in minor accidents. Should 100 fatalities in a single derailment following an earthquake be given greater consideration than 100 fatalities in a series of minor accidents? The research team concluded that two reasons exist for such consideration. First, catastrophic accidents may have indirect effects. Second, people appear to believe that more effort should be devoted to avoiding fatalities in catastrophic accidents.

The indirect effects of an accident could cripple an industry. Government actions taken in the immediate aftermath of a severe accident or an incident that narrowly missed being a catastrophe might have dramatic consequences in terms of regulation of railways or in railway traffic levels:

> The public or government agencies may over-react to a catastrophic accident by requiring very expensive and possibly irrelevant or ineffective investments to reduce future risks. Customers may lose confidence in the system and switch to other modes for extended periods of time (*111*).

An example of an accident with extreme indirect effects is the Three-Mile Island nuclear accident near Harrisburg, PA, in 1979. Although the accident caused no immediate fatalities or injuries, it led to major changes in regulation of the nuclear power industry. Additionally, negative publicity related to that accident was a major factor in essentially stopping the construction of nuclear power plants in the United States for more than 30 years.

The second reason for giving more weight to fatalities in catastrophic accidents relates to human factors. A large body of research shows that people are more concerned about risks associated with catastrophic accidents than with the risks associated with minor accidents. Researchers have identified two critical factors affecting perceptions of risks. First, people view potential accidents as “dreadful” if they are likely to result in large number of fatalities, if the fatalities are immediate, and if people have no control over their exposure to such accidents. Second, people fear the unknown: the prospect of a nuclear incident is more frightening than the well-known risks of automobile accidents. The MIT researchers concluded that JR East could add weight to the consequences of catastrophic accidents:

> Weights conceivably could be based upon both the "dread" factor and the "understanding" factor described in the literature. For railways, the "dread" factor appears to rise with the number of fatalities raised to the power of about 1/3. Using this factor, the perceived risks of an accident with 100 fatalities would be about five times greater than the aggregate perceived risks of 100 accidents with a single fatality each (*111*, p. 44).

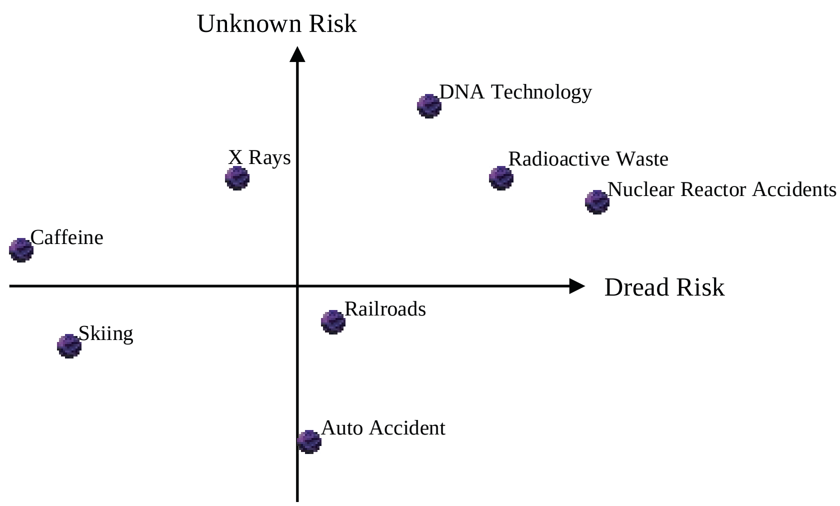
JR East's interests included not only the expected consequences of accidents, but also the distribution of consequences. If risks are to be weighted by the number of fatalities in an accident, then it is necessary to consider the entire distribution of potential fatalities. MIT therefore developed a parametric model to investigate accident consequences as a function of parameters related to train characteristics, route characteristics, and operating conditions. The use of a parametric model allows for examination of risks in considerable detail. For example, model results indicated that the risks associated with rail accidents on major passenger routes in Japan were an order of magnitude greater during peak hours than during off-peak periods.

3.3.1.5.1 Devising a Reasonable Set of Weights for Catastrophic Crashes

The MIT review of the risk assessment literature concluded:

> The literature does support the use of weights for evaluating risks associated with catastrophic accidents. According to many studies of perceived risk, the public is worried about accidents where there is a possibility of hundreds of fatalities, widespread devastation, or lingering, unknown impacts that could affect thousands of people (*111*, p. 22).

Key studies by Slovic et al. (*112*) and by Kraus (*113*) examined the way that people perceive risks associated with various kinds of activities and accidents. Both studies summarized perceived risks by placing risks within a two-dimensional framework defined by two variables: the extent to which individuals perceived risk as dreadful (x-axis), and the extent to which the risk was unknown (y-axis). According to the Slovic study, railroads were close to the origin for both dimensions (see Figure A-6). Kraus conducted a similar study for various types of rail accidents. Using Figure A-6 to overlay the results of her study on Slovic's, the perceived risk of grade crossing crashes was near automobile accidents (train collisions occurred slightly above and to the right of auto accidents), and hazardous chemicals accidents were further out in the upper right quadrant. Neither study attempted to provide a quantitative scale to their charts.



Source: Adapted from (*112*).

Figure A-6. Locations of eight hazards within the two-factor space.

Previous studies considered more than two factors that might affect perceived risk. For example, Litai (*114*) estimated eight different "risk conversion factors" for comparing perceived risks as a function of their attributes. Although Litai did not provide a means for using these factors collectively in a study of risk, his work did suggest a way to quantify the axes in a risk chart:

> . . . these factors could be adjusted to fit the two-axis framework used by Slovic and Kraus, where the center of the diagram would be the "typical risk," i.e., the risk where the risk conversion factors would be neutral (i.e., equal to 1). Thus, the factor of 30 for a catastrophe could range from about 1/6 on the "not at all catastrophic scale" (e.g., the risks associated with caffeine) to 5 on the "most catastrophic scale" (e.g., the risks of a nuclear accident). With this adjustment, the catastrophic risk would still be 30 times worse than the "not at all catastrophic risk," but it would only be five times worse than the typical risk (*111*).

Litai (*114*) estimated eight factors, but he did not try to reduce them to a two-dimensional scale, as did Slovic and others. Although the research team for NCHRP Project 08-85 does not accept all of Litai's methodology, the team agrees that the range of factors that he identified is suggestive of the quantitative scale that might be applied in the two-dimensional diagrams. Thus, the scale on the "Dread Risk" axis of Figure A-6 might be similar to Litai's catastrophic factor (and therefore range from 1/6 on the left to 5 on the right), while the scale for the "Unknown Risk" axis might be similar to Litai's factor for old versus new (and therefore range from 0.33 for the best known to 3.3 for the least known) (*111*).

Litai developed risk factors by comparing two sets of accidents: one set with a risk factor and one set without one. In that approach, an accident was either catastrophic or it was not. Bohnenblust (*115*), who assessed risks as part of the design of transportation facilities, used a step function to give heavier weights to accidents with fatalities, assigning 2 for accidents with 1 to 20 fatalities, 5 for accidents with 20 to 200 fatalities, and 10 for larger-scale accidents. The MIT study demonstrated that a continuous function could replace the step function for weighting:

$$\text{Risk factor} = \text{Fatalities}^{1/3}$$

> This factor would be 1 if there is one fatality, which certainly seems appropriate. It would be 2.1 for an accident with 10 fatalities, so it equates to Bohnenblust's assumption for the mid-range of his first set of accidents, those with one-to-20 fatalities. This factor would be 4.6 for an accident with 100 fatalities, which is close to the factor of 5 that Bohnenblust used for accidents with 21-to-200 fatalities, and it would be 9.8 for an accident with 1,000 fatalities, which is close to Bohnenblust's maximum factor of 10. . . . On this scale, derailments with expected fatalities of 10 per accident would have a weighting of 2.1, whereas grade crossing crashes with expected fatalities of 0.2 per accident would have a weighting of 0.6 (*111*, p. 23).

The y-axis in Figure A-6 represents the unknown factor, which Litai assigned a value of 10. As previously suggested, this factor of 10 represents the difference between the least known and the most-known accidents and can be provided a scale that ranges, say, from 0.3 for automobile accidents to 3.0 for risks associated with DNA. On this scale, using Kraus's results, grade crossing crashes would be assigned a value somewhere near 0.3; derailments and collisions would be about 1.2, and hazmat accidents would be somewhere above 2.

As the authors of the MIT study did not find any guidance for combining perceptions concerning two or more factors, they suggested the following equation to obtain a weight for perceived risk:

$$\text{Perceived risk} = (\text{Dread factor}^2 + \text{Unknown factor}^2)^{1/2}$$

With this equation, the dread factor dominates for catastrophic accidents because the dread factor is 10 for an accident with 1,000 fatalities whereas the maximum value of the unknown factor is approximately 3, based on the Litai studies. The perceived risk factors for derailments with 10 expected fatalities are four times higher than the perceived risk factor for grade crossing crashes with 0.2 expected fatalities:

Perceived risk derailment = (2.12 + 1.22)1/2 = 2.42.

Perceived risk grade crossing crash = $(0.6^2 + 0.25^2)^{1/2} = 0.65$.

Crashes such as derailments and collisions related to track problems, equipment failure, or human error are—like all crashes—a major concern for railroads. Most grade crossing crashes relate to errors or poor decisions on the part of the highway operator, although railroads can and generally do take steps to reduce the likelihood of such crashes, such as ensuring that buildings or vegetation along the right-of-way do not obstruct highway users' visibility.

In summary, perhaps the major conclusion from this literature review is that it is important to consider the relative importance of the different risks faced by the railroad system. The consequences associated with grade crossing crashes, derailments, and earthquakes are viewed differently by the public, and the public is also clearly concerned about the scale of the accident. The literature does not provide specific factors for assigning weights for comparing different types of accidents, but it does suggest how those weights might be determined. The methods used by Bohnenblust and Kraus, combined with Litai's factors, suggest a way to devise a reasonable set of weights. Surveys such as those used in past research could be used by JR East (or other companies or agencies) to explore how the public perceives the risks associated with the services they provide (*111*, pp. 22–25).

The JR East study did consider the possibility that serious indirect consequences could stem from a grade crossing crash. However, a review of public policy in both Japan and the United States yielded no large-scale indirect consequences:

> The legal framework, which was set into place long ago, recognizes that the primary responsibility for these accidents rests with the highway drivers and the highway agencies. The onus is on the public sector, not the private sector, to invest in a rational approach to improving crossing safety. Control measures are in general well known and safety management programs are in place. Moreover, the risks to passengers are much lower than the risks related to derailments or train-to-train collisions, and the potential for a catastrophic accident is very low. … Taken together, these conclusions indicate that it is unlikely that a grade crossing crash will result in any measurable indirect consequences of concern to the railroads. The railways, the public, and public officials are well aware of the risks, of the measures that can be considered, and they are also aware of the potential costs and benefits of those measures. Decades of experience and hundreds of accidents have led to numerous improvements in crossing safety, and it is unlikely that dramatic changes in understanding or in perceptions of risks would result from further experience (*111*, p. 42).

The research concluded that the number of fatalities would dominate the consequences of accidents, particularly for accidents with many fatalities. However, property damage and disruption of service could result in significant consequences for some accidents:

> The direct consequences of an accident can include severe disruption of service. . . . Property damages are important, but most damage is done to the trains involved and the track structure. The property damage is therefore limited by the value of the train or trains involved in the accident and the costs of repairing a section of track that is likely to be less than a kilometer in length. The property damage for the railway is therefore limited to perhaps $20 to 30 million, which will be relatively unimportant in a catastrophe involving dozens of fatalities. Likewise, the extent of service disruption depends upon the time needed to investigate, clear, and repair a limited amount of track. The time involved is related to the location, the final disposition of the equipment, and not necessarily to the number of fatalities (*111*, p. 44).

3.3.1.5.2 The Prototype Parametric Model of the Consequences of Railway Accidents

JR East had developed models to estimate accident probabilities; expected consequences such as fatalities, injuries, and passenger delay; and global risks. These models, which were based on past experience and used average values for key inputs, predicted the expected consequences of accidents. As structured, the models could not predict the expected distribution of consequences. Nor could they predict how a change in operations, traffic volumes, train speeds, or other relevant factors would affect the variation of risks or variation of risks by time of day. Also, these models did not address property damage, disruption to rail service, or disruption to highway traffic in the event of a grade crossing crash although the database contained such data.

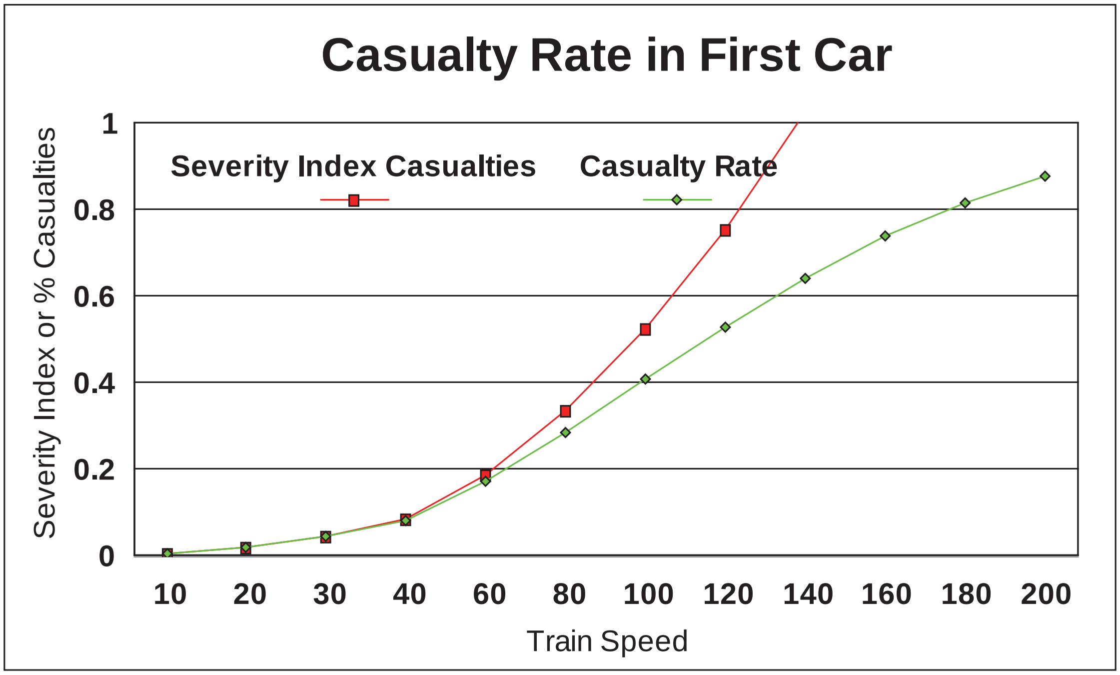
As part of the JR East research program, MIT developed a parametric model that could estimate the distribution of direct consequences of different types of accidents as a function of operating conditions, including time of day (*111*, pp. 10-11, Ch. 3). Time of day is a critical factor because the probability of accidents and the potential severity of accidents both increase when trains are more frequent and their load factors are higher. This model considered property damage, disruption to rail operations, and highway delays after a grade crossing crash. Additionally, the parametric model dealt with individual route segments. It provided a useful research tool that served as a prototype model for assessing global risks within JR East's system.

As with traditional risk-based accident models, the parametric model assesses the probability of an accident as the product of a measure of exposure and an accident rate—factors estimated using models already developed by JR East. The parametric model, however, estimates the distribution of consequences given that there is an accident; that is, risk is the product of the probability that an accident of type i will occur during time period t and the expected magnitude of consequences in category j. Consequences may incorporate weighting to reflect both the type of consequences, for example, fatalities or property damage, and the severity of the accident, based on, for example, the number of fatalities.

The basis of the JR East prototype model consisted of a core module that estimated risk for a particular segment and time period. This structure allowed for repeated iterations to support an aggregate analysis. The basic logic of the prototype model is as follows:

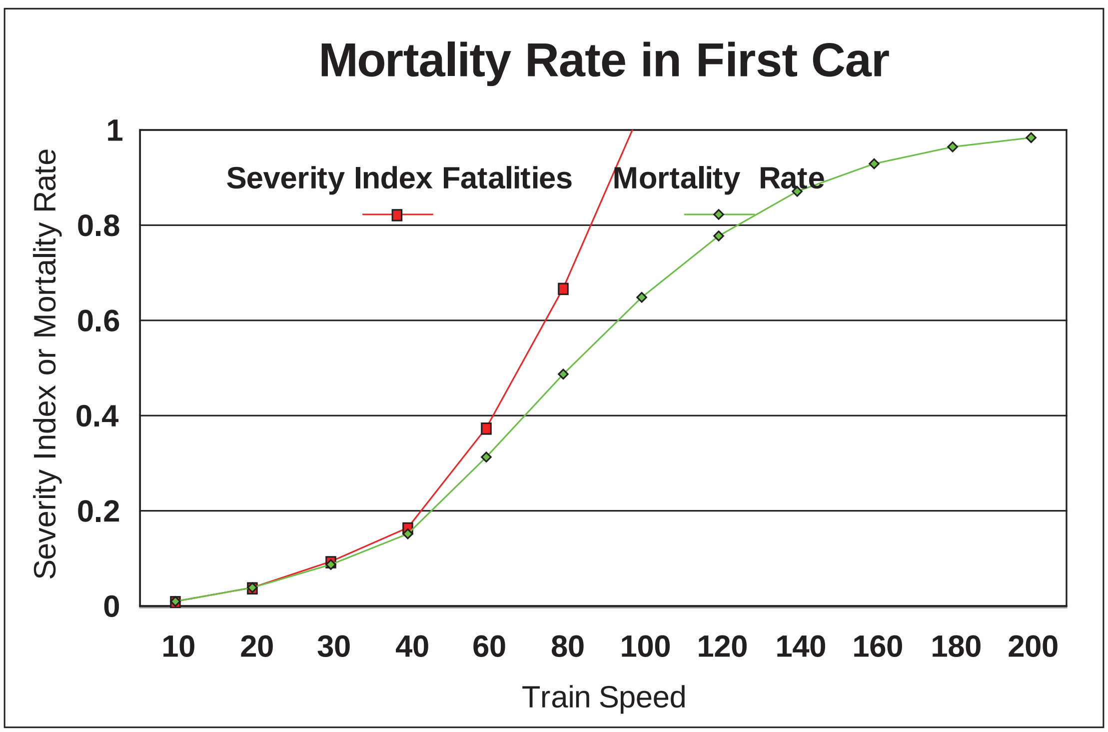
> The model incorporates logic from the prior research that used casualty and mortality tables to predict fatalities based upon the speed of collisions and the nature of the terrain at the site of the accident. The prototype allows the user to define a severity index based upon the speed at the time of collision, the weight of the obstacle that is hit, the probability of overturning, the distance that a car will fall if it turns over, and the load factor. Separate severity indices can be defined for casualties and for mortality. Two other functions predict the casualty rate and the mortality rate as a function of the severity index. The casualty rate is the percentage of passengers who are killed or injured in the first car affected by the collision. The mortality rate is the percentage of casualties that are fatalities. The prototype provides a chart showing how casualties and mortalities increase with the speed of a collision, based upon the coefficients selected by the user. Either function can be calibrated to match information available to the user regarding casualty or mortality rates (*110*, p. 30).

To demonstrate the capabilities of the JR East parametric model, Figures A-7 through A-11 provide analyses derived from model application. Figure A-7 shows two curves: the severity index increases with train speed, and the casualty rate increase with the severity index. Figure A-8 shows similar curves for the mortality rate in the first car. The parametric model first finds the casualty rate, which gives the percentage of passengers in the first car that would be killed or injured as a function of the severity index. It then finds the mortality rate, which estimates the percentage of casualties that would be fatalities. Combining the results of these two functions makes it possible to predict the expected percentage of passengers in the first car who would be injured or killed as a function of train speed at the time of the accident (Figure A-9). To adjust the parameters of the severity index to calibrate the model, compare predicated casualties to casualties for an actual set of fatal accidents with known operating conditions and load factors (see Figure A-8 and Figure A-9).



Source of data: Initial Version of the Prototype Model.

Figure A-7. The severity index for casualties and casualty rates.



Source of data: Initial version of the prototype model.

Figure A-8. The severity index for fatalities and fatality rates.

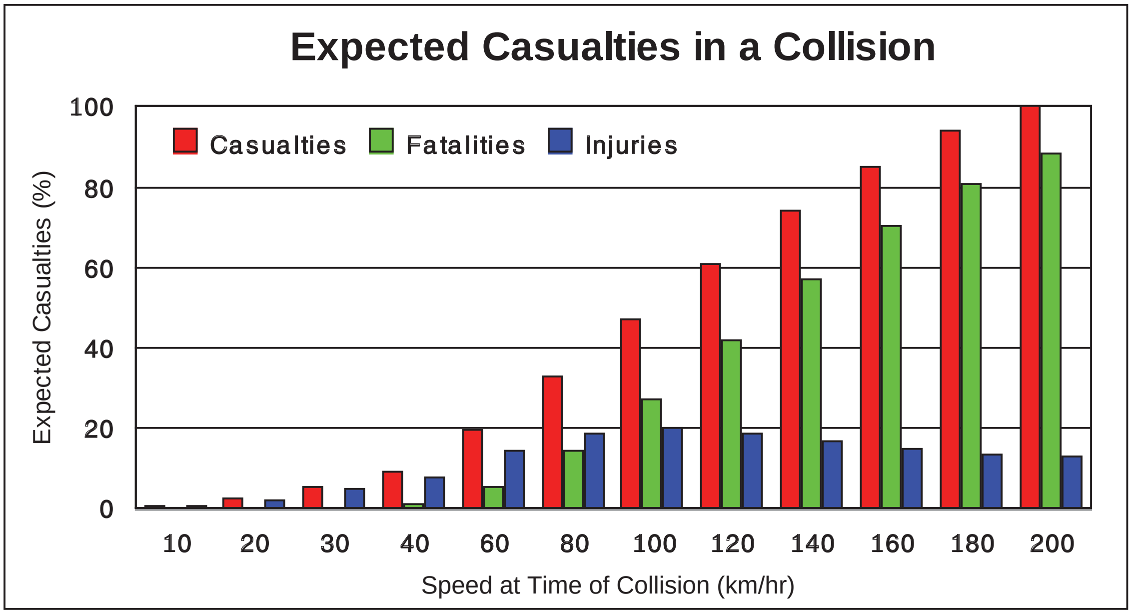


Chart displayed for calibration in the model.

Figure A-9. Expected casualties as a function of speed.

The model assumes that the casualty and mortality rates decline in following cars according to transfer functions with the following structure:

Rate in car n = (Rate in first car)($e^{-k(n-1)}$).

The parameter k is a constant determined by either calibration or expert judgment. Based on analysis done by the JR East Safety Research Laboratory, both transfer functions in the preliminary version of the MIT model used a value of 1.9.

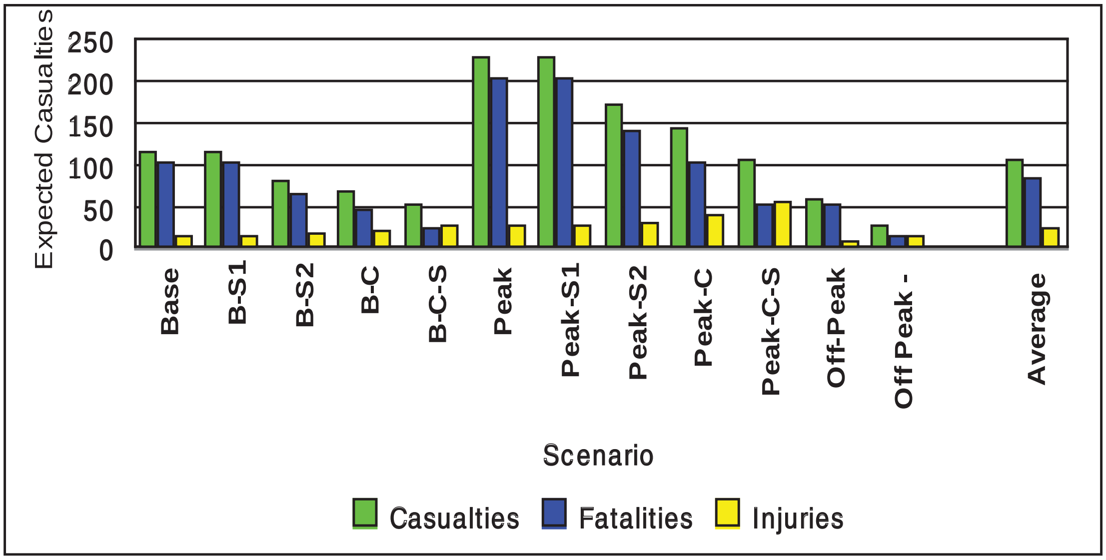
In multitrack territory, a collision or derailment may impede clearances on an adjacent track. The probability of a secondary accident depends on the first accident's severity, the time required to notify other trains of the danger, and the speed and frequency of trains on the track or blocked tracks. The model estimates the probability of a secondary collision as the ratio of the stopping distance of the train to the average headways between trains. The estimate of the consequences of a secondary accident uses the same approach as that for estimating the consequences of the initial accident.

The model uses kinematics and approximations to develop a discrete distribution for the train speed at the time of impact by calculating the time and distance required for the driver to react to a signal or other information indicating the need to stop and then to slow the train to 75%, 50%, and 25% of its initial speed. If there were a secondary accident, the probability that the accident would occur before the train would begin to decelerate equals the ratio of distance traveled during the reaction time to total stopping distance. The probability that the train speed is at least 75% of its initial speed is the ratio of distance covered once the train begins to decelerate until it slows to 75% of the initial speed to total stopping distance. Likewise, the model uses kinematics to compute the probability that the accident occurs when the train is traveling in each of three other intervals: 50% to 75% of the initial speed, 25% to 50% of the initial speed, and 0% to 15% of the initial speed. For each of these five intervals, the assumed speed at impact is the average speed over the interval—100%, 87.5%, 62.5%, 37.5%, and 12.5% of the initial speed.

The parametric model allows the user to specify up to 12 scenarios for a collision. A scenario could reflect a difference in train speeds, load factors, and train frequencies for varying times of day. Carefully structuring these scenarios makes it possible to estimate the distribution of consequences of a particular type of accident over a particular type of track.

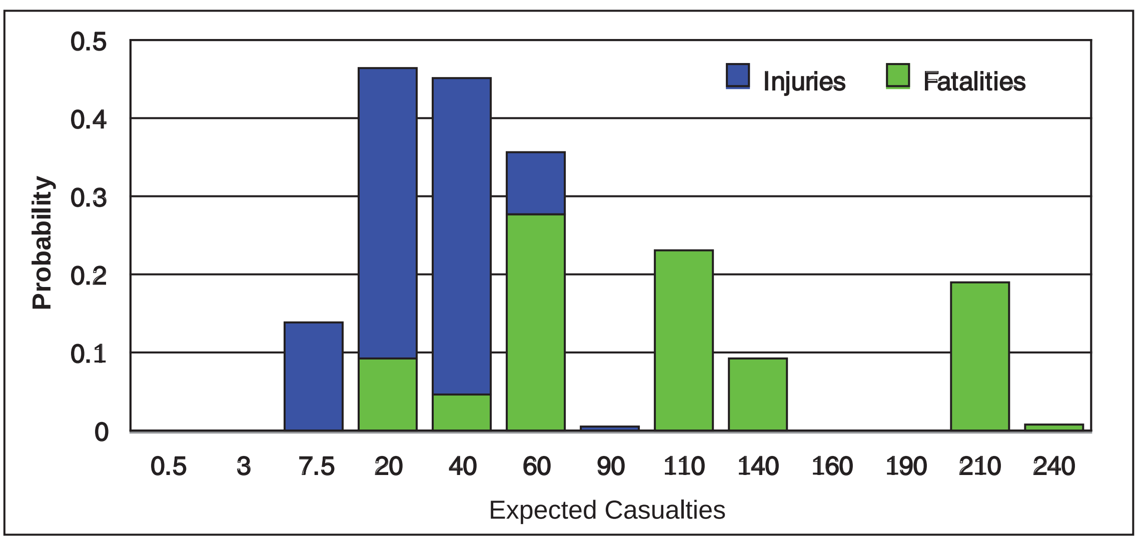
Figure A-10 shows sample results for a high-speed collision on a track segment where the speed limit is 150 km/hour on tangent track and 125 km/hour on curves. The names of the scenarios indicate whether the crash occurs on a curve (C), whether it occurs at the speed limit or a slower speed (S1 or S2), and whether the crash occurs during the peak of rush hour, near the peak, or at off-peak periods. An assumption in this analysis is that both train frequencies and passenger volumes are highest during peak periods. Similarly, the average number of passengers per car is 200 during peak periods, 100 during near-peak periods, and 50 during non-peak periods. Depending on the scenario, the total casualties could be more than 200 or less than 20.

Figure A-11 shows how the model can predict a probability distribution for the expected number of casualties and fatalities by assigning probabilities to each scenario.



Source: (*52*).

Figure A-10. Summary of casualties for each scenario—primary collision.



Source: (*52*).

Figure A-11. Distribution of casualties.

3.3.1.5.3 Consequences of Grade Crossing Crashes on JR East

During the period 1987 to 1993, the JR East database indicates that 1% of the railroad's grade crossing crashes resulted in two fatalities, 21% resulted in one fatality, and 78% resulted in no fatalities. All of the fatalities were occupants of highway vehicles. Another 3% of the crashes involved two or more injuries, and 18% involved one injury. Only 1% of the crashes resulted in injuries to train passengers or train crew members. The database also indicates the number of hours of train delay and the number of trains canceled. For grade crossing crashes, these consequences were minimal. For more than 80% of the crashes, there were fewer than 30 minutes of train delay and no train cancelations (*110*).

The parametric model estimated the extent of delays to trains and travelers as a function of the time of the line blockage and of the following variables related to supply and demand:

- Scheduled train speed and headways
- Train headways during the recovery period
- Station spacing and the number of stations affected by delay
- Passengers boarding per train at each station
- Utilization of the track
- Average load factor

To estimate the extent of delays to trains and to travelers, the analysis used deterministic queuing models. The average delay included travelers waiting at stations for delayed trains as well as passengers on trains delayed by the blockage. To translate passenger delay into cost of delay, the analysis applied an estimate of the average cost per minute for passengers. Since the JR East operated a high volume of passenger trains, its operating characteristics were more similar to the Northeast Corridor or heavy density commuter lines than to typical North American freight lines. Similarly, canceled trains during rush hour posed an especially difficult problem. During this analysis, JR East operated full trains on short headways. Hence, it was difficult for JR East trains to make up for the lost capacity of even a single canceled train. Canceling a train with 1,000 passengers could lead to tens of thousands of hours of traveler delay and costs to travelers estimated in the hundreds of thousands of dollars.

4 Principal Components of Grade Crossing Crash Costs

4.1 Introduction

This section identifies the principal components of grade crossing crash costs. The research findings are presented as a series of tables that represent taxonomy of costs. The intent of the taxonomy is to:

- comprehensively capture all relevant cost components,
- support definitional clarity while avoiding double counting of costs, and
- integrate costs into current practice crash prediction and severity methodologies.

The taxonomy of costs supports data collection, cost estimation, and development of a cost-forecast framework.

4.2 Crash Cost Taxonomy

4.2.1 Overview

The taxonomy of costs is presented in a sequence of tables as follows:

- Crash categories (Table A-14)
- Casualty categories (Table A-15)
- Principal categorization of cost components (Table A-16), including:
    - o Primary—Cost components generally associated with crashes
    - o Secondary—Costs associated with business supply chain disruption
    - o Rare catastrophic crashes—cost components from very high cost/very low-probability crashes
- Non-property damage direct cost components (Table A-17)
- Casualty costs with WTP measures for loss of life and injury and with cost components (Table A-18)
- Property damage costs (Table A-19)

4.2.2 Crash Categories

The most accepted and widely practiced method of forecasting crashes and severity in the United States is embodied in the U.S.DOT APS process. It is used by FRA's WBAPS (*98*) and GradeDec.Net (*59*), and it is also followed by a number of state and local authorities that have developed their own variants. This general procedure is to first forecast predicted crashes and then allocate predicted crashes to severity categories. In principle, given predicted crashes by severity category, a forecast average cost per crash would enable a straightforward calculation of crash costs at a specific grade crossing.

Table A-14. Crashes and costs.

Crash Type	Crash Sub-type	Number of Occurrences	Total Costs	Average Cost per Crash
Casualty	Fatal	682		
	Non-fatal injury	1,631		
Non-casualty	Property damage only	~4,000		
Total				

4.2.3 Casualty Categories

The two main types of casualties are fatalities and non-fatal injuries. Much of the highway crash literature uses the AIS six-tiered injury severity scale. The AIS system can give rise to anomalous classification of injuries, for example, high severity/low cost. This taxonomy proposes adopting the National Safety Council's three-tiered classification. The three tiers are less granular, and the system is based on police crash reporting and has been shown to have greater reported accuracy. In the NCS system, A indicates "severe"; B indicates "other visible," usually the presence of blood on a victim without loss of consciousness; and C indicates "complaint of pain."

Table A-15 further breaks out casualties by mode because

- The breakout is supported by existing data,
- There is public interest in passenger safety on public carriers vs. private travel, and
- There is public interest in the industrial safety component.

Table A-15. Casualty categories.

Mode \ Casualty		Fatalities	Injuries		
			A: Severe	**B:Moderate**	**C: Light**
Highway					
Pedestrian					
Rail	Passengers				
	Employees				

4.2.4 Categorization of Cost Components

Table A-16 itemizes the principal cost categories by effect and impact. Effect is one of three:

- Primary—Cost components generally associated with crashes
- Secondary—Business costs associated with supply chain disruption due to grade crossing crashes
- Rare catastrophic crashes—Costs differentiated by alternative approaches used in accounting or disregarding these costs

Impacts describes either (1) the manner by which society is impacted by the cost component, whether direct, indirect, or intangible; (2) the process through which the impact is perceived, such as through business supply chain disruption; or (3) the approach for evaluating the cost in cases of rare catastrophic events.

We note that the indirect and intangible costs are captured in the WTP measures for loss of life and injury.

Table A-16. Categorization of cost components.

Effect	Impact	Cost Component
Primary	Direct	Property damage Other direct costs
	Indirect	Work-related productivity loss Tax loss
	Intangible	Quality of life Pain and suffering
Secondary	Supply chain disruption	Rerouting Increased emissions from rerouted and queued highway vehicles Prevention Lost sales Inventory spoilage Increased inventory Freight and passenger delays Freight and passenger reliability - Freight: Warehouse/distribution center rescheduling and cross-docking operations - Passenger: Commuting
Rare Catastrophic Crashes	Approach 1: Disregard very small probabilities	No cost tabulated
	Approach 2: Mitigation/abatement costs	Cost equal to cost of mitigating risk to acceptable level
	Approach 3: Best guess	Estimated cost multiplied by probability of occurrence
	Approach 4: Weighted best guess	Best guess cost with weighting scheme to account for public perceptions

4.2.5 Direct Costs Not Property Damage

These crash cost components draw on both public-sector and private-sector resources. Some of these costs, such as emergency medical services, accrue as a direct consequence of a crash. Other costs, such as insurance, accrue regardless of whether a crash actually occurs. Some costs have both per crash components (variable costs) and components that accrue regardless (fixed costs). The grade crossing crash cost framework needs to allocate the variable and fixed costs to crashes by crash type.

Table A-17. Direct cost components excluding property damage.

Impact	Direct Crash cost Components Excluding Property Damage (to be allocated to crashes by crash type)
Direct	Emergency services, police, and fire
	Medical, including hospital, rehabilitation, and counseling
	Legal and administrative, including criminal prosecution, insurance claims and administration, and household help
	Investigations by rail carriers and public agencies
	Cleanup costs
	Litigation
	Post-collision hearings and community outreach
	Other outreach about crash prevention

4.2.6 Willingness-to-Pay Casualty Costs

Costs associated with loss of life and injury are calculated using WTP measures. These costs are based on estimates of what individuals are willing to pay to reduce the risk of being killed or injured. The costs are inclusive of human capital, lost productivity, and tax effects that are associated with persons being killed or injured in crashes.

Table A-18. Casualty costs.

Casualty Type	WTP Measure	Impact Areas Covered	Cost Components
Fatality	Value of a Statistical Life (VSL)	Indirect and Intangible	• Productivity losses • Tax losses • Pain and suffering • Quality of life
Injury A (Severe)	VSL * Severe Disutility Factor		
Injury B (Moderate)	VSL * Moderate Disutility Factor		
Injury C (Light)	VSL * Light Disutility Factor		

4.2.7 Property Damage Costs

Property damage costs include the costs of damage to highway vehicles and infrastructure, such as repairs to roadway surface, barriers, and signage, as well as to railroad equipment and infrastructure. More severe crashes involving casualties will generally have higher non-property direct costs associated with them, which should be accounted for and allocated accordingly.

Table A-19. Property damage costs.

Crash Type	Damages Category	Costs to Include on Per Crash Basis	
		Replacement/Repair of Damaged Property	Share of Other Direct Costs
Casualty Crashes	Highway vehicles		
	Highway infrastructure		
	Railroad equipment		
	Railroad infrastructure		
Non-Casualty Crashes—Property Damage Only	Highway vehicles		
	Highway infrastructure		
	Railroad equipment		
	Railroad infrastructure		

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Abbreviations and acronyms used without definitions in TRB publications:

A4A	Airlines for America
AAAE	American Association of Airport Executives
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI–NA	Airports Council International–North America
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
HMCRP	Hazardous Materials Cooperative Research Program
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
MAP-21	Moving Ahead for Progress in the 21st Century Act (2012)
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
PHMSA	Pipeline and Hazardous Materials Safety Administration
RITA	Research and Innovative Technology Administration
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S.DOT	United States Department of Transportation