APPLICATIONS OF ENGINEERING AND FINANCIAL ANALYSIS TO THE VALUATION OF INVESTMENTS IN RAILROAD INFRASTRUCTURE

A Record of Study

by

CRAIG EMMITT ROCO

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF ENGINEERING

May 2009

Major Subject: Engineering
College of Engineering

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Approved by:

Chair of Committee,	Ivan Damnjanovic
Committee Members,	Tim Lomax
	Luca Quadrifoglio
	Calvin Woods
	Joe Lileikis
Coordinator, College of Engineering	Robin Autenrieth

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ABSTRACT

Applications of Engineering and Financial Analysis to the Valuation of Investments in Railroad Infrastructure. (May 2009)

Craig Emmitt Roco, B.S., Stephen F. Austin State University, B.S.; M.S.; M.S., Texas A&M University

Chair of Advisory Committee: Dr. Ivan Damnjanovic

This record of study presents the findings of industry research projects performed during a one-year doctoral internship with the Austin Rail Group of HNTB Corporation. Four main internship objectives were established that address infrastructure problems related to the railroad industry and required the integration of engineering and financial analysis to develop effective project evaluation tools. Completion of the objectives resulted in:

- Transformation of the Federal Railroad Administration methodology currently used to perform highway-railroad grade crossing analyses to a system of equations that can easily be used to evaluate regional rail infrastructure investments. Transportation engineering equations based on queuing theory were extended to new but equivalent formulations that accommodate unlimited, discrete train performance data from computer simulations of rail networks.
- Application of risk assessment methods and railroad accident statistics to recommend a cost-effective alternative to legislative proposals to relocate hazardous materials transported by rail around metropolitan areas. A risk analysis model was developed to predict the risk of exposure from the release of a hazardous material following a train derailment so that changes in exposure achieved by alternative risk mitigation strategies could be observed.

- A new method of measuring the susceptibility of railroads to financial distress following the catastrophic loss of a timber railroad bridge. Economic and finance principles were used to predict financial distress by determining of the number of revenue periods required to offset economic loss.
- Demonstration of the use of financial market data in calculating the discount rate of public railroad companies for engineering analyses that involve negotiations with the public agencies. Surface Transportation Board rulings on the determination of a railroad's cost of equity were applied to a comparative assessment of costs of capital for Class I railroads. A hypothetical example was used to demonstrate the interrelationship between engineering design strategies and their effects on the pricing of compensation to a railroad for right-of-way acquisition.

These results, in fulfillment of the doctoral internship objectives, have provided HNTB with economic decision analysis tools and a series of conclusions used to provide recommendations to the Illinois, Missouri, and Texas Departments of Transportation, the Texas Legislature, and the railroad industry.

DEDICATION

This Record of Study is dedicated to the memory of my father, Harvey Emmitt Roco, who devoted his life to the love of his family and country. After serving overseas in the United States Navy during the Korean War, my father returned to Houston, Texas and began a life married to my loving mother that extended over five decades. During that time he provided generously for his family through a wholesale farm and ranch supply distributorship that he built, defended his native city as a volunteer fire fighter, served his community on civil boards, and tirelessly extended his abilities to my high school's coaches as president of the athletic booster club. Throughout his life he enjoyed the fellowship of his friends and work associates, and remained steadfast in his devotion to his family. My father was a man who exemplified a strong work ethic and perseverance, and together we shared a love of animals and a fascination with railroads, the building process, Houston history, and following our favorite sports teams. The work in this document represents a small effort by me to be of productive use to society until we are together again.

ACKNOWLEDGEMENTS

I wish to express my sincere appreciation to the following people for their role in my doctoral studies:

The chairman of my doctoral advisory committee, Dr. Ivan Damnjanovic, for the generosity of his time and the interest he has shown in my academic work. I have enjoyed our shared interest in project finance since his arrival at Texas A&M University, and I am grateful for the opportunities he extended me as a doctoral student.

My internship sponsor, Mr. Joe Lileikis, for providing me the opportunity as a member of HNTB Corporation's Austin Rail Group to work on challenging transportation and economic issues facing society, and for the knowledge that I have gained from his vast background and experience in the railroad industry.

Dr. Tim Lomax and Dr. Luca Quadrifoglio, for their service to the Zachry Department of Civil Engineering and the Texas Transportation Institute (TTI), and for their willingness to serve as members of my doctoral committee. I appreciate their thoughtful consideration and inquiry concerning the results of my internship experience and for the time this required of them.

Dr. Calvin Woods, for his effectiveness as a teacher during my undergraduate program in civil engineering, and for his friendship and council during my graduate education. I appreciate the time he has given to serve as a member of my doctoral committee, and I am pleased that my academic work at Texas A&M University has concluded under his observance.

Dr. Ken Reinschmidt, a distinguished professor of civil engineering both in position and in character who has freely shared with me his time, insights, and the knowledge gained from extensive industry and academic experience. Dr. Reinschmidt has been as valuable a friend and teacher as one could hope to find in an academic program, and his perspective on life and approach to engineering analysis will remain with me throughout my career.

Dr. Steve Roop, Director of the Multimodal Transportation Program at TTI, for providing me the opportunity to develop research interests in economic and financial analyses related to the railroad industry, for introducing me to important transportation issues that confront society, and for allowing me the opportunity to pursue my doctoral work while employed at TTI. I am grateful for the kindness and consideration that he and his entire staff have extended to me.

Finally, I wish to thank the entire faculty and staff at the Zachry Department of Civil Engineering for their hospitality and generosity and for providing me the opportunity to contribute to the education of engineering students at Texas A&M University. The Zachry Department of Civil Engineering is a very special department within a unique and wonderful university whose ultimate service to the state and to society is not likely to be exceeded.

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CHAPTER I

INTRODUCTION

The practice of engineering in industry differs from that of performing engineering research in academia by the extent to which professional duties involve the resolution of non-technical issues. Engineering practice frequently involves economic evaluations or policy formulation and analysis, requiring new methods of applying information from diverse disciplines in ways that are not considered fundamental research. As a result, the Doctor of Engineering degree is structured to emphasize the integration of engineering principles with issues deemed important to industry and society, demonstrated primarily through performance during a one-year internship with a private firm or public agency.

This record of study documents the application of both engineering and business principles during a one-year internship with the engineering and architecture firm of HNTB Corporation, headquartered in Kansas City, Missouri. Consulting services were provided to public and private sector clients during the internship as a member of the Texas Rail Group, located in HNTB's Austin, Texas office. Considering that a number of services provided by the Rail Group focus on resolving conflicts between the market-driven needs of railroad companies and the societal objectives of public agencies, fulfillment of the internship objectives presented in this chapter rely to great extent on the integration of engineering principles with those of finance and economics.

This chapter first provides a history of HNTB Corporation that examines how events in the United States and abroad transformed the firm as it strived to find opportunity in an ever-changing world. The corporate structure of HNTB is then presented as a reference

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This record of study follows the style of *Transportation Research Record*.

to the Rail Group's placement within the overall context of the firm, emphasizing the various levels of oversight and control that guides management in decision-making processes. Then, internship objectives are outlined, which represent specific identifiable industry needs that are addressed through the application of knowledge acquired during the Doctor of Engineering academic program. The organization of this record of study is provided at the end of this chapter as orientation to the sequencing of approaches and solutions presented to demonstrate fulfillment of each objective.

1.1 HNTB Corporate History

The foundation for what eventually would become the engineering and architectural firm known as HNTB Corporation was laid by Dr. John Alexander Low Waddell, an 1875 graduate from Rensselaer Polytechnic Institute and renowned bridge engineer, and to whom a Doctor of Engineering degree is included among his academic achievements. By 1886, Dr. Waddell had established an engineering practice in Kansas City, Missouri after several years of academic service and employment with railroad companies. The Waddell "A" Truss, originally constructed as a single track bridge for the Kansas City Southern Railway (Figure 1.1), was patented in 1894.[1]

Figure 1.1 Configuration of Waddell "A" Truss Bridge.

Dr. Waddell partnered with Ira G. Hedrick from 1899 to 1906, followed by a partnership begun in 1907 with John L. Harrington, an academically devoted engineer with B.S., A.M., and C.E. degrees from the University of Kansas and both B.S. and M.S. degrees from McGill University. The firm of Waddell & Harrington designed landmark bridges during its seven years of existence, including the Detroit-Superior Bridge over the Cuyahoga River in Cleveland, Ohio (Figure 1.2) and the Colorado Street Bridge over the Arroyo-Seco in Pasadena, California (Figure 1.3).[2]

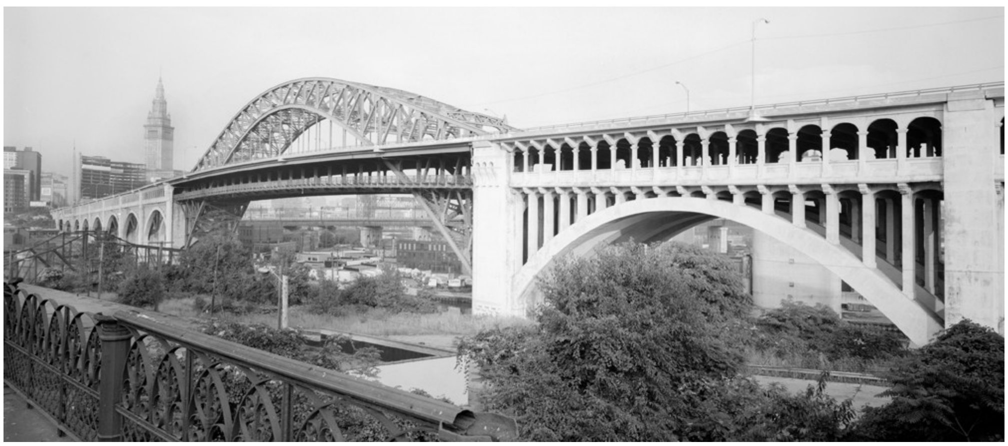


Figure 1.2 Detroit-Superior Bridge over Cuyahoga River in Cleveland, Ohio.

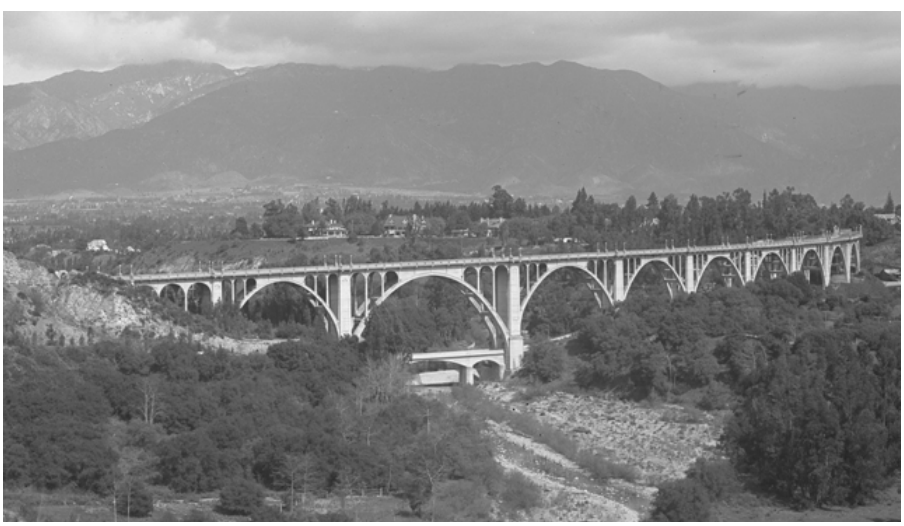


Figure 1.3 Colorado Street Bridge over Arroyo-Seco in Pasadena, California.

Waddell's best known work materialized through his design of the South Halsted Street Bridge in 1892, years prior to his partnership with either Hedrick or Harrington. The South Halsted Street Bridge over the South Chicago River in Chicago, Illinois consisted of a single Pratt-truss span 130 feet in length with a vertical lift height of 155 feet, making it the first large-scale, high-clearance lift span of its type in the United States. The firm of Waddell & Harrington designed more that two dozen vertical lift bridges between 1907 and 1914 before dissolving the partnership over differences concerning how to improve the design of Waddell's original lift mechanism. Waddell went on to found Waddell & Hardesty in 1927 with Shortridge Hardesty, the precursor to the firm known today as Hardesty & Hanover.

Harrington provided continuity in the firm's engineering practice through the promotion of Ernest E. Howard and Louis R. Ash, both of whom began with the firm (i.e., Waddell & Hedrick) in 1901. Harrington, Howard & Ash thrived as a bridge design firm under the new partnership, particularly in the expanding market for vertical lift bridges. Between 1914 and 1928, the firm is estimated to have completed at least 45 vertical lift bridges, 13 bascule bridges, and six rolling bascules bridges for railroad clients both in the United States and abroad.

The firm broadened its client base during the years of Harrington, Howard & Ash by designing privately-financed highway toll bridges in the northeast. In order to forge strong relationships with the bankers who financed these private facilities, Harrington sent Enoch R. Needles to establish a new office in the financial district of New York City in 1922. Shortly after joining the firm in 1917, Needles' ability to gain the trust and friendship of business associates led to field assignments all across the country, and ultimately resulted in the development of important contacts upon his arrival in New York City.

The early 1920s was a time of firm-wide success and recognition. Howard received the distinguished Fitch Rowland Prize for his publications on vertical lift bridges, Harrington was serving as President of the American Society of Mechanical Engineers, and the entire firm was busy designing bridges located as far away as Russia and in response to the booming real estate market occurring in Florida. The late 1920s, however, was met with significant challenges. Differences in temperament between Harrington and his partners resulted in the dissolution of the partnership in 1928, prompting Ash and Howard to reorganize as Ash, Howard, Needles & Tammen in deference to the contributions of Needles and Henry C. Tammen, a gifted engineer who joined the firm (i.e., Waddell & Harrington) in 1908.[2]

Tragedy struck both the firm and the country as the 1920s drew to an end. The stock market crash and start of the Great Depression in 1929 began just as Ash, Howard, Needles & Tammen had turned a year old. The firm experienced the tragic loss of Ash due to illness the following year, most likely attributable to his earlier decent into pier caissons during a personal inspection of the Vicksburg Bridge being constructed over the Mississippi River. Several of the firm's other bridges were also entering the construction phase in 1929, such as the Burlington-Bristol Bridge over the Delaware River with its record-breaking 540-ft vertical lift span (Figure 1.4). Even though, the prevailing financial panic drastically curtailed prospects for new design work.

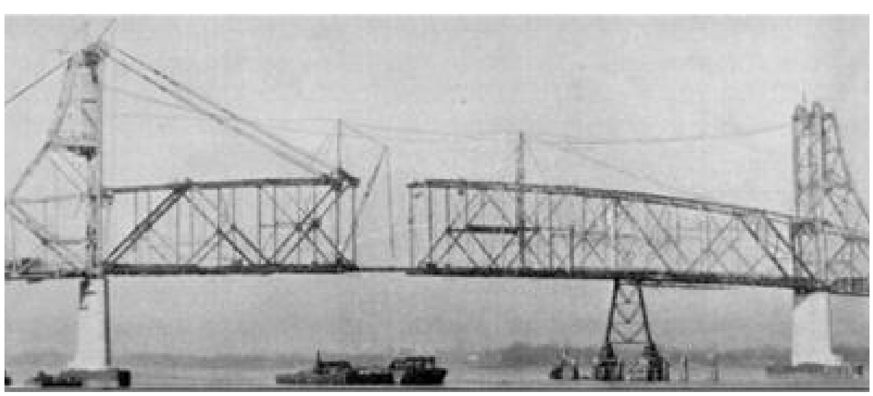


Figure 1.4 Construction of Lift Span on Burlington-Bristol Bridge.

Two of Franklin D. Roosevelt's first acts upon entering the presidency in 1933 were to increase funding for the Reconstruction Finance Corporation (RFC), created by President Herbert C. Hoover in 1931, from $300 million to $3 billion and to create the Public Works Administration (PWA). The experience Needles gained in New York City through interactions with bankers on revenue bond projects made him particularly adept at acquiring funds for infrastructure projects from the RFC and PWA in Washington, but it was his preparedness as an engineer by which necessary permits and plans awaited this financial opportunity.

As the Great Depression came to a close and worldwide aggression culminated into World War II, 1941 marked a rebirth at the firm under a new partnership of Howard, Needles, Tammen & Bergendoff (HNTB). Ruben N. Bergendoff's persistence resulted in employment with the firm (i.e., Harrington, Howard & Ash) in 1922 despite Harrington's warnings that "all of the big bridges have been built." After being laid off at the onset of the depression, Bergendoff returned to the firm's Kansas City office in 1933 as the chief designer of the 2,126-ft long South Omaha Bridge, a continuous warren through truss bridge over the Missouri River between Omaha, Nebraska and Council Bluffs, Iowa – proof that not all of the big bridges had been built.[2]

The company's role as predominantly a bridge design firm took a dramatic turn in response to the War Department's need for the construction of military facilities during World War II. HNTB soon came to oversee the development of facilities that included railways, airfield runways, highways, drainage structures, buildings water and wastewater systems, and gas and electrical distribution systems. Experiences that came with wartime projects such as the Southwestern Proving Grounds in Hope, Arkansas and the Bluebonnet Ordinance Plant (Naval Weapons Industrial Reserve Plant) near Waco, Texas prepared the firm for an expanded role in the design of civil works.

Major work in the area of toll road design began when the newly formed Maine Turnpike Authority selected the firm as its consulting engineer near the end of World War II in 1945. Unlike previous toll road projects in the United States, the Maine Turnpike was the first to be financed entirely with private capital, backed by revenue bond issues. The success of this project provided bankers and public agencies with the confidence to pursue similar toll roads in other states. HNTB was often selected to provide general engineering consultant (GEC) services based on the experiences the firm acquired by managing multiple teams of specialists during the development of military facilities for the War Department. HNTB's performance as GEC for the 118-mile New Jersey Turnpike (opened 1952), the firm's first major project in this capacity, led to many subsequent GEC contracts, such as the Kansas City Turnpike and the Florida Turnpike (Figure 1.5). With passage of the National Interstate and Defense Highway Act by President Dwight D. Eisenhower in 1956 came the opportunity to apply its experience with turnpikes to the development of the interstate highway system.

Figure 1.5 Portion of Original 109-Mile Florida Turnpike.

Previous experience in project finance and in the development of military facilities created additional business opportunities as passenger air travel began to grow during the 1950s. The firm's initial consulting services to Miami International Airport on financial issues grew to include all aspects of airport design. HNTB was able to apply its pavement design knowledge to major runway expansion projects at the airport (Figure 1.6), and capitalized on its ability to administer revenue bond programs by securing the role of GEC to the airport. The firm's long-term commitment to offering a full range of aviation services eventually materialized as a consolidation of aviation staff in its Alexandria, Virginia office in 1971.

Figure 1.6 Pavement Construction at Miami International Airport.

Inevitable conflicts between infrastructure development and population growth in the United States culminated in a modern environmental movement that began in the late 1960s. The adverse effects of growing vehicle use on the expanding roadway network was perhaps first brought to the public's attention by the 1969 blowout of an oil well off the coast of Santa Barbara, California. In this event, the decision by Union Oil Company of California (Unocal) not to install well casing to sufficient depths from Platform Alpha resulted in a significant oil spill that polluted the Santa Barbara County shoreline. Concern for air quality also grew during this time, first from large scale releases of pollutants by factories and power plants, and then from the shear numbers of smaller releases by vehicles that used the extensive roadway network. The National Environmental Protection Act (NEPA) signed by Richard M. Nixon in 1969 represented a landmark shift toward national polices that would “encourage productive harmony between man and his environment.”[3]

Along with NEPA, core provisions of the Clean Air Act (1970) and the Clean Water Act (1972) guided greater resources toward environmental quality and pollution remediation. In response to the new requirements mandated by these polices, HNTB expanded its services to include environmental consulting by acquiring the Indianapolis-based sanitary engineering consulting firm of Henry B. Steeg & Associates in 1973. This acquisition gave the firm capabilities beyond the experience gained in preparing environmental impact studies for transportation projects, providing expertise in the unrelated but highly important area of water and wastewater treatment.[2]

Other mergers and acquisitions during the 1970s expanded HNTB’s services in chemical, electrical and mechanical engineering (Frankfurter & Associates) and architecture (Kivett & Myers). Although HNTB’s origins rest in the design of railroad bridges, it was not until the acquisition of T.K. Dyer in 1982 that it became a full-service firm to the railroad industry. This addition brought expertise in track and signal design for railroad and public transit infrastructure, leading to work on projects such as the reconstruction of the Boston-to-Washington, DC high-speed rail corridor.

1.2 HNTB Corporate Structure

HNTB Corporation is an employee-owned organization comprised of Infrastructure, Architecture, and Federal Services practice areas. The chief executive officer (CEO) of HNTB Corporation presides over the presidents of six divisions in addition to the chief sales officer, finance officer, contracting officer, and chief operations officer, as shown in Figure 1.7. The chief sales officer guides the efforts of individuals that serve as national marker sector leaders, who in turn facilitate interactions between the company and their respective markets and provide council to group leaders.

As Figure 1.8 shows, the Austin office is a component of the South Central District of HNTB's Central Division along with other offices in Texas, Louisiana, and Mississippi. Office leaders report to the Central Division President, who also presides over the division sales officer, business manager, human resources (HR) consultant, and operations officer.

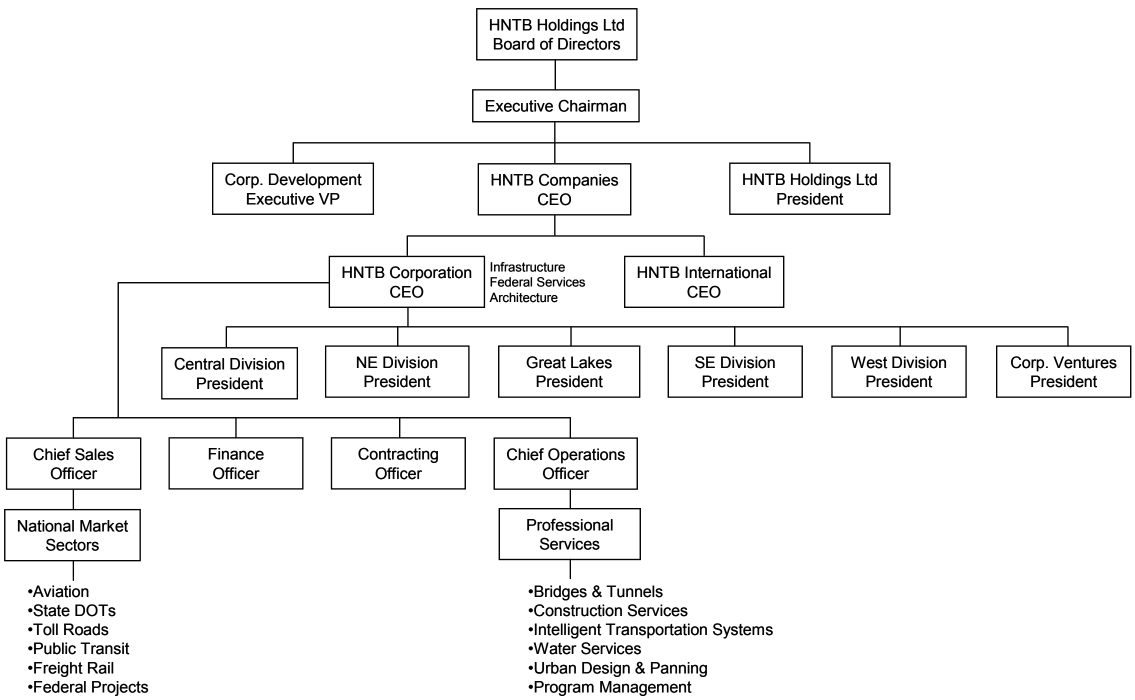


Figure 1.7 HNTB Companies Corporate Structure.

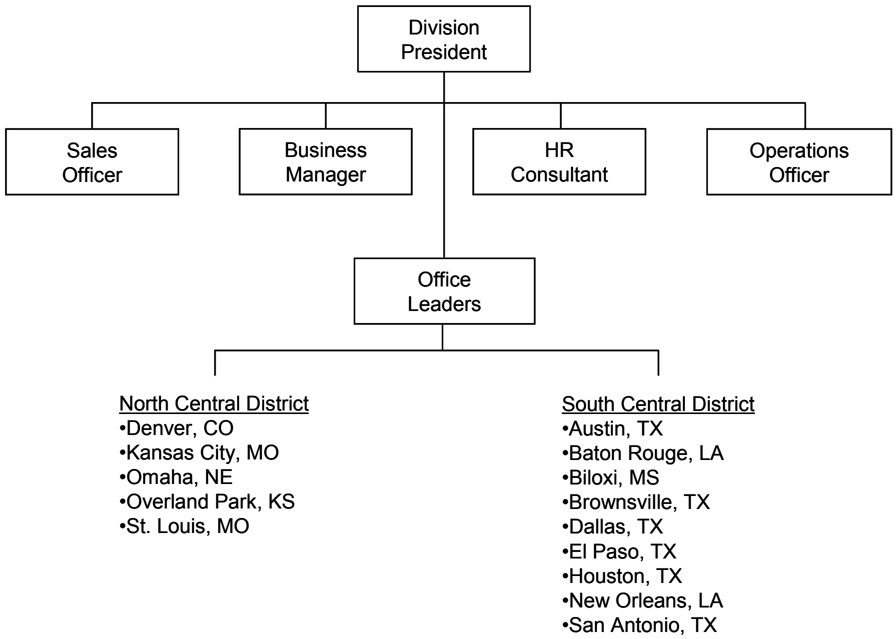


Figure 1.8 HNTB Corporation Central Division Structure.

1.3 Description of Internship Position

In January 2002, Texas Governor Rick Perry had presented the Texas Transportation Commission with a vision for a network of new multimodal corridors throughout the state, named the Trans-Texas Corridor (TTC). The purpose of the Texas Department of Transportation (TxDOT) had historically been to plan, design, construct, and maintain the state's roadway system, with virtually no emphasis on the planning and design of freight and passenger rail facilities that the TTC would require. HNTB's Texas Rail Group was established in Austin by Mr. Joe Lileikis two years later in order to provide the state with railroad expertise that was unavailable to the agency internally.

The rail group has grown in the last several years to include a staff of nine engineers with expertise in railroad planning, civil site design, track design, railroad bridge design, and project feasibility assessment. This group, with Mr. Lileikis now serving as HNTB Associate Vice President and Central Division Rail Market Sector Leader, is managed by a team of engineers that average over 25 years of experience with Class I and shortline freight railroads, Amtrak's northeast corridor, and engineering consulting firms that serve the rail industry. Figure 1.9 shows the relationship between the rail group staff, the Austin office and Central Division management, and the client and market leadership.

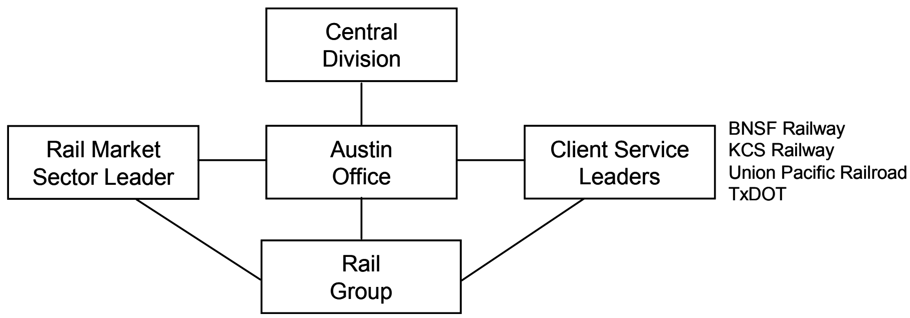


Figure 1.9 HNTB Rail Group-Client Relationships.

Rail projects performed at the Austin office have expanded beyond the TTC concept to include traditional engineering services such as the design and construction of new or relocated corridors, railroad bridge inspections, and the development of passenger rail systems. As state populations and the need for transportation continue to grow, public agencies have become more interested in the evaluation of rail-related issues out of concern for the environment and public welfare. Considering that freight and passenger rail transportation is fuel efficient, can relieve roadway congestion, and lessens the burden of pavement maintenance, rail infrastructure is now foreseen by the public sector as a solution to some of today's transportation problems. On the other hand, the spread of urban centers and the associated conflicts between the daily lives of their inhabitants and local railroad operations has heightened concerns over railroad-roadway grade crossing safety, roadway mobility, and exposure to the transport of hazardous materials (Figure 1.10).

Figure 1.10 Railroad Tank Car used for Transport of Hydrochloric Acid.

Public agencies have begun to seek the cooperation of private railroads in recent years as the interdependence of both sectors in creating safe and effective transportation systems becomes more apparent. Public participation has gone even further through passage of legislation that permits the expenditure of public funds on rail infrastructure, such as the Texas Rail Relocation and Improvement Fund and the federal Rail Line Relocation and Improvement Capital Grants Program. These legislative developments have created a need for new decision-making strategies that quantify the benefits of public sector rail investments to their costs and help formulate cost-sharing strategies for public-private partnerships. The Doctor of Engineering internship, under the supervision of Mr. Lileikis, has focused on developing decision-making strategies that the Austin Rail Group can use to advise both public and private sector clients on rail infrastructure investments.

1.4 Internship Objectives

The primary intent of the Doctor of Engineering internship is to apply engineering analysis knowledge and skills to economic, financial, and risk assessments in a way that complements and strengthens the Austin Rail Group's capabilities in rail planning and design. The work assignments and products completed during the internship are intended to enhance the company's position as a comprehensive provider of rail services by elevating the decision-making capabilities of both public and private clients in their capital budgeting process. The degree to which the intent of this internship has been met is structured around the completion of four fundamental objectives, as outlined below. Appendix A contains a final report submitted by Mr. Lileikis (the internship supervisor) that discusses the adequacy of each completed objective in meeting the needs of HNTB Corporation.

Objective 1

Rail relocation projects are usually proposed to eliminate train-automobile conflicts at grade crossings, and may involve the relocation of an entire rail corridor from a high population density area to a low population density area. Models that are currently used to calculate the public costs associated with blocked grade crossings require broad assumptions to be made about train characteristics. Furthermore, these models are generally intended to analyze specific grade crossings or, at most, a series of grade crossings on a rail corridor. The relocation of a rail corridor within a rail network may actually alter railroad operations throughout the network, requiring each grade crossing in a region to be analyzed. A new model capable of analyzing an entire rail network should use transportation engineering equations that have been adopted by governmental authorities in order to maintain the credibility of the results. Therefore, fulfillment of Objective 1 (Chapter II) is intended to:

> *Demonstrate the effective transformation of standard mathematical solutions into equations and computational tools that meet the unique needs of industry.*

Objective 2

The densification of urban populations around rail corridors has, in effect, increased the potential exposure of these populations to rail-transported hazardous materials. While railroads are required by law to provide service to shippers of hazardous materials, public agencies are seeking ways to reduce the risk of exposure to these materials. Since the exposure to rail-transported hazardous materials has just recently become a major public issue, the analysis of this problem must establish how these risks are quantified and determine the most readily available means of mitigating the risks in light of public funding constraints. The reasonableness of various mitigation strategies can be examined by applying available academic research to actual case studies as fulfillment of Objective 2 (Chapter III), which is intended to:

> *Demonstrate an appropriate selection and application of published literature to evaluate the effects of proposed transportation policy.*

<u>Objective 3</u>

The loss of a timber railroad bridge due to fire occurs more frequently than might be expected. This problem might be viewed as strictly a private-sector concern if it were not for the fact that the financial distress caused by a bridge loss could force a marginally profitable railroad out of business, requiring freight that was previously shipped by rail to use the roadway system. While performing a risk analysis of a specific railroad's finances is impractical, particularly when considering the proprietary information that would be needed, a generic model can be prepared that provides insight to the potential for financial distress. The development of this model represents fulfillment of Objective 3 (Chapter IV), which is intended to:

> *Use accounting principles to transform inventories of infrastructure data into relative financial risks associated with a corporation's loss of a physical asset.*

<u>Objective 4</u>

The railroad industry's cost of capital is an important determinant in establishing revenue adequacy for rail line abandonment cases, resolving disputes on shipping rates, negotiating trackage rights, and in reviewing merger applications. The analysis of engineering projects is typically more focused on identifying relevant cash flows than with determining an appropriate discount rate, particularly when the analysis is performed within an organization where the cost of capital is known internally. In cases where consulting services are provided to both a public and private sector client, as in the case of a public-private partnership, the engineer must rely on publicly available information when selecting discount rates for an economic analysis. Fortunately, sufficient information exists to determine cost of capital when the private sector client is a public company. The application of public information to evaluate projects from the perspective of corporations represents fulfillment of Objective 4 (Chapter V), which is intended to:

> *Apply methodologies used in financial markets to the development of parameters required to perform engineering economic analyses.*

1.5 Organization of this Record of Study

The outline of the record of study is as follows:

- Chapter I – Introduction
    - HNTB Corporate History
    - HNTB Corporate Structure
    - Description of Internship Position
    - Internship Objectives
- Chapter II – Simulation-Based Regional Grade Crossing Analysis
    - FRA Impedance Analysis Method
    - Rationale for a New Approach
    - An Alternative Impedance Analysis Method
    - Application of the Alternative Methodology
        - Example Cases
    - Academic and Industry Observations
- Chapter III – Application of Risk Assessment to Public Policy
    - Hazardous Materials Exposure Risk Factors

    - Emergency Response Actions
    - Probability of Hazardous Material Release
    - Railroad Corridor Exposure Risk
    - Approaches to Exposure Risk Mitigation
        - Example Cases
    - Academic and Industry Observations
- Chapter IV – Financial Risk of a Timber Railroad Bridge Catastrophe
    - Risk Assessment Methodology
    - Incorporation of Industry Data
    - Trend Analysis
    - Applications of the Methodology
    - Academic and Industry Observations
- Chapter V – Use of Financial Market Data in Railroad Negotiations
    - Calculating Cost of Capital
        - Cost of Equity
        - Cost of Capital
    - Application of Cost of Capital to Negotiations
        - Net Present Value Analysis
    - Academic and Industry Observations
- Chapter VI – Summary and Conclusions
    - Summary
    - Conclusions
- Appendix A – Final Report by the Internship Supervisor
- Appendix B – Sample Grade Crossing Analysis Computer Code
- Appendix C – Hazardous Materials List

CHAPTER II

SIMULATION-BASED REGIONAL GRADE CROSSING ANALYSIS

As the boundaries and population densities of urban areas continue to grow, conflicts between trains and automobile traffic at highway-rail grade crossings become more burdensome to society. Measurement of the time that vehicles are impeded by trains at these grade crossings is inexact due to the variability of both vehicle and train traffic that occur on a daily and, in fact, hourly basis. Yet the public sector has begun to focus more attention on reducing grade crossing conflicts and finds it important to understand the real societal costs of impedance before spending scarce resources at any one location. Practical approaches to calculating impedance are constrained by the degree of accuracy in traffic data and the level of effort that can be committed to an analysis.

The Federal Railroad Administration (FRA) has made considerable advancements over time in providing state and local authorities with a practical means of measuring grade crossing impedance with its GradeDec.Net program. This web-based application is intended to be used as an investment analysis tool in support of the resource allocation decisions faced by transportation officials.[4] The FRA methodology uses impedance and safety as the two primary sources of public cost associated with vehicle-train interactions, with distinctly separate methods of denominating their effects on society. Despite the advances made in measuring the effects of grade crossing impedance, this methodology is not well suited to the analysis of investments in railroad infrastructure that affect entire rail networks, such as with the construction of a rail bypass around a metropolitan area.

This chapter presents a new grade crossing analysis methodology that can be used to efficiently analyze an entire rail network while preserving the mathematics behind the transportation engineering equations adopted by the FRA. The information in this chapter fulfills Objective 1, which is intended to:

> *Demonstrate the effective transformation of standard mathematical solutions into equations and computational tools that meet the unique needs of industry.*

2.1 FRA Impedance Analysis Method

Conflicts between trains and automobile traffic at highway-rail grade crossings are predicted using roadway traffic data on file with public agencies and train data either provided by railroad companies or compiled through independent observation. Differentiation of the roadway traffic mix in GradeDec.Net is made according to percentages of cars, trucks, and buses within the average daily traffic (ADT). A convenient aspect of using ADT data is the ease with which the mix of vehicle types can be converted to an equivalent number of standard vehicles that are likely to interact with train traffic, resulting in delay time and time-in-queue estimates in units of vehicle-hours. These volumes are ultimately used to estimate arrival rates and build-up rates of queues at blocked grade crossings.

The FRA bases traffic arrival and departure patterns at a blocked roadway on equations derived from a simplified form of queuing theory for a roadway bottleneck. Figure 2.1 illustrates the simplified model for the upstream behavior of an undersaturated traffic signal (same as a blocked grade crossing), based on a vehicle arrival rate (λ), departure rate (μ), and free flow speed (v).[5] The extent of roadway queuing is shown by a progression in cumulative numbers of vehicles affected during queue build-up (B_1) and a constant number of vehicles affected during restoration to free flow speed (B_2). Figure 2.1 also shows that D_1 represents the number of dispersed vehicles (zero vehicles) while the grade crossing is blocked (point L to point J), and D_2 represents the cumulative number of dispersed vehicles that have returned to free flow speed.

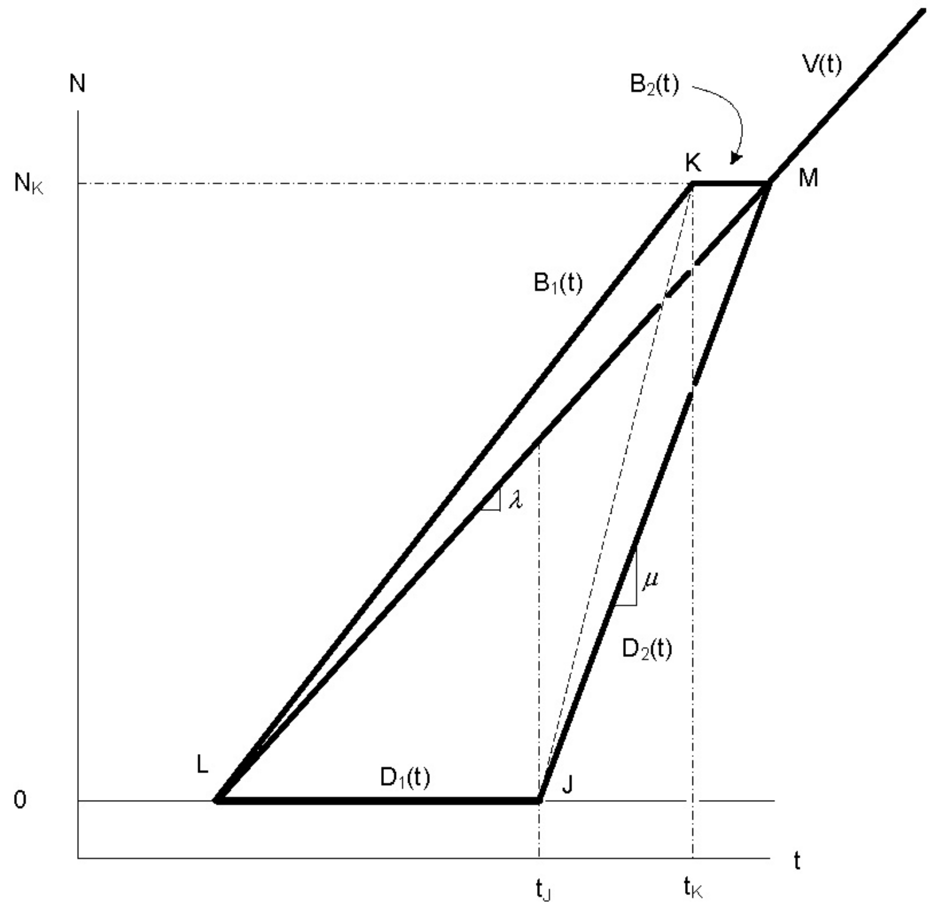


Figure 2.1 Traffic Arrival and Departure Patterns at Blocked Roadway.

Delay time represents the time required for a vehicle to traverse a blocked grade crossing in excess of the time that would be required if no train had impeded its progress. Time-in-queue is equal to the time that a vehicle actually spends waiting in a queue at the blocked grade crossing, and has been shown to be a fixed multiple of delay.[6] Together, delay time and time-in-queue represent the temporal measure of impeded vehicle mobility. The basic train characteristic used by the FRA to determine grade crossing impedance is the crossing block time (*CBT*) for a specified time interval – grade crossing safety, on the other hand, is a function of train volume and maximum allowable track speed. Of the two impedance measures, delay time is used to determine the cost of time wasted by motorists at blocked grade crossings, and time-in queue is used to determine the cost of fuel and oil consumed and engine emissions released by vehicles that are queued at the blocked crossing.

Grade Crossing Block Time

The FRA methodology characterizes railroad events at grade crossings by calculating a separate *CBT* (in minutes) for passenger, freight, and switch trains. Since variability in train length (L_{tr}) and train speed (S_{tr}) is expected, average lengths and speeds are assumed for each of these three train types when calculating *CBT* using Eq. 2.1.

$$CBT = \frac{L_{tr}}{S_{tr}(5280/60)} + \frac{36}{60} \qquad (2.1)$$

An average crossing block time (*ACBT*) is used in the remainder of FRA delay and time-in-queue equations, based on a weighted average of the *CBT* for numbers of passenger (n_p), freight (n_f), and switch (n_s) trains (Eq. 2.2).[4] Consequently, the total time that vehicles are prevented from entering a grade crossing is a weighted average of average block times for three discrete train types.

$$ACBT = \frac{n_p CBT_p + n_f CBT_f + n_s CBT_s}{n_p + n_f + n_s} \qquad (2.2)$$

Delay Time and Time-in-Queue

ACBT is used to determine the number of vehicles per lane affected by a blocked crossing (N_K) using Eq. 2.3. The vehicle departure rate (μ) is assumed constant at 0.5 vehicles/lane-second, while the average vehicle arrival rate (λ) is found using Eq. 2.4.

$$N_K = \frac{60\lambda\mu ACBT}{\mu - \lambda} \qquad (2.3)$$

$$\lambda = \frac{PCE}{(lanes)(hrs/period)(3600)} \qquad (2.4)$$

The passenger car equivalents (PCE) in Eq. 2.4 is equal to the average daily traffic (ADT) on the roadway multiplied by the sum of percent cars, 1.8 times the percent trucks, and 2.73 times the percent buses in the vehicle mix. Delay time (*w*) is then calculated according to the FRA equation shown as Eq. 2.5, and time-in-queue (t_q) is calculated according to Eq. 2.6.

$$w = N_K \left[60ACBT + \left(\frac{1}{\mu} - \frac{1}{\lambda} \right) \left(\frac{N_K + 1}{2} \right) \right] \frac{lanes}{3600} \quad (2.5)$$

$$t_q = N_K \left[60ACBT + \left(\frac{1}{\mu} - \frac{1}{z} \right) \left(\frac{N_K + 1}{2} \right) \right] \frac{lanes}{3600} \quad (2.6)$$

The calculation of time-in-queue in Eq. 2.6 is a function of the rate of growth at the back of the queue (z), shown as Eq. 2.7. This rate of growth is controlled by the free flow vehicle speed (v) of the roadway and a vehicle queue density (k) assumed constant at 0.05 vehicles/lane-foot.

$$z = \frac{\lambda v k}{vk - \lambda} \quad (2.7)$$

2.2 Rationale for a New Approach

The FRA methodology bases delay time and time-in-queue calculations on a weighted average of block times for passenger, freight, and switch trains (Eq. 2.2). Each of these block times are themselves a function of an average train length and train speed per train type (i.e., passenger, freight, and switch). Restricting the analysis to three pre-defined train types requires the use of averaging at a level that unnecessarily generalizes train behavior, perhaps for the sake of avoiding what is foreseen as a highly iterative process.

Considering that delay time (Eq. 2.5) and time-in-queue (Eq. 2.6) are functions of both *ACBT* and N_K, and that N_K is itself a function of *ACBT*, any deviation in *ACBT* from the true grade crossing block time will be magnified when the term is squared (i.e., inserting Eq. 2.3 into Eq. 2.5 and Eq. 2.6). The generalization of train behavior using *ACBT* may be even less desirable when performing a major investment study on the construction of a rail bypass around a metropolitan area. Rail bypasses are designed to accommodate freight trains that would otherwise pass through the metropolitan area (e.g., intermodal, grain, etc.) while freight trains that service local customers (e.g., coal, rock, etc.) remain active on the original lines. For these projects, transportation officials may desire a more accurate description of the effects that each train type has on grade crossing impedance.

The accuracy of delay time and time-in-queue calculations using the FRA methodology in Eq. 2.5 and Eq. 2.6 are dependent on how well roadway and train parameters represent actual train-vehicle interactions at a grade crossing. GradeDec.Net typically captures fluctuations in vehicle traffic over 24 hours by distributing ADT among four six-hour periods of equal duration (early AM, late AM, early PM, and late PM), where one of the unique distribution profiles of vehicle traffic shown in Figure 2.2 is selected by the GradeDec.Net user. For example, the "AM Peak" distribution profile assumes that 50 percent of ADT occurs between 6 AM and 12 PM.

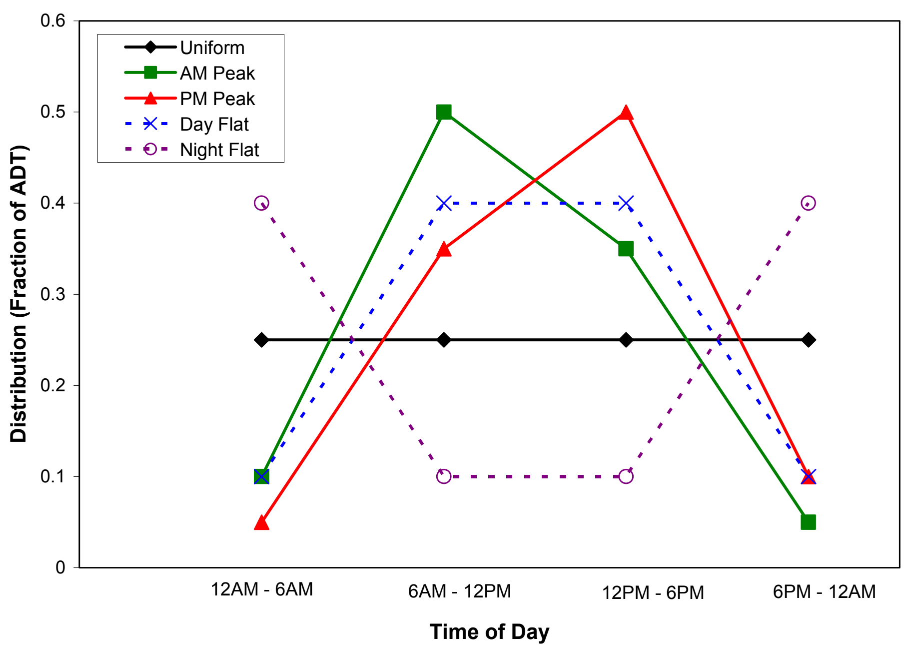


Figure 2.2 GradeDec.Net Traffic Distribution Profiles.

Table 2.1 includes sample train data for a rail corridor similar to that compiled by the Austin Rail Group in the assessment of a regional rail network in Texas. In this particular sample, all trains would be classified in GradeDec.Net as either freight or switch trains despite the fact that some of these train events are actually only yard engine moves. Regardless of how each of these train events are grouped into freight and switch train categories, each group would have significant variability in both train length and train speed. For example, consolidating local, work/power, and yard engine movements in Table 2.1 into the switch train category would require a statistical distribution of switch train length that captures a variation of 2,000 feet, and a distribution of freight train length that captures a variation of 3,400 feet. Since the FRA methodology also uses a single average speed to describe freight train movements and a single average speed to describe switch train movements, the level of detail provided in Table 2.1 would unnecessarily be generalized when calculating *ACBT*.

Table 2.1 Sample Train Data for Single Rail Corridor.

Train Type	Daily Train Count	Train Speed (mph)	Train Length (ft)
Auto	4	30.4	6000
Manifest	16	25.5	7200
Intermodal	6	24.6	6300
Shortline	1	13.6	5000
Priority Manifest	16	26.6	5200
Loaded Coal	3	20.2	7200
Empty Coal	3	26.2	7200
Empty Grain	3	26.0	6000
Loaded Grain	3	23.2	6000
Other Unit	1	31.4	3800
Local	3	18.2	2500
Work/Power	1	13.9	1300
Yard Engine	6	8.9	50

GradeDec.Net uses probability distributions for the train length and train speed of each train type to describe the variability in *CBT* for passenger, freight, and switch trains in Eq. 2.2.[4] However, Table 2.1 shows that the variability in these parameters can be quite large when numerous train types must be generalized according to only three train types. GradeDec.Net then uses a single *ACBT* to calculate delay time and time-in-queue at a grade crossing, which is then multiplied by the total number of daily trains at a percentage of these trains that operate during the appropriate six-hour time period (early AM, late AM, early PM, and late PM).

2.3 Alternative Impedance Analysis Method

The current FRA methodology unnecessarily generalizes train events by classifying all train operations according to passenger, freight, or switch service. Rather than assigning average values to these three train types, each discrete train event on record can be incorporated into impedance calculations by separating roadway parameters from train parameters in Eq. 2.5 and Eq. 2.6.

The incorporation of discrete train events into grade crossing impedance calculations implies that actual crossing block times will be used instead of an average crossing block time; that is, the methodology should be based on a collection of *CBT* values as opposed to an *ACBT*. Therefore, the number of vehicles affected by a blocked crossing (N_K) first shown as Eqn. 3 is now a function of *CBT*, as shown as Eq. 2.8.

$$N_K = \frac{60\lambda\mu CBT}{\mu-\lambda} \qquad (2.8)$$

For the case of delay time, Eqn. 2.8 is substituted into Eq. 2.5 to give Eq. 2.9.

$$w = \frac{60\lambda\mu CBT}{\mu-\lambda}\left[60CBT + \left(\frac{1}{\mu}-\frac{1}{\lambda}\right)\left(\frac{60\lambda\mu CBT/(\mu-\lambda)+1}{2}\right)\right]\frac{lanes}{3600} \qquad (2.9)$$

The bracketed terms in Eq. 2.9 can be expressed as shown in Eq. 2.10.

$$w = \frac{60\lambda\mu CBT}{\mu-\lambda}\left[60CBT + \left(\frac{1}{\mu}-\frac{1}{\lambda}\right)\left(\frac{60\lambda\mu CBT}{2(\mu-\lambda)}+\frac{1}{2}\right)\right]\frac{lanes}{3600} \qquad (2.10)$$

Eq. 2.10 is expanded to give:

$$w = \left[\frac{3600\lambda\mu CBT^2}{\mu-\lambda} + \left(\frac{1}{\mu}-\frac{1}{\lambda}\right)\left(\frac{3600\lambda^2\mu^2 CBT^2}{2(\mu-\lambda)^2}\right) + \left(\frac{1}{\mu}-\frac{1}{\lambda}\right)\left(\frac{30\lambda\mu CBT}{\mu-\lambda}\right)\right]\frac{lanes}{3600} \qquad (2.11)$$

The numerical values in Eq. 2.11 are reduced and roadway parameters are isolated from *CBT* as follows:

$$w = lanes\left[\frac{\lambda\mu}{\mu-\lambda}+\left(\frac{1}{\mu}-\frac{1}{\lambda}\right)\left(\frac{\lambda^2\mu^2}{2(\mu-\lambda)^2}\right)\right]CBT^2 + lanes\left(\frac{1}{\mu}-\frac{1}{\lambda}\right)\left(\frac{\lambda\mu}{120(\mu-\lambda)}\right)CBT \quad \text{...(2.12)}$$

Eq. 2.12 can be rewritten in terms of *CBT* and coefficients α and β, which are strictly functions of FRA roadway parameters, to express delay time as shown in Eq. 2.13. Units for the coefficients α and β are vehicle-hours/min^2 and vehicle-hours/min, respectively.

$$w = \alpha CBT^2 + \beta CBT \quad \text{........(2.13)}$$

Where,

$$\alpha = lanes\left[\frac{\lambda\mu}{\mu-\lambda}+\left(\frac{1}{\mu}-\frac{1}{\lambda}\right)\left(\frac{\lambda^2\mu^2}{2(\mu-\lambda)^2}\right)\right] \quad \text{........(2.14)}$$

$$\beta = lanes\left(\frac{1}{\mu}-\frac{1}{\lambda}\right)\left(\frac{\lambda\mu}{120(\mu-\lambda)}\right) \quad \text{........(2.15)}$$

The case of time-in-queue (Eq. 2.16) has the same form as delay time (Eq. 2.13), but with z substituted for λ in coefficients α and β as shown in Eq. 2.17 and Eq. 2.18.

$$t_q = \alpha CBT^2 + \beta CBT \quad \text{........(2.16)}$$

Where,

$$\alpha = lanes\left[\frac{\lambda\mu}{\mu-\lambda}+\left(\frac{1}{\mu}-\frac{1}{z}\right)\left(\frac{\lambda^2\mu^2}{2(\mu-\lambda)^2}\right)\right] \quad \text{........(2.17)}$$

$$\beta = lanes\left(\frac{1}{\mu}-\frac{1}{z}\right)\left(\frac{\lambda\mu}{120(\mu-\lambda)}\right) \quad \text{........(2.18)}$$

Since the *CBT* used to calculate delay time (Eq. 2.13) and time-in-queue (Eq. 2.16) is for a single train event, whereas the FRA methodology uses *ACBT* to represent all train events, total impedance can be represented as the sum of impedance values for each discrete train event. Using delay time as an example, total delay time (w_T) can be expressed as the summation of the numbers of trains for each train type (n_i) times the delay time for each train type (w_i) for all train types (N), as shown in Eq. 2.19.

$$w_T = \sum_{i=1}^{N} n_i w_i \text{ .... (2.19)}$$

Substituting Eq. 2.13 into Eq. 2.19 gives the modified solution to delay time, as follows:

$$w_T = \sum_{i=1}^{N} n_i \alpha CBT_i^{\,2} + \sum_{i=1}^{N} n_i \beta CBT_i \text{ .... (2.20)}$$

Since the FRA methodology captures fluctuations in vehicle data by distributing traffic volumes according to time periods, and since α and β are constant for a given time period (i.e., ADT is constant), w_T for a specific time period can be determined using Eq. 2.21. The solution described for delay time in Eq. 21 is also applicable to time-in-queue except that Eq. 2.17 and Eq. 2.18 are used to calculate α and β instead of Eq. 2.14 and Eq. 2.15.

$$w_T = \alpha \sum_{i=1}^{N} n_i CBT_i^{\,2} + \beta \sum_{i-1}^{N} n_i CBT_i \text{ .... (2.21)}$$

2.4 Application of Alternative Methodology

Three cases are examined that compares the FRA methodology to the modified solution for calculating delay time presented in Eq. 2.20. In each case, a single grade crossing is evaluated assuming an ADT of 2,400 cars (no trucks or buses), one lane, and a free flow speed of 35 mph.

Case 1: Single Freight Train

A single 7,000-foot freight train operates at 25 mph during the early PM over a grade crossing having an "AM Peak" distribution of vehicle traffic (see Figure 2.2). The allocation of vehicles over four six-hour time periods for a grade crossing of 2,400 ADT is shown in Table 2.2, which shows that 840 vehicles enter the grade crossing during the early PM.

Table 2.2 Vehicle Traffic Distributions for Case 1.

Time Period	Time Window	Distribution of ADT	Vehicles
Early AM	12AM - 6AM	0.10	240
Late AM	6AM - 12PM	0.50	1200
Early PM	12PM - 6PM	0.35	840
Late PM	6PM - 12AM	0.05	120

Delay time is calculated using the FRA methodology as follows:

$$CBT = \frac{7000}{25(5280/60)} + \frac{36}{60} = 3.7818$$

$$\lambda = \frac{840}{(1)(6)(3600)} = 0.03889$$

$$N_K = \frac{60(0.03889)(0.5)(3.7818)}{0.5 - 0.03889} = 9.5684$$

$$w = 9.5684\left[60(3.7818) + \left(\frac{1}{0.5} - \frac{1}{0.03889}\right)\left(\frac{9.5684+1}{2}\right)\right]\frac{lanes}{3600} = 0.2700$$

Delay time is calculated using the modified solution as follows:

$$\alpha = (1)\left[\frac{(0.03889)(0.5)}{0.5-0.03889} + \left(\frac{1}{0.5} - \frac{1}{0.03889}\right)\left(\frac{(0.03889)^2(0.5)^2}{2(0.5-0.03889)^2}\right)\right] = 0.02108$$

$$\beta = (1)\left(\frac{1}{0.5} - \frac{1}{0.03889}\right)\left(\frac{(0.03889)(0.5)}{120(0.5-0.03889)}\right) = -0.00833$$

$$w = (0.02108)(3.7818)^2 + (-0.00833)(3.7818) = 0.2700$$

Thus, Case 1 shows that the FRA methodology (Eq. 2.5) and the modified solution (Eq. 2.13) yield the same delay time (0.2700 vehicle-hours) since there can be no generalization of train behavior for a single train event.

Case 2: Single Freight and Switch plus Freight Trains

In addition to the single 7,000-foot freight train operating at 25 mph in the early PM in Case 1, a single 50-foot yard engine and a 7,000-foot freight train operates over the same grade crossing during the late AM. Table 2.2 shows that 1,200 vehicles enter the grade crossing during the late AM when the combined yard engine plus freight train activity occurs. Therefore, the events in each time period are accompanied by different roadway parameters as a result of unique vehicle arrival rates (see Eq. 2.4).

The *CBT* for a 7,000-foot freight train operating at 25 mph has been calculated in Case 1 as 3.7818 minutes. A similar calculation for a 50-foot yard engine operating at nine mph yields a *CBT* of 0.6631 minutes. Since both train types operate in the late AM time period, the FRA methodology requires the calculation of *ACBT* (Eq. 2.2) as follows:

$$ACBT = \frac{(1)(3.7818) + (1)(0.6631)}{2} = 2.2225$$

Results based on the FRA methodology are summarized in Table 2.3, including the *ACBT* of 2.22 minutes during the late AM and a *CBT* (i.e. a single train event) of 3.78 minutes during the early PM. The *ACBT* for the weighted average of a switch and freight train event during the late AM yields a delay time of 0.1358 vehicle-hours, and the *CBT* for the single freight train event during the early PM yields a delay time of 0.2700 vehicle-hours (same as Case 1).

Table 2.3 FRA Methodology Delay Time Parameters for Case 2.

Time Period	Train Event	Train Length (ft)	Train Speed (mph)	ACBT (min)	λ (veh/ln-sec)	N_K (veh/ln)	w (veh-hr)
Early AM	none	-	-	-	-	-	-
Late AM	Engine & Freight	50 & 7000	9 & 25	2.2225	0.0556	8.3345	0.1358
Early PM	Freight	7000	25	3.7818	0.0389	9.5684	0.2700
Late PM	none	-	-	-	-	-	-

Since delay times in Table 2.3 represent the effect of a single train event, total delay time (w_T) for a specific time period is the product of delay time (w) and the number of trains (n) in that period. The number of trains in a single time period using the FRA methodology is inclusive of all train types (i.e., passenger, freight, and switch), so the total delay time during late AM is:

$$w_T = (2)(0.1358) = 0.2716$$

The total delay time during early PM is:

$$w_T = (1)(0.2700) = 0.2700$$

Table 2.4 summarizes the roadway parameters needed to calculate delay using the modified solution, where the α and β roadway coefficients for the early PM time period are the same as in Case 1. The respective *CBT* for the yard engine and freight trains are 0.6631 minutes and 3.7818 minutes, so the total delay time during the late AM using the modified solution (Eq. 2.21) is:

$$w_T = (0.03125)[(1)(0.6631)^2 + (1)(3.7818)^2] + (-0.00833)[(1)(0.6631) + (1)(3.78)]$$
$$= 0.4237$$

The total delay time during early PM using the modified solution is:

$$w_T = 0.02108[(1)(3.7818)^2] + (-0.00833)[(1)(3.7818)] = 0.2700$$

Case 2 shows that the FRA methodology (Eq. 2.5) and the modified solution (Eq. 2.21) yield the same total delay time for early PM (0.2700 vehicle-hours) since there is a single train event in that time period. However, the two methods yield different total delay times for late AM since more than one train type operates in that time period.

The FRA methodology bases delay time on a weighted average block time (Eq. 2.2), which is multiplied by two train events to yield a total delay time of 0.2716 vehicle-hours during late AM. In contrast, the modified solution essentially sums the delay times of each train type to give a total delay time of 0.4237 vehicle-hours during the same time period. Since the modified solution uses exact block times for each train event, the FRA methodology is shown to unnecessarily underestimate total delay time in the late AM by 36 percent.

Table 2.4 Modified Solution Delay Time Parameters for Case 2.

Roadway Parameter	Time-of-Day			
	12AM-6AM	6AM-12PM	12PM-6PM	6PM-12AM
Distribution	0.10	0.50	0.35	0.05
PCE	240	1200	840	120
k (veh/ft-ln)	0.05	0.05	0.05	0.05
μ (veh/sec-ln)	0.5	0.5	0.5	0.5
λ (veh/sec-ln)	0.0111	0.0556	0.0389	0.0056
α (veh-hr/min^2)	0.00568	0.03125	0.02108	0.00281
β (veh-hr/min)	-0.00833	-0.00833	-0.00833	-0.00833

Case 3: Multiple Trains and Train Types

Case 3 is based on the sample train data shown in Table 2.1. This data is presented again in Table 2.5 with assumed distribution profiles for each train type according to the four six-hour time periods used in GradeDec.Net. For example, each of the four daily auto trains operates on the corridor in different time periods, resulting in a uniform distribution of 25 percent in each period. Each train type in Table 2.5 could be subdivided according to differences in train speeds and train lengths, but Case 3 assumes that these parameters are essentially constant. Alternatively, statistical distributions of train speed and train length could be applied to each train type, which would likely contain less variability than statistical distributions currently used to describe generalized train behavior for passenger, freight, and switch classifications.

Table 2.5 Assumed Daily Distributions of Trains for Case 3.

Train Type	Daily Train Count	Train Speed (mph)	Train Length (ft)	Time-of-Day Distribution Profiles			
				12AM-6AM	6AM-12PM	12PM-6PM	6PM-12AM
Auto	4	30.4	6000	0.25	0.25	0.25	0.25
Manifest	16	25.5	7200	0.25	0.25	0.25	0.25
Intermodal	6	24.6	6300	0.33	0.00	0.33	0.33
Shortline	1	13.6	5000	0.00	1.00	0.00	0.00
Priority Manifest	16	26.6	5200	0.25	0.25	0.25	0.25
Loaded Coal	3	20.2	7200	0.33	0.33	0.33	0.00
Empty Coal	3	26.2	7200	0.00	0.33	0.33	0.33
Empty Grain	3	26.0	6000	0.00	0.33	0.33	0.33
Loaded Grain	3	23.2	6000	0.33	0.33	0.33	0.00
Other Unit	1	31.4	3800	0.00	0.00	1.00	0.00
Local	3	18.2	2500	0.00	0.33	0.67	0.00
Work/Power	1	13.9	1300	0.00	0.00	1.00	0.00
Yard Engine	6	8.9	50	0.00	0.50	0.50	0.00

The FRA methodology requires each train listed in Table 2.5 to be defined as either freight or switch trains (there are no passenger trains in this example). Table 2.6 includes the likely list of freight trains with statistics summarizing the train count, average speed, and average length for each time period; Table 2.7 includes the likely list of switch trains and train statistics.

Table 2.6 FRA Methodology Freight Train Statistics for Case 3.

Train Type	Freight Train Counts			
	12AM-6AM	6AM-12PM	12PM-6PM	6PM-12AM
Auto	1	1	1	1
Manifest	4	4	4	4
Intermodal	2	0	2	2
Shortline	0	1	0	0
Priority Manifest	4	4	4	4
Loaded Coal	1	1	1	0
Empty Coal	0	1	1	1
Empty Grain	0	1	1	1
Loaded Grain	1	1	1	0
Other Unit	0	0	1	0
Totals	13	14	16	13
Avg. Speed (mph)	25.5	24.9	25.9	26.2
Avg. Length (ft)	6261	6214	6150	6261

Table 2.7 FRA Methodology Switch Train Statistics for Case 3.

Train Type	Switch Train Counts			
	12AM-6AM	6AM-12PM	12PM-6PM	6PM-12AM
Local	0	1	2	0
Work/Power	0	0	1	0
Yard Engine	0	3	3	0
Totals	0	4	6	0
Avg. Speed (mph)	-	11.2	12.8	-
Avg. Length (ft)	-	662	1075	-

Table 2.8 summarizes the parameters necessary for calculating delay time using the FRA methodology, where *ACBT* (Eq. 2.2) for each time period is the weighted average block time based on the train counts, average speeds, and average lengths of freight and switch trains listed in Tables 2.6 and 2.7.

Table 2.8 FRA Methodology Delay Time Parameters for Case 3.

FRA Parameter	FRA Methodology Calculations			
	12AM-6AM	6AM-12PM	12PM-6PM	6PM-12AM
ACBT (min)	3.39	2.96	2.82	3.32
λ (veh/sec-ln)	0.0111	0.0556	0.0389	0.0056
N_K (veh/ln)	2.31	11.09	7.13	1.12
n (trains)	13	18	22	13
w (veh-hr)	0.0371	0.2489	0.1441	0.0033
w_T (veh-hr)	0.4819	4.4783	3.1684	0.0427

In addition to evaluating each time period separately, total daily delay time is found by summing the results in Table 2.8 as follows:

$$w_T = 0.4819 + 4.4783 + 3.1684 + 0.0427 = 8.1713$$

The modified solution in Case 3 uses each discrete train event rather than statistical averages of freight and switch train classifications. This method matches the α and β roadway coefficients in Table 2.4 to each train event in Table 2.5.

Table 2.9 Modified Solution Delay Times for Case 3.

Train Type	Daily Count	CBT (min/train)	Modified Solution Calculations			
			12AM-6AM	6AM-12PM	12PM-6PM	6PM-12AM
Auto	4	2.84	0.0222	0.2289	0.1467	0.0000
Manifest	16	3.81	0.2027	1.6862	1.0964	0.0360
Intermodal	6	3.51	0.0814	0.0000	0.4606	0.0107
Shortline	1	4.78	0.0000	0.6735	0.0000	0.0000
Priority Manifest	16	2.82	0.0869	0.9010	0.5773	0.0000
Loaded Coal	3	4.65	0.0840	0.6364	0.4168	0.0000
Empty Coal	3	3.72	0.0000	0.4017	0.2609	0.0079
Empty Grain	3	3.22	0.0000	0.2973	0.1919	0.0023
Loaded Grain	3	3.54	0.0416	0.3615	0.2343	0.0000
Other Unit	1	1.98	0.0000	0.0000	0.0658	0.0000
Local	3	2.16	0.0000	0.1278	0.1609	0.0000
Work/Power	1	1.66	0.0000	0.0000	0.0444	0.0000
Yard Engine	6	0.66	0.0000	0.0247	0.0113	0.0000
w_T (veh-hr)			0.5189	5.3391	3.6674	0.0569

Results for the modified solution are listed in Table 2.9 for each train type, where Eq. 2.20 is used to calculate delay times for each time period. Total daily delay time is found by summing the results in Table 9 as follows:

$$w_T = 0.5189 + 5.3391 + 3.6674 + 0.0569 = 9.5824$$

Thus, the modified solution yields a total daily delay time of 9.58 vehicle-hours while the FRA methodology yields a total daily delay time of 8.17 vehicle-hours, a difference of 1.41 vehicle-hours per day under the grade crossing conditions assumed in these demonstration cases. Delay times for Case 3 based on the FRA methodology were consistently lower than delay times based on the modified solution for each of the four six-hour time periods, ranging from 7.1 percent lower during early AM to 25.1 percent lower during late PM. Consequently, the generalization of train behavior from what are actually diverse sets of field data (e.g., Table 2.5) can result in considerable underestimation of delay time.

2.5 Academic and Industry Observations

Objective 1 was established to address the Austin Rail Group's need to analyze the effects of capital investments that the public sector has recently proposed as a means of reducing highway-railroad grade crossing conflicts within large urban areas. These projects usually involve re-routing trains over new rail bypasses that consequently modify railroad operations on all existing corridors. Therefore, the effect of operational changes to a regional rail network requires a systems analysis, usually in the form of computer simulation, which produces large volumes of train data. The FRA GradeDec.Net model is tailored to small numbers of grade crossings and a few representative train types and, thus, is not well suited to the obligation of a consulting firm to its client – to provide an economic analysis that is grounded in sound engineering practice and adheres to the budget. In this particular case, adherence to sound engineering practice was demonstrated by integrating transportation engineering formulas that have been adopted by the governing agency (the FRA) into useful mathematical forms that provide clients with information of improved reliability at no greater cost.

A principle medium in which mathematical transformations have been emphasized in the Doctor of Engineering program is through theoretical coursework such as foundation and geotechnical engineering. For example, advanced foundation engineering requires the application of plasticity theory toward the derivation of bearing capacity equations suited to particular design scenarios. As with all engineering analyses, however, the accuracy of both the original and proposed grade crossing analysis methodologies are subject to the quality of information. Failure to properly simulate rail network operations or adjust for variability in roadway traffic volumes will lessen the degree of accuracy in these analyses. In contrast to a research oriented program, the Doctor of Engineering internship emphasizes the practical application of new developments, where computational models conform to existing software applications. As a result, rather than constructing a computer model using a code such as that outlined in Appendix B, a similar model was constructed for the Austin Rail Group using Microsoft Excel.

CHAPTER III

APPLICATION OF RISK ASSESSMENT TO PUBLIC POLICY

In addition to the exposure of automobiles to trains at highway-rail grade crossings, the densification of urban populations has also increased the exposure of the public to rail-transported hazardous materials. The transport of these materials has been essential to the functioning of the U.S. economy, delivering chemicals used to purifying drinking water, grow agricultural products, support industrial and manufacturing processes, and meet other needs demanded by society. The railroads carry close to two million shipments of hazardous materials each year, and are required to provide this service upon reasonable request as part of their common carrier obligation.[7] Nevertheless, the heightened concerns for national security in the early 2000s drew attention to the risks posed by shipments of hazardous materials by rail, prompting the Pipeline and Hazardous Materials Safety Administration (PHMSA), in consultation with the FRA and the Transportation Security Administration (TSA), to propose revisions to existing regulations.

A Notice of Proposed Rulemaking was issued by PHMSA in December 2006 regarding the enhancement of rail transportation safety and security for hazardous materials shipments, the primary intention of which was to require each railroad company to compile more extensive records on specific shipments of hazardous materials and analyze the safety and security risks along their respective routes.[7] The proposed rulemaking also intended for the railroads to assess alternative routing options and base their routing decisions according to this perceived level of safety and security risk. The public entities soon took the initiative to perform their own assessments of routing alternatives, often including the construction of new rail corridors around urban centers as a means of reduce the risk of exposure to hazardous materials.

In April 2007 the National Capital Planning Commission, which is charged with central planning for federal land and buildings in the Washington, DC area, completed a study that assessed the feasibility of reducing hazardous materials-related risk by constructing new rail alignments outside of the National Capitol vicinity.[8] At the state level, a bill prepared by the 80th Texas Legislature was enacted into law in June 2007 requiring a similar rail study to be prepared. Texas House Bill 160 called for an investigation into the economic feasibility of relocating freight trains that carry hazardous materials away from residential areas for municipalities having a population greater than 1.2 million.[9]

This chapter examines the economics of making different types of rail infrastructure investments to reduce the risk of exposure to hazardous materials. The analysis provided in this chapter fulfills Objective 2, which is intended to:

> *Demonstrate an appropriate selection and application of published literature to evaluate the effects of proposed transportation policy.*

3.1 Hazardous Materials Exposure Risk Factors

The transport of hazardous materials without incident, or the release of a hazardous material in an uninhabited area, essentially poses no risk to humans. For urban areas, however, the potential exposure to a release of hazardous material increases in proportion to the population density and the likelihood that an event will occur. The eventuality of a rail-related hazardous material incident could be attributed to a number of safety factors faced by the railroads. Figure 3.1 shows the proportions of causes that the FRA has attributed to train accidents from 2001 to 2006, indicating that track condition and human factors caused almost 72 percent of all train accidents during this period. The FRA has further concluded that nearly all accidents resulting in the release of a hazardous material are due to a derailment (i.e., track condition) or human factor.[10]

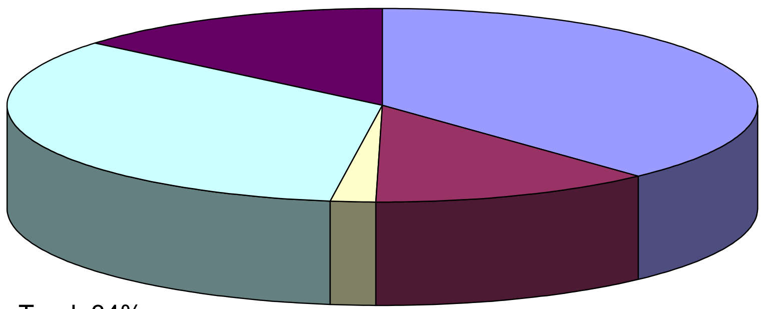


Figure 3.1 Causes of Non-Grade Crossing Train Accidents, 2001-2006.

Of the two most relevant performance-related risk factors (i.e., track condition and human factors), track condition is most interrelated to the issue of rail infrastructure investment. Tangible factors such as the location of a rail line and the frequency in which hazardous materials are transported also play a major role in the degree of risk to urban areas. Human factors, while a crucial element of rail safety, is less directly associated with physical measures of infrastructure and are by definition influenced by parameters such as the experience and alertness of the engineer.

The FRA correlates track condition to sets of criteria for five track classes. Parameters such as track gage tolerance, numbers of good ties, rail surface condition, and track alignment dictate the maximum speed at which freight and passenger trains are allowed travel, as prescribed in the Code of Federal Regulations (CFR) under 49 CFR 213 – Track Safety Standards.[11] Table 3.1 lists the maximum allowable speed for both freight and passenger trains, where a higher track class corresponds to higher quality track conditions.

Table 3.1 Maximum Allowable Train Speeds per Track Class.

Track Class	Freight Train Speed (mph)	Passenger Train Speed (mph)
Excepted Track	10	not allowed
Class 1	10	15
Class 2	25	30
Class 3	40	60
Class 4	60	80
Class 5	80	90

As should be expected, railroad accident data shows that fewer incidents occur on higher quality track (i.e., higher track classes). Table 3.2 lists information compiled by the FRA's Office of Safety on freight train accidents involving derailments from 1992 to 2001.[12] This information shows that the numbers of cars derailed per billion car-miles drops significantly as track class increases even though trains operate at significantly higher speeds over higher quality track, reflected by the higher average speeds during an accident at higher track classes.

Table 3.2 Freight Train Accident Speeds and Derailment Rates, 1992-2001.

FRA Track Class	1	2	3	4	5
Maximum Track Speed (mph)	10	25	40	60	80
Average Speed (mph)	8.7	17.7	26.3	33.6	37.0
Cars Derailed per 10^9 car-miles	3979	726	300	77	42

3.2 Emergency Response Actions

For the purpose of investigation a hazardous material is considered to be any substance that requires an emergency response when released into the environment. The U.S. Department of Transportation lists over 400 chemicals in the Emergency Response Guidebook (ERG), which is a guide for first responders during the initial phase of a hazardous material incident.[13] As an example, Table 3.3 includes the first seven hazardous materials listed in the ERG (see Appendix C for a full listing). The emergency response number is an ERG designation used for easy identification of each chemical and to distinguish between chemical compounds of similar composition, such as bromine (1744) and bromine trifluoride (1746). The name or emergency response number of each hazardous material directs emergency personnel to a specific section of the ERG that outlines the response action required in the event of a release.

Table 3.3 Hazardous Materials Classifications and Protective Action Distances.

Name of Hazardous Material	Emergency Response ID Number	Classification (49CFR172.101)	US DOT ERG Protective Action Distance			
			Small Spills		Large Spills	
			Day (mi)	Night (mi)	Day (mi)	Night (mi)
Ammonia, anhydrous	1005	2.3	0.1	0.1	0.4	1.4
Boron trifloride	1008	2.3	0.1	0.4	1.1	3.0
Carbon monoxide	1016	2.3	0.1	0.1	0.4	1.5
Chlorine	1017	2.3	0.2	0.8	1.5	4.6
Coal gas	1023	2.3	0.1	0.1	0.2	0.3
Cyanogen	1026	2.3	0.2	0.8	0.7	2.7
Ethylene Oxide	1040	2.3	0.1	0.1	0.5	1.5

Table 3.3 also describes the general type of hazardous material for each primary classification number in the U.S. Code of Federal Regulations (CFR), which is the hazardous material classification system used by the railroad industry.[14] The emergency response numbers in Table 3.3 are matched to a corresponding CFR classification number used by the railroads to identify the following types of substances:

- Class 1 – Explosives
- Class 2 – Gases
- Class 3 – Flammable/Combustible Liquids
- Class 4 – Flammable/Spontaneously Combustible Solids
- Class 5 – Oxidizers/Organic Peroxides
- Class 6 – Poisonous/Infectious Materials
- Class 7 – Radioactive Materials
- Class 8 – Corrosive Materials
- Class 9 – Miscellaneous Materials

The ERG includes protective action distances (see Table 3.3) that establish the downwind limits of exposure when a hazardous material is released into the environment. A protective action zone of a hazardous material release is the square of the protective distance, and is considered to be the area in which persons may become incapacitated and unable to take protective action and/or incur serious or irreversible health effects. The exposure area defined by this protective action zone for a hazardous material release on a rail corridor is illustrated in Figure 3.2. Protective action distances in Table 3.3 are based on the time of day, since less atmospheric mixing occurs at night (i.e., less dispersal), and on the size of a spill. In general, small spills may typically involve a release of hazardous material approximately equal to a 55-gallon drum. However, for railroad tank cars, which average 16,000-gallon capacity, small spills are considered as releasing no greater than five percent of the car's contents.[15]

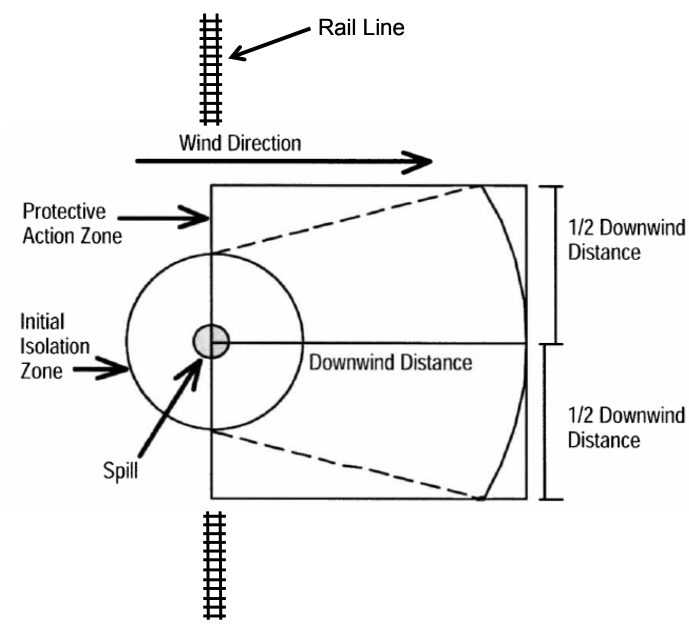


Figure 3.2 Exposure Area for Hazardous Material Release on Rail Corridor.

Figure 3.3 illustrates how the risk factors of track condition, hazardous material carload volume, and population (or demographics) can be integrated with the statistical information in Table 3.1 to assess the public's risk of exposure to hazardous materials transported by rail through urban areas. Table 3.2 shows that derailment frequency is a function of the number of railcar miles traveled as well as track condition – for a route of fixed length, railcar miles increases as the number of carloads shipped over the route increases. In addition, the exposure area illustrated in Figure 3.1 infers that exposure risk for an affected area is a function of the numbers of people that happen to be within that area (i.e., the population density along the rail corridor).

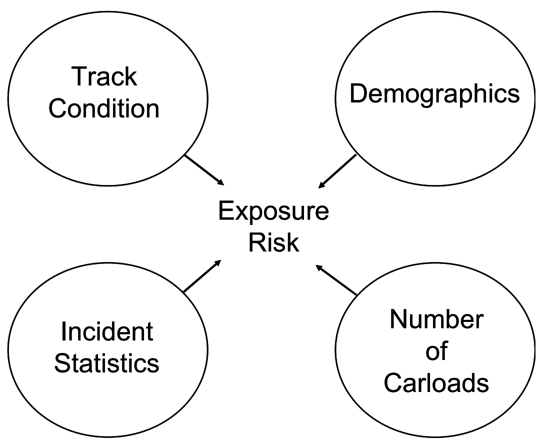


Figure 3.3 Risk Factors of Rail-Transported Hazardous Materials.

3.3 Probability of Hazardous Material Release

The release of hazardous material from a railroad tank car following an accident (i.e., a derailment) may be the result of damage to either the tank shell or to appurtenances such as loading/unloading fittings. Barkan et al have found that the release of a hazardous material following a railroad tank car accident can be modeled through a regression analysis of tank car accident histories as a probability function based on tank car thickness.[16] Figure 3.4 shows the relationship between tank car thickness (t) and the probability of release following an accident ($P_{R/A}$) plotted over a range of tank thicknesses from ½ inch to one inch, which is representative of most North American railroad tank cars. This model indicates that increasing tank thickness beyond approximately ¾ inch does not significantly add to tank car safety.

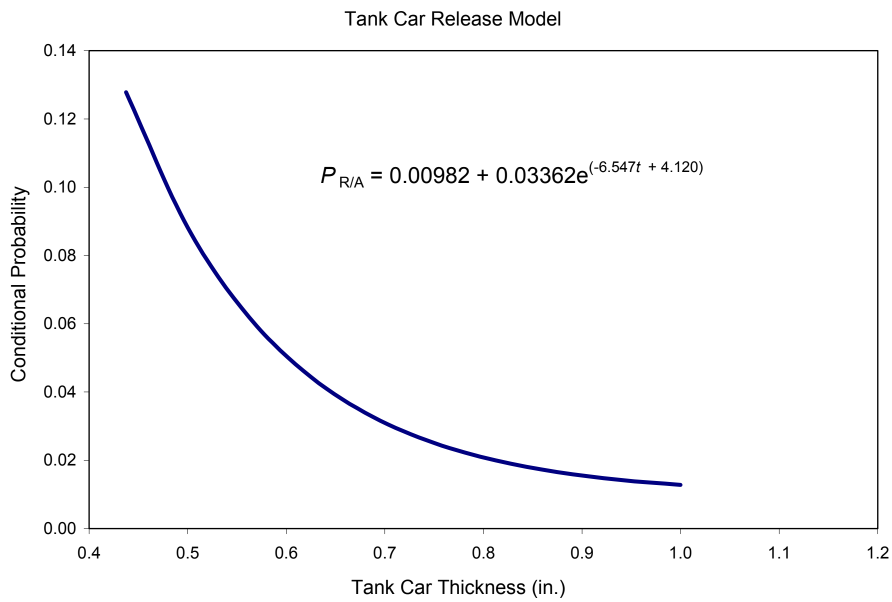


Figure 3.4 Effect of Tank Thickness on Release Probability.

The negative exponential model shown in Figure 3.4 is based on accident data that reports tank thickness but does not include the speed or force at impact or the track class, any of which could be correlated to track condition (i.e., track class). Moreover, statistical distributions on tank car thicknesses that transport hazardous materials in a particular urban area are not reported.

Statistics from the FRA's Office of Safety can be used in lieu of the equation shown in Figure 3.4 to predict the probability of release based on track class. Table 3.4 lists the release rates of tank cars that derailed from 1992-2001 according to track class.[12] The release rates in Table 3.4 are similar in function to Figure 3.3, but allow risk assessments to be prepared according to existing or proposed track conditions. Unlike the probability of release based on tank car thickness, the FRA statistics below show how release rates increase as hazardous materials are transported at higher speeds.

Table 3.4 Hazardous Material Tank Car Release Rates after Derailment, 1992-2001.

FRA Track Class	1	2	3	4	5
Maximum Track Speed (mph)	10	25	40	60	80
Average Speed (mph)	8.7	17.7	26.3	33.6	37.0
Release Rate (%)	2.5	10.5	10.1	12.7	13.1

The accident statistics presented in Tables 3.2 and 3.4 can be used to predict the probability of a hazardous material release (P_R) from a railroad tank car according to the multiplication law of conditional probabilities.[17] Eq. 3.1 shows that when the probability of two events, the probability of a derailment (P_A) and the probability of a release following a derailment ($P_{R/A}$), are known then (P_R) (i.e., the probability that these events intersect) can be calculated. Table 3.5 lists the release probability per billion railroad tank car mile traveled for each track class.

$$P_R = P_A \times P_{R/A} \qquad (3.1)$$

Table 3.5 Hazardous Material Release Probabilities Based on Track Condition.

FRA Track Class	1	2	3	4	5
Maximum Track Speed (mph)	10	25	40	60	80
P_A (derailments/10^9 car-mi)	3979	726	300	77	42
$P_{R/A}$ (releases/derailments)	2.5%	10.5%	10.1%	12.7%	13.1%
P_R (releases/10^9 car-mi)	99	76	30	10	6

Table 3.5 describes the probability of release from railroad tank cars in terms of numbers of expected releases per billion car-miles for each track class. Figure 3.4 plots P_R versus track class, showing that overall release rates significantly decrease as track class increases despite the potential for cars to be subjected to greater impact forces at higher maximum track speeds. This outcome reflects a disproportionately greater reduction in

total derailments due to higher track quality than that of the corresponding increases in hazardous material release rates at higher track speeds. As a result, the risk of transporting hazardous materials on existing rail corridors can be reduced by upgrading track rated as Class 1 through Class 3 to either Class 4 or Class 5. Figure 3.5 shows, however, that upgrading a Class 4 track to a Class 5 track would not significantly reduce the risk associated with transporting hazardous materials by rail.

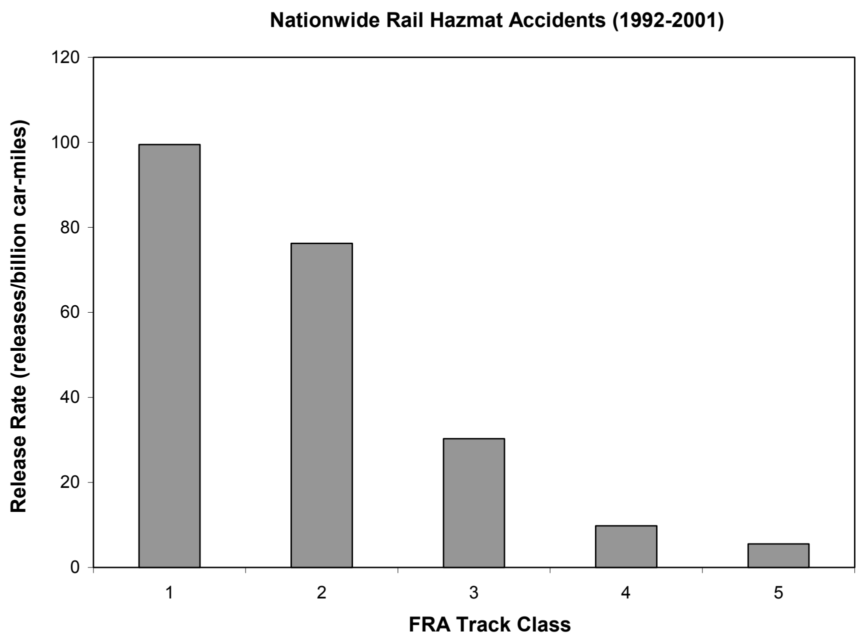


Figure 3.5 Relationship of FRA Track Class to Release Probability.

3.4 Railroad Corridor Exposure Risk

Railroad tank cars post hazardous material placards for emergency response personnel to use in determining the appropriate response action. However, statistical information on the type and frequency that specific chemicals are transported over a particular rail corridor is not likely to be available without consent of the railroad company. As Table 3.3 shows, the maximum protective action distance for chlorine (4.6 miles) is much greater than for coal gas (0.3 miles) even though both are in the same CFR classification (gases). In cases where the numbers of shipments per CFR classification is the only information known, an assessment of exposure risk can be based on a series of statistical measures prepared from Appendix C. For example, Tables 3.6 and 3.7 report protective action zones for both small spills and large spills using the minimum, maximum, most frequently occurring (i.e., mode), and average protective action distance within each CFR classification. The risk analysis can then be based on a relative risk preference, based either on generalized assumptions or on other available information.

Table 3.6 ERG Protective Action Zones for Small Spills.

CFR Class	Daytime Exposure Area (sq.mi.)				Nighttime Exposure Area (sq.mi.)			
	Minimum	Maximum	Mode	Average	Minimum	Maximum	Mode	Average
1	0.04	0.25	0.25	0.20	0.04	0.25	0.25	0.20
2	0.01	13.69	0.01	0.42	0.01	49.00	0.64	2.60
3	0.01	0.49	0.01	0.05	0.04	3.24	0.09	0.38
4	0.01	0.36	0.01	0.04	0.01	4.41	0.01	0.57
5	0.01	0.04	0.01	0.02	0.01	0.81	0.36	0.26
6	0.01	0.64	0.01	0.09	0.01	4.84	0.01	0.73
7	0.01	0.01	0.01	0.01	0.16	0.16	0.16	0.16
8	0.01	0.09	0.01	0.01	0.01	1.21	0.01	0.11
9	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01

Table 3.7 ERG Protective Action Zones for Large Spills.

CFR Class	Daytime Exposure Area (sq.mi.)				Nighttime Exposure Area (sq.mi.)			
	Minimum	Maximum	Mode	Average	Minimum	Maximum	Mode	Average
1	0.04	0.25	0.25	0.20	0.04	0.25	0.25	0.20
2	0.04	49.00	2.25	6.28	0.09	49.00	49.00	19.88
3	0.25	49.00	0.64	3.38	1.00	49.00	24.01	12.25
4	0.04	31.36	0.04	3.81	0.64	49.00	49.00	15.75
5	0.01	2.89	1.44	1.06	0.16	18.49	12.96	8.16
6	0.01	49.00	49.00	4.85	0.01	49.00	49.00	11.40
7	0.25	0.25	0.25	0.25	4.41	4.41	4.41	4.41
8	0.04	7.84	0.25	0.53	0.09	42.25	16.00	4.27
9	0.09	0.09	0.09	0.09	0.64	0.64	0.64	0.64

General Assumptions

Railroad operations are relatively uniform over a 24-hour period, suggesting that there is an equal (50 percent) probability of a hazardous material release during the day or night. Also, research on tank car accidents indicates that the proportion of large spills and small spills is approximately 22 percent and 78 percent, respectively.[18] These assumptions can be used to transform the exposure areas in Tables 3.6 and 3.7 to a single representative protective action zone, based on proportions of assumed spill size and time of release. Eq. 3.2 defines the representative protection action zone in terms of the probability of a daytime release ($\%_D$) and nighttime release ($\%_N$), the probability of a small release ($\%_S$) and large release ($\%_L$), and the respective exposure areas in Tables 3.6 and 3.7.

$$A = \%_D\left[(\%_S)(A_{D/S}) + (\%_L)(A_{D/L})\right] + \%_N\left[(\%_S)(A_{N/S}) + (\%_L)(A_{N/L})\right] \quad (3.2)$$

Table 3.8 lists the exposure areas for each CFR classification using Eq. 3.2, assuming uniform railroad operations and typical sizes of spills from tank cars transporting hazardous materials. These results are independent of the actual numbers or types of hazardous material shipments that occur on a particular rail corridor and statistical measures that have been used to represent the hazardous materials listed in Appendix C.

Table 3.8 Exposure Area per Hazardous Material Classification.

CFR Class	Expected Exposure Area (sq.mi.)			
	Minimum	Maximum	Mode	Average
1	0.04	0.25	0.25	0.20
2	0.02	35.25	5.92	4.07
3	0.16	12.30	2.77	1.90
4	0.08	10.75	5.43	2.40
5	0.03	2.70	1.74	1.13
6	0.01	12.98	10.85	2.12
7	0.58	0.58	0.58	0.58
8	0.02	6.05	1.81	0.58
9	0.09	0.09	0.09	0.09

A representative exposure area can also be calculated based on the proportions of hazardous materials per CFR classification shipped on a rail corridor – this necessary information is likely to be obtained only with the consent of railroad and governmental sources. Eq. 3.3 converts the exposure areas for each CFR class (A_{class}) in Table 3.8 to a representative exposure area for a rail corridor (A_{cor}) based on the percentage of hazardous material shipments of each CFR class ($\%_{class}$).

$$A_{cor} = \sum (\%_{class})(A_{class}) \quad (3.3)$$

The annual exposure risks for each rail corridor can be calculated using Eq. 3.4, based on A_{cor} using Eq. 3.3, P_R using Table 3.5, the corridor length (L_{cor}), the population density along the corridor (D_{pop}), and the total number of hazardous material shipments during the year (S_{rail}).[15]

$$R_{\exp} = (A_{\exp})(D_{pop})(L_{corr})(S_{rail})(P_R) \quad (3.4)$$

3.5 Approaches to Exposure Risk Mitigation

Legislation such as Texas House Bill 160 required an investigation into the feasibility of relocating freight trains that carry hazardous materials away from municipalities. However, this particular legislation also required the cost of necessary infrastructure to be reported so that the economic feasibility of related public policy could be understood.[9] This section presents two example cases that describe the alternative approaches to risk mitigation. Case 1 assumes that all shipments of hazardous materials can be relocated to a new bypass. However, most shipments of hazardous materials within municipal areas are a product of railroads providing services to local customers, as required by federal law under common carrier obligations.[19] Case 2 demonstrates how investment in track upgrades on an existing rail corridor can be an economically preferred alternative to relocating hazardous material shipments.

<u>Case 1: General Risk Analysis</u>

Each year 100,000 carloads of hazardous material are shipped within a municipality over a single 15-mile rail corridor comprised of Class 2 track. The exact chemical composition of these shipments is not known, though all trains originate from a plant that produces flammable and combustible liquids (CFR Class 3). The average population density along the existing corridor is 2,000 people per square mile, while that of a proposed 30-mile, $180 million rail bypass is 200 people per square mile. The maximum consequence of this scenario can be examined first by predicting the frequency with which a release of hazardous material might occur. Considering that 1.5

million car-miles (100,000 carloads ×15 miles) of hazardous materials are shipped over the corridor each year, the release probability of 76 releases per billion car-miles (Table 3.5) gives a release frequency (*T*) of:

$$T = (1 \text{ yr}/1.5 \text{ x } 10^6 \text{ car-mi})(10^9 \text{ car-mi}/76 \text{ releases}) = 9 \text{ years / release}$$

The exposure risk for the Class 2 track can be found using Eq. 3.4 and a maximum exposure area for CFR Class 3 hazardous materials (Table 3.8) as follows:

$$R_{exp} = (12.3 \text{ mi}^2)(2{,}000 \text{ people/mi}^2)(15 \text{ mi})(100{,}000 \text{ cars})(76/10^9 \text{ car-mi})$$
$$= 2{,}804 \text{ people/year}$$

Assuming that the proposed bypass is constructed to a standard of Class 4 track, the release frequency on the new facility would be:

$$T = (1 \text{ yr}/3.0 \text{ x } 10^6 \text{ car-mi})(10^9 \text{ car-mi}/10 \text{ releases}) = 33 \text{ years / release}$$

The exposure risk of the new bypass facility would be:

$$R_{exp} = (12.3 \text{ mi}^2)(200 \text{ people/mi}^2)(30 \text{ mi})(100{,}000 \text{ cars})(10/10^9 \text{ car-mi})$$
$$= 74 \text{ people/year}$$

Case 1 shows that the construction of a bypass would significantly reduce exposure to the release of a hazardous material on a high-volume rail corridor. Even though the total car-miles increase due to the added length of the new rail corridor, the higher track class and lower population density lowers exposure risk.

<u>Case 2: Track Upgrades</u>

Train speeds within metropolitan areas are generally governed by operational constrains of a congested rail network. The railroads maintain track conditions according to the speeds dictated by these constraints, insuring that maintenance programs meet, but do not unnecessarily exceed, 49 CFR 213 (Table 3.1). Thus far, proposed policy has not addressed the economic potential of system-induced limits to operating train speeds as a as a component of effective exposure risk mitigation.

Table 3.9 lists the baseline statistics first presented in Table 3.5, but now includes scenarios in which track conditions are upgraded to successively increasing track classes. For example, when Class 1 track is upgraded to Class 2 track the derailment rate decreases from 3,979 per billion car-miles to 726 per billion car-miles. When train speeds are maintained at the original speed due to system-induced operational limits, the probability of a release due to this upgrade decreases from 99 per billion car miles to 18 per billion car-miles. Furthermore, as Table 3.9 shows, upgrading Class 1 track to Class 4 track reduces the derailment rate from 99 per billion car-miles to 8 per billion car-miles. Figure 3.6 shows the significant reduction in release probability for the lower track classes when track upgrades are implemented.

Table 3.9 Reduction in Release Probability with Track Upgrade.

Maximum Track Speed (mph)	10	25	40	60	80
Existing FRA Track Class	1	2	3	4	5
P_A - Baseline Condition	3979	726	300	77	42
P_A - Class 2 minimum	726	726	300	77	42
P_A - Class 3 minimum	300	300	300	77	42
P_A - Class 4 minimum	77	77	77	77	42
$P_{R/A}$ - constant	2.5%	10.5%	10.1%	12.7%	13.1%
P_R - Baseline Condition	99	76	30	10	6
P_R - Class 2 minimum*	18	76	30	10	6
P_R - Class 3 minimum*	8	32	30	10	6
P_R - Class 4 minimum*	2	8	8	10	6

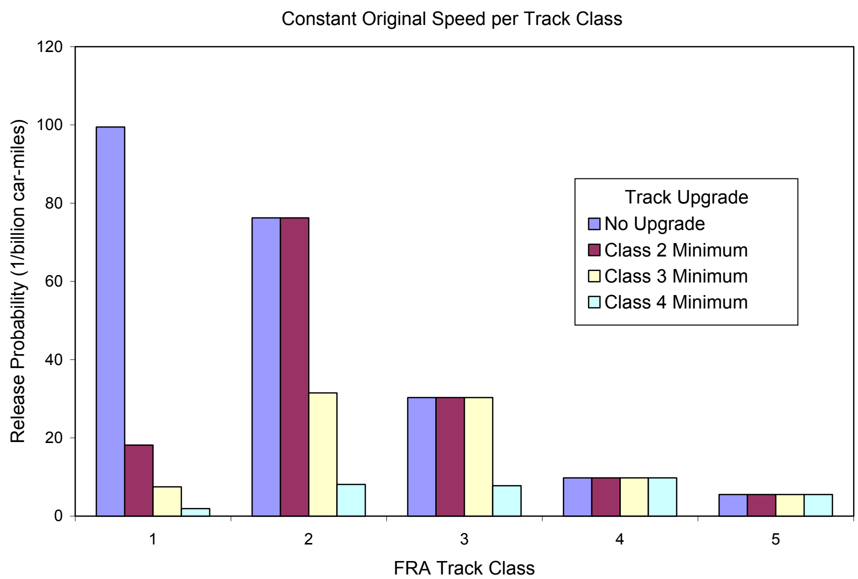


Figure 3.6 Reduction in Release Probability with Track Upgrades.

If the Class 2 track in Case 1 is upgraded to Class 4 track at a cost of $200,000 per mile, while maintaining existing train speeds, the exposure risk becomes:

$$R_{exp} = (12.3 \text{ mi}^2)(2{,}000 \text{ people/mi}^2)(15 \text{ mi})(100{,}000 \text{ cars})(8/10^9 \text{ car-mi})$$
$$= 295 \text{ people/year}$$

The construction of a bypass in Case 1 reduces exposure risk from 2,804 people per year to 74 people per year at a cost of $180 million, or a reduction in exposure of 15 people per million dollar investment. Track upgrades in Case 2 reduce exposure from 2,804 people per year to 295 people per year, or a reduction in exposure of 836 people per million dollar investment. The economics of track upgrades in Case 2 become more favorable in light of the fact that the majority of hazardous material shipments cannot be relocated to rail bypasses without the bypass alignment being partly constructed in the area of higher population density, and without interfering with the railroad's common carrier obligation.

3.6 Academic and Industry Observations

Objective 2 was established to address the Texas Legislature's desire to assess the feasibility of relocating hazardous materials shipped by rail to alternative rail corridors. In fact, results that parallel the analysis in this chapter were submitted by the Austin Rail Group to the State of Texas recommending track upgrades as a realistic and economic alternative to pursuing the public policy considered in House Bill 160. This risk mitigation strategy is currently a component of the state's initiative to improve rail conditions in Houston, Texas as it coordinates with the activities of the Gulf Coast Freight Rail District.

This analysis was restricted to the interrelationship between track infrastructure and the risk of exposure to hazardous materials. However, risks beyond those related to hazardous material tank car derailments exist, such as the release of hydrochloric acid from tank cars exposed to fire following the derailment and ignition of fuel tank cars near Baltimore in 2001.[20] Relevant issues not discussed in this analysis also include the risks inherent in additional handling of hazardous materials at rail yards that would be required for rerouting of tank cars.[21] Regardless of the extent of analysis, uncertainties associated with hazardous material risks require the application of probability and statistics. The principle means by which the Doctor of Engineering program provided the appropriate background for risk analyses was through coursework in statistics and uncertainty modeling in civil engineering management.

CHAPTER IV

FINANCIAL RISK OF A TIMBER RAILROAD BRIDGE CATASTROPHE

The vast railroad network in Texas is an important part of the state's transportation system. Over 40 freight railroads operate on approximately 10,386 miles of track, providing employment to more than 19,000 residents and a combined income of over $1.3 billion annually.[22] This rail network not only serves as a major employer, but also provides an efficient means of transporting large volumes of bulk and containerized freight both within the state itself and between Texas and other states. In doing so, a significant portion of heavy cargo avoids using the highway system and, as a result, extends the life of roadway pavements.

The state's rail network moves close to 10 million carloads of freight annually or about 400 million tons each year.[22] In part, the movement of this amount of freight is made possible by several thousand railroad bridges that traverse waterways, roadways, and any general change in surface elevation that cannot be accommodated under the constraints of track grade design. Consequently, these railroad bridges represent a critical link to the sustained movement of rail freight and are treasured assets to railroad companies.

In most instances, either a natural or manmade railroad bridge catastrophe would bring about an instant disruption of service, and would result in financial distress from both the loss of the physical asset and from the loss of operating revenue. The magnitude of financial distress due to a bridge loss is directly proportional the size and length of the bridge, with the overall impact that this distress imposes upon a corporation dependent on the profitability and financial position of the firm. Ideally, the affected railroad would have protection against the impact of a bridge loss through insurance, protection further bolstered by the size of the company's cash reserves and operating revenue. However, the sufficiency of these protections is usually only known within a railroad itself and not to transportation agencies that wish to understand the risk of being subjected to an increase in roadway truck traffic following the failure of a company.

The uncertainty of financial impact upon a railroad company extends the general notion of risk associated with a structural failure beyond that of the condition and loading of bridge components, and to the risks that actually threaten the financial viability of the rail line. This second aspect of risk is of particular importance to the transportation planning process considering the ramifications of shifting large volumes of freight from a bankrupt rail line to the highway system.

This chapter presents a generic model that can be used to understand the relative risks of financial distress within railroad companies following the catastrophic loss of a timber bridge. This model provides a means for transportation agencies to comparatively rank this susceptibility in the absence of a railroad's proprietary financial information. The development of this model fulfills Objective 3, which is to:

> *Use accounting principles to transform inventories of infrastructure data into relative financial risks associated with a corporation's loss of a physical asset.*

4.1 Risk Assessment Methodology

The economic effect of losing a timber railroad bridge due to a disaster such as a fire or flood will vary according to the cost of replacing a specific bridge and the revenue that is lost during reconstruction. The unexpected need to replace a bridge corresponds to an unexpected expense rather than a capital investment, so the economic analysis is treated as a measure of financial burden rather than a determination of return on investment. The burden that this unexpected expense has on a railroad will depend on the company's financial position (e.g., cash reserves, insurance coverage, etc.), and the decision to rebuild a timber bridge will depend on the potential for the line to continue generating net positive value despite the costs incurred. Considering the impracticality of performing a pro forma analysis of a particular railroad's finances, this analysis bases the economic impact of a bridge loss on the time required for revenues from restored service to offset expenses and lost operating income.

Figure 4.1 illustrates the cash flows expected during construction time (t_c) and restored operating time (t_o), assuming that the decision to rebuild the bridge is made immediately after its loss. In this scenario, construction extends from $t_c = 0$ to $t_c = n$, where n equals the number of time periods over which bridge replacement occurs. Operating income from restored rail operations extends from $t_o = 0$ to $t_o = N$, where N equals a number of time periods into the future – in this analysis, N equals the number of time periods required for the present value of operating income following restored service to equal the present value of financial loss associated with reconstruction and suspended operations.

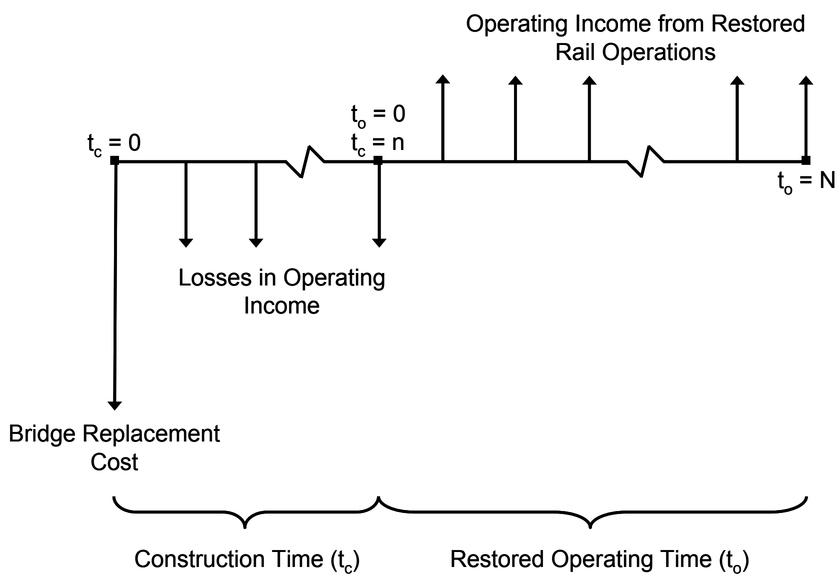


Figure 4.1 Cash Flow Diagram for Time Sequence of Bridge Reconstruction and Restoration of Rail Operations.

By using the time to offset financial loss (N) as a measure of a company's ability to recover from a catastrophic event, an assessment of timber bridges can be prepared that identifies locations where an unusually large amount of time is required for a company to replace this loss relative to that of other bridges in the statewide inventory.

The present value of cash outflows in a bridge replacement consists of the construction cost (C) and the discounted value of lost operating income that occurs over the construction period (n) at a discount rate equal to the company's cost of capital (i). Operating income is measured as the revenue remaining after paying operating expenses (e.g., salaries, fuel, equipment, etc.). A company's operating margin (M) represents the percentage of revenues (R) remaining after deducting these operating expenses,[23] which means that the operating income lost during a bridge replacement is the product of operating margin (M) and total revenues (R). The present value of financial loss (i.e., the cost) can found using Eq. 4.1.

$$PV_{cost} = C + MR\left[\frac{(1+i)^n - 1}{i(1+i)^n}\right] \qquad (4.1)$$

Eq. 4.1 incorporates revenue and operating margin as parameters since revenue generated by a particular rail line should be easier to estimate (e.g., from shipping charges, carload volumes, etc.) than estimating a company's operating income directly. Similarly, the present value of cash inflows from restored rail operations also uses these parameters as the basis for determining operating income (MR) following restored rail operations. In this analysis, operating income is realized over an unknown number of periods (N) until the financial loss (PV_{cost}) is offset by cash inflows (PV_{rev}) equal to:

$$PV_{rev} = \frac{MR\left[\frac{(1+i)^N - 1}{i(1+i)^N}\right]}{(1+i)^n} \qquad (4.2)$$

The time required to replace the financial loss incurred by a catastrophic event is determined by computing the time required for PV_{rev} to equal PV_{cost}, which is found by using Eqs. 4.1 and 4.2 to solve for N as follows:

$$PV_{cost} = PV_{rev} \quad (4.3)$$

Substituting Eq. 4.1 and Eq. 4.2 into Eq. 3 gives:

$$C + MR\left[\frac{(1+i)^n - 1}{i(1+i)^n}\right] = \frac{MR\left[\frac{(1+i)^N - 1}{i(1+i)^N}\right]}{(1+i)^n} \quad (4.4)$$

Eq. 4.4 can be expressed as:

$$\left(\frac{Ci}{MR} + 1\right)(1+i)^n - 1 = \frac{(1+i)^N - 1}{(1+i)^N} \quad (4.5)$$

Or, more conveniently:

$$(1+i)^N = \frac{1}{\left[2 - \left(\frac{Ci}{MR} + 1\right)(1+i)^n\right]} \quad (4.6)$$

Eq. 4.6 can be solved for the number of periods required to replace lost revenue by using the natural log identity, $\ln(x^k) = k \ln(x)$, as follows:

$$N = \frac{\ln\left(\frac{1}{\left[2 - \left(\frac{Ci}{MR} + 1\right)(1+i)^n\right]}\right)}{\ln(1+i)} \quad (4.7)$$

Since ln(x) is undefined at values of x less than or equal to zero, there is a limiting cost-to-revenue ratio (C/R) for which N exists. The limiting condition for which N is defined in Eq. 4.7 is:

$$2 - \left[\left(\frac{C}{R}\right)\left(\frac{i}{M}\right) + 1\right](1+i)^n > 0 \quad (4.8)$$

And the limiting cost-to-revenue ratio is:

$$\frac{C}{R} < \frac{M}{i}\left[\frac{2}{(1+i)^n} - 1\right] \quad (4.9)$$

Eq. 4.9 indicates that the cost-to-revenue ratio reaches a maximum at $n = 0$, or:

$$\frac{C}{R} < \frac{M}{i} \quad \text{(4.10)}$$

For example, if a railroad company's operating margin is 16.0 percent, its cost of capital is 6.5 percent, and rail traffic could be temporarily diverted to another line at no additional cost (i.e., $n = 0$), then the present value of future operating income would, over a period of time, equal the present value of the bridge reconstruction cost as long as $C/R < 2.46$. On the other hand, there would never be enough time for the present value of cash inflows from restored operations to equal the bridge reconstruction cost if the cost-to-revenue ratio approaches 2.46. This limitation is due to the diminishing contribution that the cash inflow from each subsequent year adds to net present value. The impact that discounting annual cash inflows in this example have on net present value are shown in Figure 4.2 (i.e., plotting the present value factor for a uniform series of cash flows).

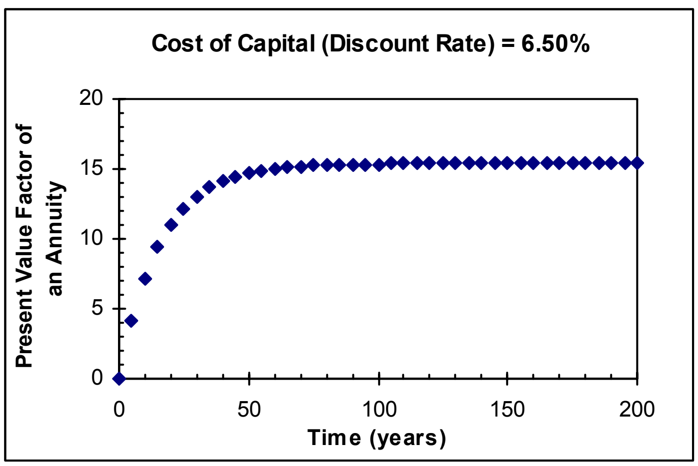


Figure 4.2 Diminishing Effect of Revenues in Additional Time Periods.

Though the true impact of a bridge catastrophe on a railroad company cannot be simply measured by the number of time periods required for operating income to replace the financial loss, this approach approximates the extent of burden that a catastrophe would place on a company's financial position. Corporate executives will most likely have considered the time required to replace their financial loss when pricing the value of insurance or, on low-revenue rail lines, when determining if continued operations on the line would be financially possible.

4.2 Incorporation of Industry Data

Timber railroad bridge spans are based on an approximate 15-foot design length,[24] whereas concrete replacement bridges are typically constructed using a single concrete span to replace two timber spans due to the greater strength and constructability that prestressed concrete beams offer over that of timber stringers. In general, new concrete spans in a replacement bridge can be assumed to require approximately 10 days to construct at a cost of $6,000 per foot ($180,000 per new 30-foot span). Construction of a new bridge may also require two days of mobilization once the decision to replace the original bridge has been made.

The Surface Transportation Board issued a decision on January 17, 2008, to estimate a company or industry cost of equity using the Capital Asset Pricing Model (CAPM).[25] Based on this guidance, a typical cost of capital (i) in Texas is assumed to be approximately 6.68 percent (see Chapter V for calculation of Union Pacific Railroad cost of capital). Information on operating margins (M) can be obtained from the income statements of publicly traded railroad companies, which are reported to the Securities and Exchange Commission and made available through online financial data services.[26]

Figure 4.3 outlines the basic components of an income statement for the purpose of distinguishing between revenue, operating income, and net income.[23] In this sample statement, the operating margin equals 25 percent since operating income (MR) is 25 percent of the $100 million in operating revenue (R), or $25 million. Taxable income of $24.5 million is obtained by deducting an assumed $0.5 million interest expense from operating income. At an assumed tax rate of 34 percent, taxes on the taxable income equal $8.3 and net income equals taxable income less taxes, or $16.2 million.

	($ million)
Operating Revenue (*R*)	100.0
Operating Expenses	75.0
Operating Income (*MR*)	25.0
Interest Paid	0.5
Income before Taxes	24.5
Taxes	8.3
Net Income	16.2

Figure 4.3 Sample Income Statement.

Revenue statistics for publicly traded railroad companies are available from filings with the Securities and Exchange Commission and from online financial data services, whereas revenue statistics for private companies are not typically released to the public. Whether a rail line is publicly or privately owned, the financial performance of any specific line is considered to be proprietary information. Consequently, estimates of revenues for rail lines listed in a statewide inventory must be based on sources that compile industry data for release to the public.

Industry data is often published according to railroad classification, as published under 49 CFR Part 1201.[27] Table 4.1 lists the criteria by which railroads are classified as of March 2009. Class I railroads are defined as those with revenue of at least $250 million, whereas regional railroads have revenues between $20 million and less than $250 million, and operate lines of at least 350 miles in length. Shortlines earn less than $20 million in annual revenue and operate lines less than 350 miles long, while switching and terminal railroads are classified according their function rather than according to a revenue threshold.

Table 4.1 Classification Guidelines for U.S. Railroads, 2009.

Type of Railroad	Revenue Range (million)	Line Distance (miles)	U.S. Total
Class I	$250+	-	7
Regional	$20+	350+	33
Shortline	<$20	<350	323
Switching & Terminal	-	-	196

Table 4.2 lists national revenue statistics compiled by the Association of American Railroads (AAR) according to railroad classification (i.e., Class I, Regional, Shortline, or Switching & Terminal) for 2008.[28] Considering that revenue statistics compiled by AAR and the financial disclosures of public railroad companies both report revenues on a national basis rather than by state or per line, operating revenue (*R*) earned on a particular rail line is not likely to be readily available. Table 4.2 also shows the percent of U.S. track within Texas for each track classification

Table 4.2 National Railroad Revenue Statistics and State Estimates, 2005.

STB Railroad Classification	U.S.Track Miles	Total Revenue ($ billion)	State of Texas Track Miles	Percent of U.S. Track Miles in Texas
Class I	94,801	50.3	8,270	8.72%
Regional	16,713	1.7	382	2.29%
Shortline	21,960	1.2	803	3.66%
Switching & Terminal	6,455	0.8	931	14.42%

The information in Table 4.2 cannot be correlated to revenue per mile of track within the state since captive shippers (i.e., companies served by only one railroad) often generate greater revenue per carload for the railroads than companies that benefit from competitive pricing. For example, a principle justification for the Union Pacific Railroad in acquiring Southern Pacific Railroad assets in 1996 was the Southern

Pacific's position as the lone provider of rail service to the plastics and chemical industries in the Bayport Industrial District near Houston, Texas. This arrangement led to the formation of a limited partnership (San Jacinto Rail Limited) between BNSF Railway and local chemical companies to pursue the construction of a competing 13 mile, $80 million track build-in from an existing BNSF mainline.[29] As an alternative to relying on proprietary line revenues, the financial risk of a bridge catastrophe can be examined by scenario analysis or simulation.

The sample income statement presented in Figure 4.3 reflects an operating margin of 25 percent, based on operating revenue of $100 million and expenses of $75 million. Actual operating margins from the 2007 annual reports of public railroad companies are listed in Table 4.3, which shows no apparent trend in the size of margin with respect to the type of railroad. For example, the average operating margin for Class I railroads in 2007 was 25.05 percent, while that for Pioneer Rail, which operates a number of shortline railroads, was 20.73 percent. The operating margin from Pioneer Rail's shortline operations in 2007 was much higher than the 12.11 percent margin produced by RailAmerica's regional and shortline operations.

Table 4.3 Operating Margins for Selected Public Railroad Companies, 2007.

Railroad	Type	Operating Margin (%)
BNSF Railway	Class I	22.47
Union Pacific Railroad	Class I	20.73
CSX Transportation	Class I	22.49
Norfolk Southern	Class I	27.41
Canadian National	Class I	36.42
Kansas City Southern	Class I	20.40
Florida East Coast Railway	Regional	19.70
Genesse & Wyoming	Regional & Shortlines	18.76
RailAmerica	Regional & Shortlines	12.11
Pioneer Rail	Shortlines	20.73

Rail line revenues and operating margins should be used to predict a railroad company's susceptibility to the loss of a timber bridge with an understanding of industry dynamics and prevailing market conditions. Operating revenues earned at the time of a bridge loss may or may not be representative of revenues expected to be generated in the future, just as operating margins are periodically subject to non-recurring expenses. The effects of these issues are captured in the variability of operating margins over the last eight years in Figure 4.4.

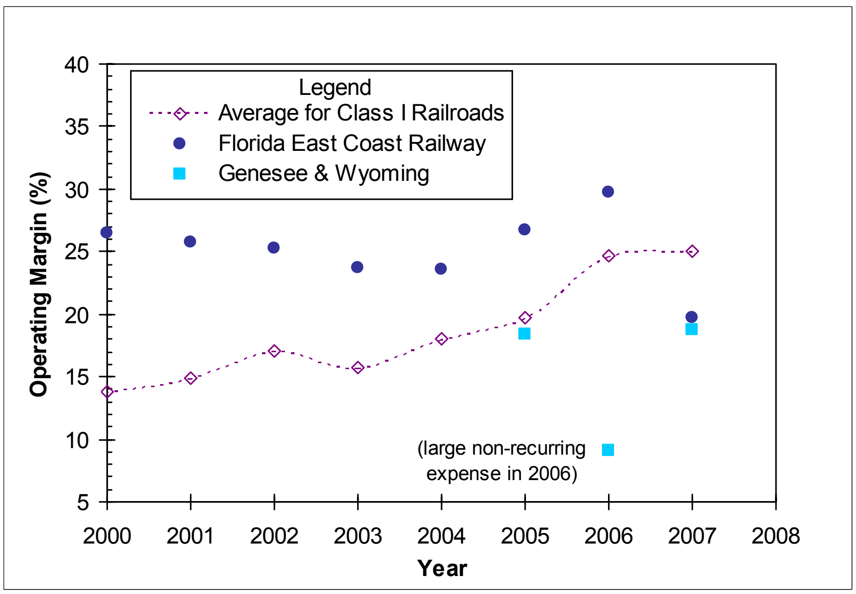


Figure 4.4 Eight-Year History of Railroad Operating Margins.

Plots of operating margins from annual reports between 2000 and 2007 in Figure 4.4 show how the average operating margin for Class I railroads increased from 13.86 percent in 2000 to 25.05 percent in 2007. This figure also contrasts the operating performance of the Class I railroads listed in Table 4.3 to that of the Florida East Coast Railway and Genesee & Wyoming, Inc. over the same eight-year period. These plots show how reliance only on 2007 data to assume that the Florida East Coast Railway's operating margin is always lower than those of Class I railroads would be incorrect. In fact, Florida East Coast Railway's operating margin outperformed the average operating margin for Class I railroads by an average of 41 percent between 2000 and 2007.

From the financial information available for Genesee & Wyoming, Inc., the company would appear to maintain an operating margin of about 18.60 percent if it were not for a large non-recurring expense in 2006. A comparison of Florida East Coast and Genesee & Wyoming in Figure 4.4 shows that these regional railroads' operating margins may be quite different in some years but nearly the same a few years later. Consequently, distinctions between the operating efficiency of Class I, regional, and shortline railroads from a financial standpoint cannot necessarily be made, nor can the representative nature of data in a single year be assumed.

4.3 Trend Analysis

Considering the dynamics of revenues and operating margins described above, trends in loss replacement period (N) are plotted in Figures 4.5 through 4.7 to evaluate the extent of expected variation. These plots incorporate the industry parameters outlined above into Eq. 4.7 as follows:

- Cost of capital (i) = 6.68%
- Construction cost (C) = $180,000 per concrete replacement span
- Expected duration of bridge replacement (n) = 10 days per concrete replacement span, plus two days for mobilization

Figures 4.5 through 4.7 plot N at four levels of operating revenue (R), ranging from $250,000 to $10 million per year, against numbers of timber spans lost in a catastrophic event. A comparison of these plots shows that the replacement period begins to approach infinity (i.e., reach the limit defined in Equation 4.9) more quickly at lower revenues and operating margins. These plots show that at low operating margins and revenues, the loss of only a few timber spans would require such a lengthy loss replacement period that continuing to operate an uninsured line might be unjustifiable.

In fact, railroad companies operating at low margins and revenues might be the least capable of affording property insurance that would lessen the impact of a catastrophic event and allow the line to continue serving its customers.

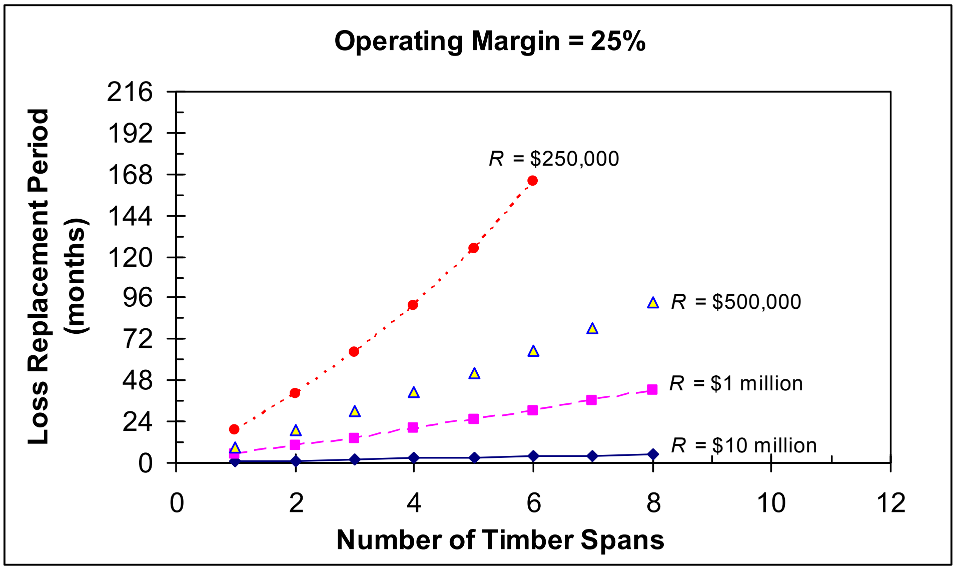


Figure 4.5 Loss Replacement Periods at a 25 Percent Operating Margin.

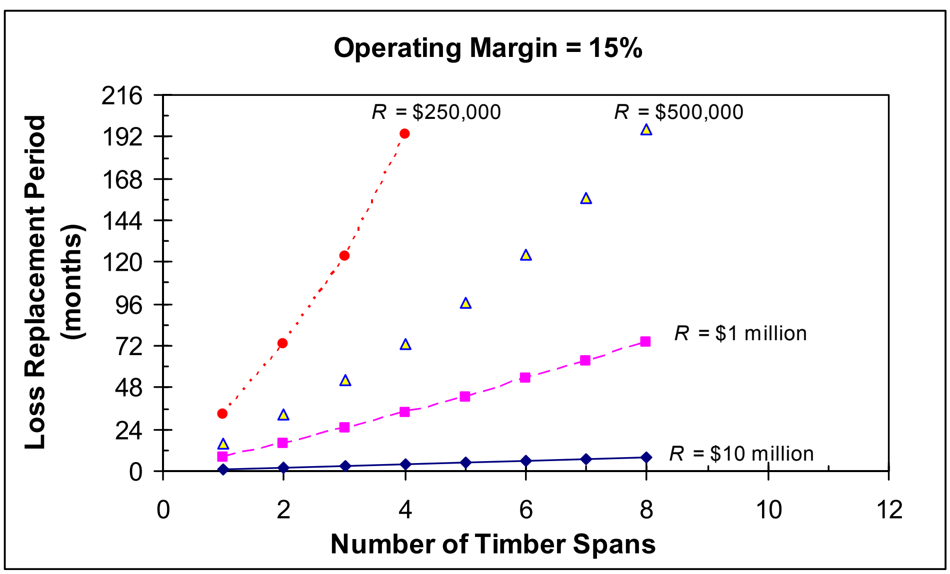


Figure 4.6 Loss Replacement Periods at a 15 Percent Operating Margin.

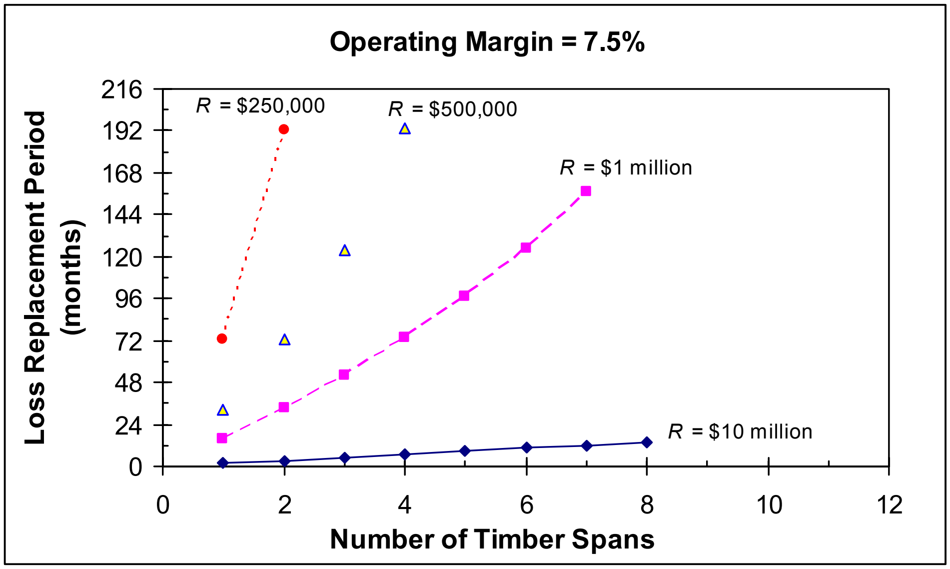


Figure 4.7 Loss Replacement Periods at a 7.5 Percent Operating Margin.

Figures 4.5 through 4.7 show that as line revenue approaches several million dollars, a railroad's loss replacement period grows very modestly as the number of timber spans lost in a catastrophe increases. In contrast to the sensitivity that revenues of $1 million or less have to numbers of spans lost and operating margins, the consistent horizontal trends at revenue of $10 million in each plot indicate that lines generating at least $10 million can be categorized as having low financial risk when supported by bridges of only moderate lengths. For example, a 36-span timber bridge on a line generating at least $10 million in revenue with an operating margin of 25 percent would have a loss replacement period of 24 months, whereas an 18-span bridge (i.e., one-half as long) on a line generating $1 million in revenue at the same operating margin would have a replacement period of 113 months.

The results in the form presented in Figures 4.5 through 4.7 can be transformed into an alternative trend analysis that shows the replacement period as a function of line revenue for specific numbers of spans. For example, Figure 4.8 summarizes the relationship for timber bridges consisting of up to eight spans assuming an operating margin of 20 percent and a nominal cost of capital equal to 6.68 percent. The trends in Figure 4.8 reflect points of exponential growth in the replacement period at low operating revenues, and reach these points earlier as the number of spans increase. For example, the replacement period for a two-span bridge begins to exhibit infinite growth at an operating revenue equal to about $0.5 million, whereas this same trend for an eight-span bridge begins at about $1.5 million.

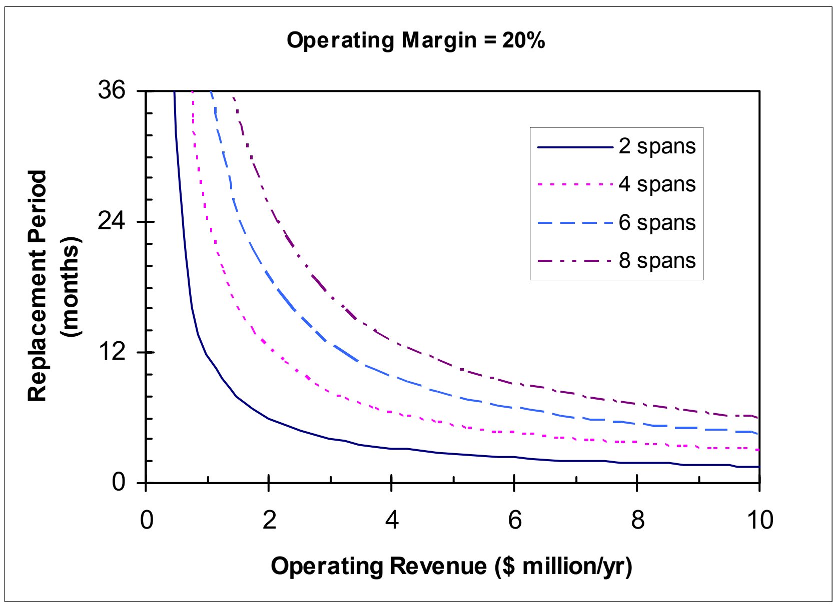


Figure 4.8 General Analysis of Loss Replacement Period.

Figure 4.8 also shows that the replacement periods for bridges of modest length stabilize as operating revenues approach $10 million, reflecting the fact that financial risk is comparatively small for rail lines comprised of only a few spans and that generate several million dollars in operating revenue.

4.4 Application of Methodology

Financial performance indicators such as revenues, costs of capital, and operating margins are normally treated as annual values, so the most convenient use of Eq. 4.7 is to base input parameters on annual values and then convert the output parameter N from an annual value to an equivalent number of days or months. Four hypothetical cases of bridge losses are analyzed in the next section using a cost of capital of 6.68 percent and an operating margin of 18.7 percent.

Table 4.4 contains results from the analysis methodology using four hypothetical cases of bridge losses (Bridges A, B, C, and D) that vary in the numbers of original timber spans and annual revenues generated by their respective rail lines. Bridge A is a six-span bridge on a high-volume line that generates $200 million in revenue per year. Based on the expected cost and duration of bridge replacement, the total present value of expenses plus lost revenue would be $3.93 million, requiring 37 days of restored operations to offset this cost – this may not be a particularly realistic case since a catastrophe on a high-revenue line would be counteracted by a remedial measure such as rerouting if possible (see Bridge D).

Bridge B is on a relatively low volume line consisting of only two spans. The two original timber spans are expected to be replaced by a single concrete span within 12 days at a cost of $180,000. Even though the time and cost of reconstructing this bridge is much less than Bridge A, the time required for revenues from restored operations to offset the total cost is more than twice as long due to its low revenue generating potential.

Bridge C is on a rail line that generates the same annual revenue as the line containing Bridge B but consists of 10 timber spans. Without access to alternative routes or the financial capacity to accelerate construction, the low revenue from this line would require a full year of restored operations to offset the losses incurred by a catastrophe. A railroad with limited earnings potential such as this might be incapable of devoting a fiscal year to replacing costs, and could be forced out of business.

Bridge D is on a line that generates a large amount of revenue and consists of 10 timber spans. This line is owned by a company having access to other routes and, therefore, experiences no time out of service. Even though the replacement cost of this bridge is $900,000, only 23 days are required to offset this expense since revenue continues to be generated during reconstruction.

Table 4.4 Relative Risk Analysis of Example Timber Bridge Replacements.

Bridge	No. of Timber Spans	Line Revenue (*R*) ($/year)	Construction Cost (*C*) ($)	Time Out of Service (*n*) (days)	Total Cost NPV ($)	Cost Offset Time (*N*) (days)
A	6	200,000,000	540,000	32	3,925,084	37
B	2	4,500,000	180,000	12	208,612	88
C	10	4,500,000	900,000	52	1,023,548	450
D	10	75,000,000	900,000	0	900,000	23

The hypothetical cases in Table 4.4 illustrate how a statewide inventory of timber bridges can be used to identify lines that might discontinue service in the event of a catastrophic timber bridge loss. Rather than attempting to predict the severity that a bridge loss has on the particular financial position of a railroad, the analysis methodology provides a means of comparing the time required for operating income from restored rail operations on a specific line to offset the financial loss relative to that of bridges on all other lines. Locations requiring the largest amounts of time for operating income to replace the financial loss (e.g., Bridge C in Table 4) should be considered as bridges having the greatest risk of not being reconstructed. The state can use pavement analysis models that predict the long-term cost of adding trucks to a particular roadway in the event that rail service is lost, then use this added public cost as a guideline in deciding whether to finance part or all of the railroad bridge replacement.

4.5 Academic and Industry Observations

Objective 3 was established to address concerns by the Texas Department of Transportation that the loss of a timber railroad bridge would place additional truck traffic on public roadways and add to the state's pavement maintenance cost as a result. Advanced knowledge of the rail network's susceptibility to a bridge catastrophe can assist public agencies in developing strategies to determine those instances where public financing of private infrastructure is warranted. Therefore, the analysis methodology presented in this chapter contributes to the transportation planning process by outlining factors that can contribute to the loss of a railroad bridge and by examining the issues that affect a firm's ability to recover from this type of catastrophe.

Considering the variability in response time of actual bridge losses, the circumstances that influence a railroad company's ability to resume operations following the loss of a timber bridge requires further investigation. Two timber railroad bridges lost to fire in February 2009, a 312-foot CSX bridge near Mobile, Alabama and a similar Great Western bridge near Greeley, Colorado, have had dramatically different effects on the shippers that these lines serve. In the first instance, CSX worked with other railroads to continue providing service to Mobile until a new bridge had been built 12 days later.[30] In contrast, the Great Western bridge fire resulted in a complete loss of service and an indefinite time of bridge replacement.[31] The principle means by which the Doctor of Engineering program provided the appropriate background for this financial risk analysis was through coursework in accounting, financial management, and construction engineering. Additional work related to the uncertainties and assumptions presented herein should incorporate probability and statistics to quantify the risks inherent in timber bridge assets.

CHAPTER V

USE OF FINANCIAL MARKET DATA IN RAILROAD NEGOTIATIONS

One of the railroad industry's primary financial parameters involved in negotiations and disputes before the STB is the corporate cost of capital. A railroad's cost of capital serves as the basis for determining revenue adequacy, resolving disputes on rates and trackage rights, and in reviewing merger applications. With such economic value at stake, the means of calculating a railroad's cost of capital itself can be quite contentious. Calculations yielding a higher cost of capital lead to revenues being discounted at a higher rate, which is of benefit to the railroad industry by lowering the present value of revenues claimed to be earned on a rail line. Lower line revenue can sway the STB to permit the abandonment of a branch line or increase rail shipping rates. On the other hand, calculations that yield a lower cost of capital can be used to support a shipper's (i.e., a railroad customer's) claim that rail shipping rates should be lower.

The cost of capital is comprised of both debt and equity components. The cost of debt represents a company's cost of borrowing, the rate at which is generally not widely disputed since these rates are, at least in part, observable through the interest rates they offer on corporate bonds. The cost of equity represents the return that shareholders require on their investment in a company.[23] Given that shares of corporate stock are openly traded in the marketplace (e.g. the New York Stock Exchange), there can be considerable disagreement on a company's true cost of equity. Whereas bonds are essentially contracts between a company and bondholders, shareholders constantly revise their expectations for returns as they weigh the opportunity cost of investing in one company versus another.

With important decisions at state in the railroad industry, and in light of the difficulty in identifying shareholder expectations, the STB devotes careful attention to the methodology used to calculate cost of equity. Since 1981, the cost of equity has been based on a single-stage Discounted Cash Flow (DCF) model shown in Eq. 5.1.[25]

$$R_e = \frac{D}{P} + g \quad (5.1)$$

The STB has used this model to estimate return on equity (R_e) by adding the ratio of dividend (D) to share price (P) to a forecasted growth rate (g) based on an average of security analyst's 5-year forecast in the growth of a company's earnings per share. Disputes over this method have centered on the use of dividend payments in the absence of additional performance measures, and a reliance on a single growth rate that is assumed to remain constant in perpetuity. In January 2008, the STB ruled that costs of capital in the railroad industry must follow the Capital Asset Pricing Model (CAPM), which is thought to more fully conform to current finance practice and more accurately capture the market's expectations for equity holdings.[25]

The CAPM method of calculating cost of capital relies more on market returns from railroad stock rather than stock price and the size of dividends. This chapter demonstrates the use of the CAPM in engineering analyses that require the integration of design and economics as they pertain to the private sector. An example design scenario is used to fulfill Objective 4, which is to:

Apply methodologies used in financial markets to the development of parameters required to perform engineering economic analyses.

5.1 Calculating Cost of Capital

The CAPM shown as Eq. 5.2 calculates return on equity as the sum of a risk-free interest rate (R_f) obtainable from U.S. Treasuries of suitable maturity and a risk premium (R_p).[23] This risk premium represents the additional interest that shareholders expect as compensation for investing in stocks rather than government-backed notes.

$$R_e = R_f + \beta R_p \quad (5.2)$$

Since the risk premium is measured as the difference between historic market returns (R_m) and the risk-free rate, the CAPM can also be expressed as Eq. 5.3. In both Eq. 5.2 and 5.3, a risk beta factor (β) is used to adjust the market risk to fit the risk profile of a particular company or industry. Stocks that perform in unison with the market have a beta close to one, while stocks of greater volatility and lower volatility have betas greater than one and less than one, respectively.

$$R_e = R_f + \beta(R_m - R_f) \quad (5.3)$$

According to electronic data sources such as Bloomberg Market Data, interest rates on 10-year treasuries (i.e., risk free notes) have averaged approximately 4.25 percent. Historic returns on corporate stock from 1928 to 2007 (Figure 5.1) have averaged 11.69 percent.[32]

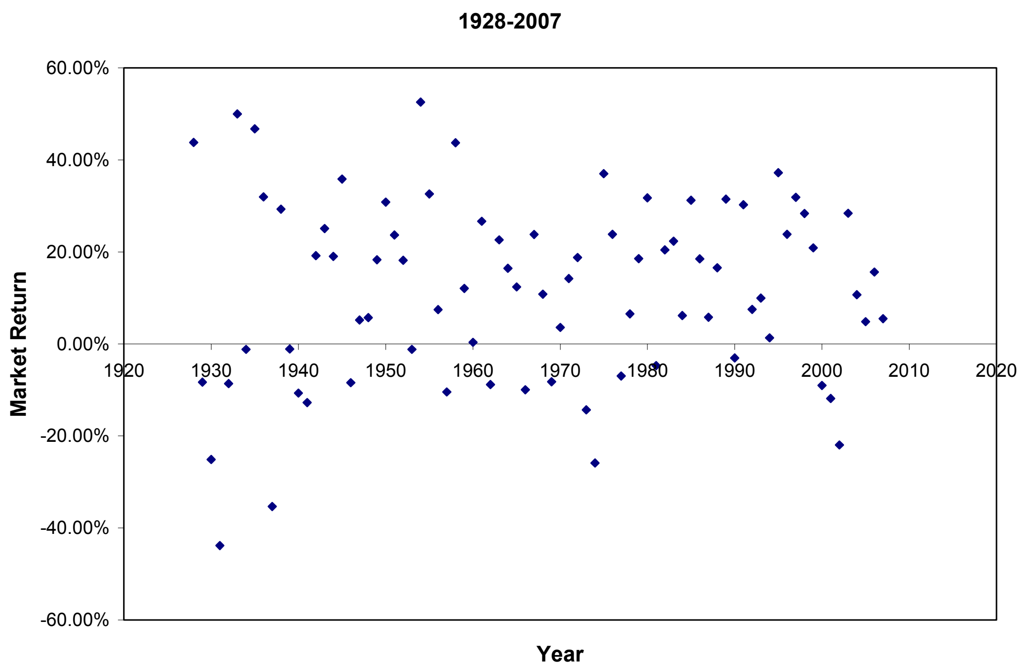


Figure 5.1 Historic Returns on the U.S. Stock Market.

Cost of Equity

Based on the STB's guidelines for determining returns on risk-free treasuries and stock market investments, the market risk premium on equity is:

$$R_p = \left(R_m - R_f\right) = \left(11.69 - 4.25\right) = 7.44\%$$

The market risk premium is adjusted to fit the risk profile of a railroad by factoring the market risk premium by the company's equity beta. This equity beta is calculated as the covariance between the returns on a company's stock and the returns on the market, divided by the variance of market returns.[23] For example, the equity beta of Union Pacific Corporation is calculated as the covariance between returns on Union Pacific stock and returns on the S&P 500 market index ($\sigma_{UP\text{-}S\&P}$) divided by the variance of returns on the S&P 500 market index ($\sigma^2_{S\&P}$), shown in Eq. 5.4.

$$\beta = \frac{\sigma_{UP-S\&P}}{\sigma^2_{S\&P}} \qquad (5.4)$$

The STB ruling stipulates that beta calculations must be based on five-year, weekly industry data. By calculating the percent change in weekly share prices of Union Pacific and the S&P 500 over the last 260 weeks (5 years), a covariance of returns (R) on these stocks can be determined using Eq. 5.5.

$$\sigma_{UP-S\&P} = \frac{\sum_{i=1}^{n}\left[\left(R_i - \bar{R}\right)_{UP}\left(R_i - \bar{R}\right)_{S\&P}\right]}{n-1} \qquad (5.5)$$

A company's equity beta can also be determined by measuring the relationship between returns on a stock and the market through linear regression, as shown in Figure 5.2.[23] In the case of Union Pacific, a plot of weekly returns on Union Pacific stock versus returns on the S&P 500 yields a slope, which is equal to the equity beta, of 0.9749. Based on Eq. 5.2, the preceding results yields a cost of equity for Union Pacific equal to:

$$R_e = R_f + \beta\left(R_p\right) = 4.25 + 0.9749\left(7.44\right) = 11.50\%$$

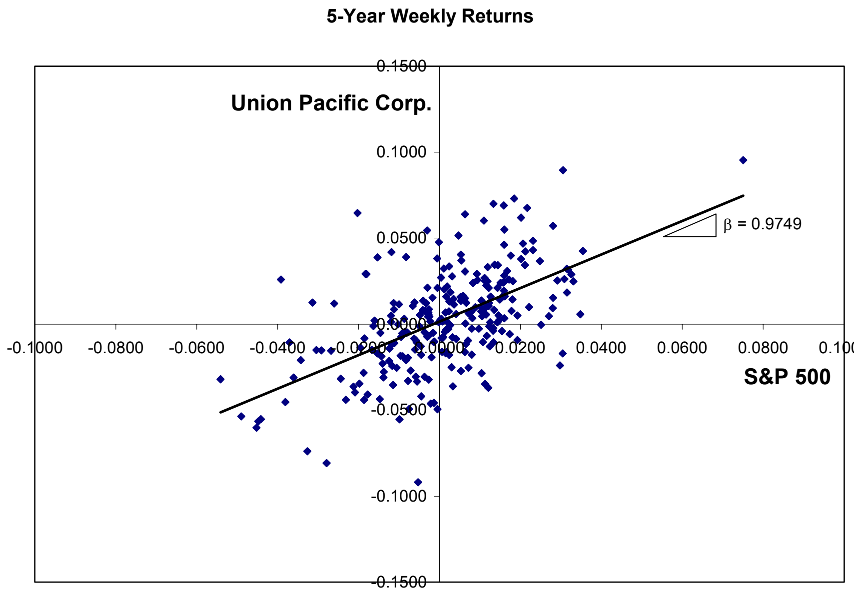


Figure 5.2 Correlation of Union Pacific Stock Returns to Market Performance.

<u>Cost of Capital</u>

In addition to the cost of equity, a railroad's cost of capital is also determined by the cost of debt (R_d). The cost of equity and cost of debt are used to find a weighted average cost of capital (WACC), based on the percent debt financing (k_d), percent equity financing (k_e), and the company's statutory tax rate (T), as shown in Eq. 5.6.[23]

$$WACC = k_d(1-T)R_d + k_e R_e \quad (5.6)$$

Reports filed by Union Pacific with the Securities and Exchange Commission (SEC) show that the company was financed in 2007 with approximately 30 percent debt and 70 percent equity, and taxed at a corporate rate of 37.8 percent.[26] Bloomberg Market Data indicates that the annual yield on 10-year investment grade corporate bonds has averaged 5.61 percent, which if used with Union Pacific's cost of equity yields a WACC equal to:

WACC = (0.303)(1-0.378)(0.0561) + (0.697)(11.50) = 9.08%

The calculation of Union Pacific's cost of capital uses market rates that are intrinsically adjusted for inflation. The need to adjust annual cash flows for inflation in engineering analyses can be eliminated by reducing the WACC by the expected inflation rate. An inflation rate of 2.40 percent yields a cost of capital in real terms of 6.68 percent for Union Pacific.[34] Table 5.1 includes the equity beta and resulting cost of capital for other Class I railroads, showing that different costs of debt and equity, as well as different amounts of leveraged financing, will yield different costs of capital.

Table 5.1 Class I Discount Rate Parameters.

Class I Railroad	Equity Beta	Debt (%)	Equity (%)	Cost of Equity (%)	Cost of Capital (%)	Discount Rate (%)
CSX	1.23	42.70	57.30	13.30	9.28	6.88
KCS	1.50	50.40	49.60	15.19	9.50	7.10
NS	1.27	39.60	60.40	13.58	9.75	7.35
UP	0.99	33.00	67.00	11.62	9.07	6.67

Table 5.2 contrasts each railroad's costs of capital (Table 5.1) to the return on investment for each company reported by the STB. In 2007 the STB determined that Norfolk Southern was the only Class I railroad having adequate revenue (i.e., return on investment is greater than the cost of capital), which is supported by the results for Class I railroads shown in Table 5.2.

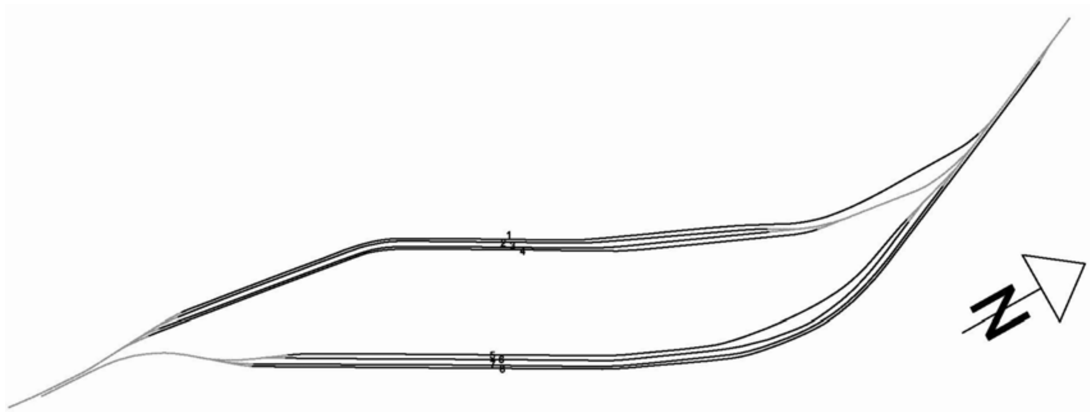
Table 5.2 Revenue Adequacy of Class I Railroads, 2007.

Class I Railroad	Cost of Capital (%)	Return on Investment (%)	Return - Cost (%)
CSX	9.28	7.61	-1.67
KCS	9.50	9.37	-0.13
NS	9.75	13.55	3.80
UP	9.07	8.90	-0.17

5.2 Applying Cost of Capital to Negotiations

In a hypothetical scenario, a department of transportation (DOT) is considering design options for a new bridge having a proposed alignment within rail yard property belonging to the Terminal Railroad & Switching Company (TRSC). Bridge design strategies included the need to construct either five piers or eight piers at the rail yard, and a baseline price must be established for the DOT to offer TRSC as compensation.

The existing track configuration at the rail yard (Figure 5.3) currently consists of eight storage tracks with combined storage capacity of approximately 30,234 feet. TRSC bases revenue on a switching fee of $102 per rail car and a turnover of switched rail cars at the rail yard three times per day. Switching yards are not likely to operate at 100 percent of theoretical capacity, and instead operate at a capacity equal to approximately 70 percent of total track. Assuming operations at 70 percent of capacity, TRSC is expected to currently generate about $36.4 million annually.



Track	Storage Length (ft)
1	4375
2	3169
3	3280
4	3600
5	3500
6	3500
7	3980
8	4830
Total =	30,234

Figure 5.3 Existing Track Configuration at Terminal Railroad Switching Company Rail Yard.

Loss of revenue in any single year correlates to TRSC's inability to increase track storage capacity in that year due to the existence of bridge piers. The TRSC has determined that ultimate track storage capacity without bridge piers will be 270,470 total feet and that ultimate track storage capacity with five and eight I-70 bridge piers would be reduced to 259,167 total feet and 239,380 total feet, respectively. The TRSC should begin to lose revenue in the year that growth in switching service warrants expansion of track storage capacity beyond either 259,167 total feet in the case of five piers, or 239,380 total feet in the case of eight piers, but is prohibited from doing so due to the spatial constraints posed by the particular pier configuration. The calculation of economic loss over a specified project life is based on:

- Project life (duration)
- TRSA cost of capital
- Estimate of annual growth in switching business
- Time to ultimate capacity (with and without piers)

The DOT and TRSC have agreed to base the price of compensation on a 100-year project life and a cost of capital equal to 5.0 percent. Table 5.3 shows the probability distribution of near-term growth in switch rail traffic used by the FRA to assist public agencies with the allocation of resources for the resolution of grade crossing problems.[4] These statistics reflect a normal distribution with a mean annual growth of 2.95 percent, which can be used to predict the near-term annual growth in revenue for TRSC.

Table 5.4 shows the FRA's probability distribution for long-term growth in switch rail traffic, which reflects a distribution skewed to the left having a mean annual growth of 2.00 percent and a 90th percentile annual growth of 2.50 percent. These statistics can be used to predict the long-term annual growth in revenue for TRSC.

Table 5.3 Near-Term Growth in Switch Rail Traffic.

Percentile	Percent Annual Growth
1%	2.3147
5%	2.5008
10%	2.6000
20%	2.7201
30%	2.8068
40%	2.8808
50%	2.9500
60%	3.0192
70%	3.0932
80%	3.1799
90%	3.3000
95%	3.3992
99%	3.5853

Table 5.4 Long-Term Growth in Switch Rail Traffic.

Percentile	Percent Annual Growth
1%	0.5527
5%	1.0578
10%	1.3000
20%	1.5668
30%	1.7415
40%	1.8796
50%	2.0000
60%	2.1125
70%	2.2248
80%	2.3465
90%	2.5000
95%	2.6149
99%	2.8063

The statistical information presented in Tables 5.3 and 5.4 suggest that a fair assessment of economic loss to TRSC over 100 years might be to negotiate around a 2.50 percent to 3.0 percent annual growth according to the following levels of uncertainty:

- 2.00 percent/year (50 percent chance of understating long-term growth)
- 2.50 percent/year (10 percent chance of understating long-term growth)
- 3.00 percent/year (virtually no chance of understating long-term growth and 50 percent chance of understating near-term growth)

Annual cash flows from switching operations consist of a period of growth that continues until ultimate yard storage capacity is reached, followed by a period of constant cash flows throughout the remainder of the project life. The time for switching business at the TRSC rail yard to reach capacity (t) is a function of the existing 30,234-ft storage capacity ($C_{existing}$), the track capacity at build-out ($C_{buildout}$), and the assumed growth in switching service (g), as shown in Eq. 5.7.

$$t = \frac{\ln\left(C_{buildout} / C_{existing}\right)}{\ln\left(1+g\right)} \qquad (5.7)$$

Therefore, the times required to reach yard capacity at assumed annual rates of growth in switch rail traffic (i.e., 2.00, 2.50, and 3.00 percent) are listed in Table 5.5, which shows that growth in switching operations would not be constrained throughout the 100-year period of analysis at a growth rate of 2.00 percent. Growth rates of 2.50 and 3.00 percent shorten the time to ultimate yard capacity to less than 100 years, with the existence of bridge piers causing this time to shorten further by four to five years. Therefore, the economic consequences of constructing bridge piers are:

- No effect if the annual growth rate is 2.00 percent
- Shortening of the time to build-out by:
  - Five years at annual growth rate of 2.50 percent
  - Four years at annual growth rate of 3.00 percent

Table 5.5 Time to Capacity at TRSC Rail Yard.

Growth (%/yr)	Time to Yard Capacity (yrs)		
	No Piers	5 Piers	8 Piers
2.00	110.7	108.5	104.5
2.50	88.8	87.0	83.8
3.00	74.2	72.7	70.0

Net Present Value Analysis

Determination of net present value (NPV) as a baseline price of compensation to TRSC is comprised of revenues earned during a business growth period (Table 5.5) and revenues earned while TRSC operates at full build-out. The NPV during the growth period (NPV_g) incorporates TRSC's cost of capital (i_{COC}) with an assumed growth rate (g) and the base year revenue (R_0), which equals \$36.4 million, using Eq. 5.8.[35]

$$NPVg = R_0\left[\frac{(1+i_{CR})^t - 1}{i_{CR}(1+i_{CR})^t}\right] \qquad (5.8)$$

The convenience rate (i_{CR}) shown in Eq. 5.8 is calculated using Eq. 5.9.[35]

$$i_{CR} = \frac{1+i_{COC}}{1+g} - 1 \qquad (5.9)$$

The annual revenue at full build-out (R_{cap}) can be calculated using Eq. 5.10.

$$R_{cap} = R_0(1+g)^t \qquad (5.10)$$

The NPV of revenues that accrue during full build-out (NPV_c) can be calculated using the time of operation at build-out (n), or $100 - t$, using Eq. 5.11.

$$NPV_c = \left[\frac{(1+i_{COC})^n - 1}{i_{COC}(1+i_{COC})^n}\right](1+i_{COC})^{-t} \qquad (5.11)$$

The net present value of cash flows over 100 years discounted at TRSC's cost of capital equals the sum of NPV_g and NPV_c. Table 5.6 lists the NPV for 5-pier and 8-pier bridge design strategies in addition to the case of no piers at the TRSC rail yard. Three scenarios have been investigated using the three annual rates of growth in switch rail traffic listed in Table 5.5 (i.e., 2.00, 2.50, and 3.00 percent) and base year revenue of \$36.4 million.

Table 5.6 Net Present Value of TRSC Revenue (100 Years).

Growth (%/yr)	Net Present Value (\$)		
	No Piers	5 Piers	8 Piers
2.0	1,168,323,488	1,168,323,488	1,168,323,488
2.5	1,351,577,090	1,349,766,823	1,345,816,052
3.0	1,548,140,176	1,542,313,070	1,530,948,955

Table 5.7 lists the NPV of the differences in each bridge design strategy. According to the results at 2.50 percent growth (only 10 percent chance of being understated), the economic loss to TRSC by the 5-pier strategy is $1.81 million and the economic loss for the 8-pier strategy is $5.76 million. Consequently, the additional loss incurred by TRSC by accommodating eight piers instead of only five piers would be $3.95 million (assuming that revenues grow at 2.50 percent).

Table 5.7 Effects of Bridge Pier Design Strategies on TRSC Revenue.

Growth (%/yr)	Net Present Value ($)		
	No Piers - 5 Piers	No Piers - 8 Piers	5 Piers - 8 Piers
2.0	0	0	0
2.5	1,810,267	5,761,038	3,950,771
3.0	5,827,106	17,191,221	11,364,115

5.3 Academic and Industry Observations

Objective 4 was established to demonstrate how the analysis of financial market data can be integrated into engineering analyses that involve the private sector. In the case of projects affecting the railroad industry, market data can be used to determine a company's cost of capital by applying the methodology stipulated by the STB. This approach provides results that are supported by STB rulings that the railroads are subjected to on a regular basis, and can be used in engineering consulting practice in negotiations involving railroad infrastructure. The principle means by which the Doctor of Engineering program provided the appropriate background for these cost of capital determinations was through coursework in financial management, financial investment analysis, and statistics.

CHAPTER VI

SUMMARY AND CONCLUSIONS

6.1 Summary

This chapter summarizes the accomplishments of the Doctor of Engineering internship and provides conclusions on the outcome of each objective.

Objective 1

A new method of analyzing the impact highway-railroad grade crossing conflicts was developed that relies on the queuing theory adopted by the FRA, while providing a more efficient and accurate means integrating train characteristic information into the analyses. The method developed as part of Objective 1 is capable of using the results from rail network simulations of regional analyses that may consist of hundreds of grade crossings. As a result, this method significantly reduces the time required to perform economic assessments of proposed infrastructure projects such as regional rail bypass corridors.

Objective 2

A proposed public policy to relocate hazardous materials transported by rail through municipalities to new rail corridors was evaluated from both a risk-based and economic perspective. Research relevant to the analysis of exposure risk was identified and applied to inventories of hazardous material shipments and railroad track conditions, and superimposed on demographic data to quantify the effects of an actual release of hazardous material in urban areas. The analysis methodology was then applied to two risk mitigation strategies to evaluate the economic feasibility of each, resulting in a recommended alternative to the existing public policy proposal.

Objective 3

The traditional engineering perspective on risk associated with timber railroad bridges was extended to include the potential for the owner of the asset to experience financial distress. Accounting concepts were applied to general bridge replacement costs and construction schedules to develop basic equations that predict the number of revenue periods required to offset expenses and lost operating income. The relationship between rail line revenue, operating margin, and bridge length was then summarized in graphical form to describe the interrelationship between these financial and physical parameters. The findings from Objective 3 were applied to timber bridge inventories using scenario analyses of line revenues to assess the relative risks associated with railroads and, as a result, predict instances where the loss of a bridge would likely lead to abandonment of the rail line.

Objective 4

Methods used to assess the performance of public companies in financial markets were applied to the calculation of discount rates necessary in engineering analyses. Recent direction by the Surface Transportation Board on calculating costs of equity for the railroad industry were used to demonstrate the integration of financial market data into feasibility assessments and valuations involving the private sector. The application of discount rates based on cost of capital was demonstrated using a hypothetical bridge design scenario requiring the valuation of economic loss to a railroad that results from right-of-way acquisition.

6.2 Conclusions

The following conclusions are derived from the Doctor of Engineering internship:

Grade Crossing Analyses

The current methodology used to determine economic costs of highway-railroad interactions at grade crossings has been improved while maintaining the transportation engineering relationships of queue theory adopted by the FRA. Extension of the FRA equations has provided a means of including unlimited, discrete train types generated by computer-simulated rail network studies for the analysis of infrastructure investments having a regional impact on mobility.

Hazardous Materials Public Policy

Track upgrades within municipal areas provide a viable alternative to relocating hazardous materials transported by rail onto new rail bypasses. In most instances, constraints to public funding and common carrier obligations of the railroads are likely to make track upgrades a more cost effective risk mitigation strategy than current public policies proposed to relocate trains carrying hazardous materials.

Timber Bridge Risks

The financial risks associated with a timber bridge catastrophe can be expressed relative to the physical characteristics of the bridge and the financial performance of the bridge owner. Specific factors that contribute to financial distress by the loss of any particular bridge, such as response time or marginal revenue, have not been identified in this analysis.

Financial Market Analysis

Sufficient information exists from financial data services to integrate market-based determinations of cost of capital into economic assessments of engineering projects. The application of Surface Transportation Board directives to calculate discount rates for private railroad companies provides a sound basis for negotiations on public projects that affect railroad revenues.

NOMENCLATURE

ADT	= average daily traffic, veh/day
ACBT	= average crossing block time, min
A_{class}	= exposure area per hazardous material classification, mi^2
α	= roadway coefficient, veh-hrs/min^2
β	= roadway coefficient, veh-hrs/min (Chapter II)
β	= equity beta, dimensionless (Chapter V)
B	= vehicle queue buildup
C	= project cost, dollars
$C_{buildout}$	= rail yard storage capacity at full build-out, ft
$C_{existing}$	= existing rail yard storage capacity, ft
D	= cumulative dispersed vehicles (Chapter II)
D	= stock dividend payment (Chapter V)
D_{pop}	= population density, people/mi^2
CBT	= crossing block time, min
g	= growth rate, percent
i	= discount rate, percent
i_{COC}	= cost of capital, percent
i_{CR}	= convenience rate, percent
k	= vehicle queue density, veh/lane-ft
k_d	= percent debt financing
k_e	= percent equity financing
L_{corr}	= corridor length, mi
L_{tr}	= train length, ft
λ	= vehicle arrival rate, veh/lane-sec
μ	= vehicle departure rate, veh/lane-sec
M	= operating margin, percent
N	= number of time periods

n = time period or number of time periods
n_f = number of freight trains
n_p = number of passenger trains
n_s = number of switch trains
N_K = number of affected vehicles at grade crossing closure
NPV = net present value, dollars
P = stock share price, dollars
P_R = probability of hazardous material release, percent
R = revenue, dollars
R_{cap} = revenue at full rail yard build-out, dollars
R_d = cost of debt, percent
R_e = cost of equity, percent
R_{exp} = risk of exposure, people/yr
R_f = risk-free rate of return, percent
R_m = historic market rate of return, percent
R_p = risk premium, percent
R_0 = revenue at existing rail yard capacity, dollars
S_{rail} = number of carload shipments per rail corridor
S_{tr} = train speed, mph
σ = covariance, unit-squared
T = hazardous material release frequency, yrs (Chapter III)
T = statutory tax rate, percent (Chapter V)
t_c = time period of construction initiation
t_o = time period of restored rail operations
t_q = time-in-queue, veh-hrs
t = thickness, in (Chapter III)
t = time (Chapter IV and V)
v = free flow vehicle speed, mph
WACC = weighted average cost of capital, percent

w = delay time, veh-hrs

w_T = total delay time, veh-hrs

z = vehicle growth rate at back of queue, veh/sec

$\%_D$ = probability of daytime release, percent

$\%_L$ = probability of large release, percent

$\%_N$ = probability of nighttime release, percent

$\%_S$ = probability of small release, percent

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APPENDIX A

INTERNSHIP SUPERVISOR FINAL REPORT

The Doctor of Engineering internship consisted of 12 consecutive months of employment at the Austin, Texas office of HNTB Corporation, comprised of engineering, financial, and economic analyses within the Austin Rail Group. During this time Craig prepared feasibility studies, computer models, risk analyses, market assessments and financial valuations on behalf of public and private sector clients related to infrastructure investment and development.

In fulfilling Objective 1 of the internship, which was to demonstrate the transformation of previous research into mathematical approaches and computer tools for use on HNTB projects, Craig initiated this process by researching the current mathematical models used in the Federal Railroad Administration's (FRA) GradeDec model and the Environmental Protection Agency's (EPA) Mobile6 model.

Finding shortcomings in each of these approaches, Craig set for the approach to incorporate actual railroad train performance measurement that were the result of running Berkeley Simulation's Rail Traffic Controller (RTC) model, and then established the defensible methodology for calculating reductions in emissions and vehicular delays associated with railroad/roadway at-grade crossings. Concurrently, this approach incorporated a realistic value associated with the reduction of at-grade crossing accidents.

This analysis essentially produced an accurate measurement of public burden reductions, and railroad operational improvement measurements, to quantify both pubic and private benefits associated with railroad infrastructure improvements, in conjunction with applicable grade separation and crossing closures proposals, for an entire rail corridor as opposed to the previous standard comprised of one single location.

In fulfillment of this objective, the end product is one which dramatically reduced the level of effort and time required to obtain economic value results, while expanding the services HNTB Corporation could provide its clients maintaining the company's long-standing credibility in the public and private sector.

Objective 2 involved the selection of appropriate engineering literature for application toward the assessment of policy proposed to reduce the public's exposure to hazardous materials.

HNTB

The 80th Texas Legislative Session enacted House Bill 160 to quantify the costs associated with relocating hazardous material movements shipped by freight rail from within urbanized areas with a population density of more than 1.2 billion people. Concurrently, HB160 required the determination of enhancements to public safety associated with this potential relocation.

In completing this objective, Craig identified an approach suited to the information available within the scope of HB160, and then constructed a mathematical model capable of integrating large amounts of information pertaining to demographics, hazardous material shipments, and recommended emergency response actions.

Through this analysis it was determined that the costs associated with relocating railroad corridors outside of urbanized areas dramatically exceeded the perceived benefit outlined in HB160. This determination led Craig to establish an alternative model that described the public benefit associated with existing railroad infrastructure improvements and a revised railroad operating policy for the movement of hazardous materials.

The results of this objective, both in its initial form as well as the recommended alternative, were subsequently submitted to the Texas Legislature for review.

Objective 3 encompassed the establishment of a risk assessment associated with the catastrophic loss of infrastructure. On March 1, 2007, the northern-most timber bridge approach to the international rail bridge crossing in Presidio, Texas was succumb to fire, completely eliminating any freight rail goods movement between the United States and Mexico at this location. The nearest rail points-of-entry for rerouting rail traffic were now El Paso and Eagle Pass, however the rail line operators at these locations differed from those at Presidio, requiring the negotiation of new operating agreements, and the determination of cost increases for goods shipped due to the increase in route-miles traveled.

The loss-of-use of the Presidio bridge prompted the State of Texas to analyze a similar type of loss of critical infrastructure for marginally profitable rail line owners, such as shortline or regional railroads, that transport critical commodities such as coal to energy generating plants within the state. Using standard accounting measures and scenario-based revenues to predict the susceptibility of rail line owners to financial distress, Craig's research determined the locations within the State of Texas where rail line access to energy plants where not redundant. Obtaining financial information from shortline rail carriers, Craig then prepared a loss-of-revenue analysis to determine the timeframe required to offset the costs associated with replacing lost infrastructure.

HNTB

Although the analysis was used to determine costs applicable to replacement of timber rail structures, the methodology Craig established can be employed, which minor revision, to the loss of track infrastructure as well.

Assisting the State with the understanding of contributing factors that could essentially terminate rail service, and the associated costs to prevent such termination, enables the State to incorporate fact-based decision making when determining whether to contribute financially, in the form of grants or loans, to a private industry thus maintaining the movement of critical goods throughout the state – for the betterment of the State's residents.

The skills required to meet Objective 4, which encompassed the application of financial market data to engineering economic analyses, were regularly used in work involving the quantification of economic impacts on the railroad industry.

Quite frequently State governmental entities, such as Departments of Transportation, impact private industry, such as railroads, when preparing roadway network expansion projects. Rarely does the State agency have a thorough understanding of the private industry's business model, and need to maintain its infrastructure, while conversely the private industry does not fully understand the associated undertakings of the State agency. Consequently, negotiations between the two entities for property acquisition, regardless of initiating party, begin at opposite ends of the spectrum, historically taking years to reach agreement during which time the immediate needs for enhancements may have waned or intensified.

In one such case, jointly the Missouri and Illinois Departments of Transportation entered into negotiations with the Terminal Railroad Company of St. Louis (TRRA) in an attempt to acquire railroad right-of-way to construct a new Interstate 70 bridge spanning the Mississippi River. At issue was the loss of future capacity at a TRRA switching yard resulting from the placement of new bridge piers.

Craig researched the railroad industry's cost of capital and historic growth rates associated with terminal railroads and switching yards, then established mathematical models that predicted full capacity at a rail yard as it exists today, and when the rail yard would be required to expand to meet the demands of capacity growth.

The multitude of scenarios Craig prepared enabled the Departments of Transportation to negotiate with the TRRA, having defensible facts, which narrowed the 'financial' gap between the entities, and brought resolution in months, not years. The economic valuations prepared for this analysis can be re-created for similar situations nationwide.

HNTB

Craig has successfully completed all the aforementioned objectives in a manner that the models established as well as the engineering, financial, and economic analyses undertaken, while satisfying the initial intent of the project at-hand, have provided value to HNTB Corporation for subsequent projects in the future.

Therefore, without hesitation, I validate that the work product for Craig's Doctor of Engineering Internship has been successfully completed.

Joseph A. Lileikis

AVP – HNTB Corporation

APPENDIX B

SAMPLE GRADE CROSSING ANALYSIS COMPUTER CODE

Import Parameters	**Description**
n = read input	number of analysis periods
adt = read input	average daily traffic at a grade crossing
k = read input	queue density
μ = read input	departure rate
v = read input	free flow vehicle speed
nacbt = read input	total of train blockage times
nacbtsq = read input	total of train blockage times squared
pcex = read input	passenger car equivalent factor
r = read input	vehicle growth rate
g = read input	train growth rate
i = read input	public discount rate
nlane = read input	number of total vehicle lanes
q = read input	queue cost
d = read input	delay cost

Initialize Variables	**Description**
rx = 0	vehicle growth factor
gx = 0	train growth factor
px = 0	public discount factor
t = 0	time period
tq = 0	queue time
td = 0	delay time
ecost = 0	cost of vehicle emissions
vcost = 0	cost of VOC consumption
dcost = 0	cost of delay time
total = 0	total cost

Calculate Costs

If (n + 1) > t:

t = t + 1

rx = $(1 + r)^t$

pce = (adt)(pcex)(rx)

$$\lambda = \frac{PCE}{(nlane)(86400)}$$

$$z = \frac{\lambda v k}{vk - \lambda}$$

$$\alpha_q = nlane\left[\frac{\lambda\mu}{\mu-\lambda} + \left(\frac{1}{\mu} - \frac{1}{z}\right)\frac{\lambda^2\mu^2}{2(\mu-\lambda)^2}\right]$$

$$\beta_q = nlane\left[\left(\frac{1}{\mu} - \frac{1}{z}\right)\frac{\lambda\mu}{120(\mu-\lambda)}\right]$$

$$\alpha_d = nlane\left[\frac{\lambda\mu}{\mu-\lambda} + \left(\frac{1}{\mu} - \frac{1}{\lambda}\right)\frac{\lambda^2\mu^2}{2(\mu-\lambda)^2}\right]$$

$$\beta_d = nlane\left[\left(\frac{1}{\mu} - \frac{1}{\lambda}\right)\frac{\lambda\mu}{120(\mu-\lambda)}\right]$$

gx = $(1 + g)^t$
nacbt = (nacbt)(gx)
nacbtsq = (nacbtsq)(gx)
tq = tq +(α_q)(nacbtsq) + (β_q)(nacbt)
td = td + (α_d)(nacbtsq) + (β_d)(nacbt)
px = $(1 + i)^t$
ecost = (ecost + (tq)(qe))/(px)
vcost = (vcost + (tq)(qv))/(px)
dcost = (dcost + (td)(d))/(px)

Else:

total = ecost + vcost + dcost

APPENDIX C

HAZARDOUS MATERIALS AND PROTECTIVE ACTION DISTANCES

Name of Hazardous Material	Emergency Response ID Number	Classification (49CFR172.101)	US DOT ERG Protective Action Distance			
			Small Spills		Large Spills	
			Day (mi)	Night (mi)	Day (mi)	Night (mi)
Ammonia, anhydrous	1005	2.3	0.1	0.1	0.4	1.4
Boron trifloride	1008	2.3	0.1	0.4	1.1	3.0
Carbon monoxide	1016	2.3	0.1	0.1	0.4	1.5
Chlorine	1017	2.3	0.2	0.8	1.5	4.6
Coal gas	1023	2.3	0.1	0.1	0.2	0.3
Cyanogen	1026	2.3	0.2	0.8	0.7	2.7
Ethylene Oxide	1040	2.3	0.1	0.1	0.5	1.5
Fluorine	1045	2.3	0.1	0.3	0.5	2.2
Hydrogen bromide, anhydrous	1048	2.3	0.1	0.3	1.1	3.6
Hydrogen chlorine, anhydrous	1050	2.3	0.1	0.3	2.2	6.5
Hydrogen cyanide	1051	6.1	0.1	0.3	0.8	2.3
Hydrogen fluoride	1052	8	0.1	0.3	1.2	2.7
Hydrogen sulfide	1053	2.3	0.1	0.2	1.3	3.9
Methyl bromide	1062	2.3	0.1	0.1	0.5	1.4
Methyl mercaptan	1064	2.3	0.1	0.2	0.8	2.8
Dinitrogen tetroxide	1067	2.3	0.1	0.3	1.0	2.5
Nitrosyl chloride	1069	2.3	0.1	0.6	2.7	6.9
Oil gas	1071	2.3	0.1	0.1	0.2	0.3
Diphosgene	1076	2.3	0.6	2.6	4.1	7.0
Phosgene	1076	2.3	0.6	2.6	4.1	7.0
Sulfur dioxide	1079	2.3	0.2	0.8	1.3	3.9
Trifluorochloroethylene	1082	2.3	0.1	0.1	0.3	0.5
Acrolein	1092	6.1	0.3	1.1	3.0	6.3
Allyl alcohol	1098	6.1	0.1	0.1	0.2	0.4
Ethylene chlorohydrin	1135	6.1	0.1	0.2	0.5	1.0
Crotonaldehyde	1143	6.1	0.1	0.1	0.3	0.5
Dimethyldichlorosilane	1162	3	0.2	0.7	1.9	4.9
Dimethylhydrazine	1163	6.1	0.1	0.1	0.4	0.8
Ethyl chloroformate	1182	6.1	0.1	0.2	0.6	1.1
Ethyleneimine	1185	6.1	0.2	0.5	1.2	2.5
Ethyltrichlorosilane	1196	3	0.2	0.7	1.9	4.9
Methyl chloroformate	1238	6.1	0.2	0.5	1.1	2.4
Methyl chloromethyl ether	1239	6.1	0.2	0.6	1.6	3.5
Methyldichlorosilane	1242	4.3	0.1	0.4	1.0	3.0
Methylhydrazine	1244	6.1	0.2	0.3	0.9	1.8
Methyltrichlorosilane	1250	3	0.1	0.3	0.8	2.5
Methyl vinyl ketone	1251	6.1	0.8	2.1	7.0	7.0
Nickel carbonyl	1259	6.1	0.5	2.2	2.9	6.1
Trichlorosilane	1295	4.3	0.1	0.6	1.6	4.1
Trimethylchlorosilane	1298	3	0.1	0.2	0.5	1.7
Vinyltrichlorosilane	1305	3	0.1	0.5	1.1	3.1
Phosphorus pentasulfide	1340	4.3	0.1	0.4	0.6	2.4
Calcium phosphide	1360	4.3	0.3	1.3	3.9	7.0
Pentaborane	1380	4.2	0.6	2.1	3.3	6.9
Sodium dithionite	1384	4.2	0.1	0.1	0.3	0.8
Aluminum phosphide	1397	4.3	0.4	1.7	5.6	7.0
Lthium amide	1412	4.3	0.1	0.2	0.2	1.0
Magnesium aluminum phoshide	1419	4.3	0.4	1.6	4.9	7.0
Sodium phosphide	1432	4.3	0.2	1.1	2.9	7.0
Tetranitromethane	1510	5.1	0.2	0.4	0.5	1.0
Acetone cyanohydrin	1541	6.1	0.1	0.2	0.5	1.9
Methyldichloroarsine	1556	6.1	0.2	0.5	0.8	2.2
Arsenic chloride	1560	6.1	0.2	0.2	0.6	1.1
Bromoacetone	1569	6.1	0.1	0.4	0.5	1.5
Chloropicrin	1580	6.1	0.3	0.5	1.2	2.2
Chloropicrin methyl bromide	1581	2.3	0.1	0.4	1.3	3.7
Chloropicrin methyl chloride	1582	2.3	0.1	0.3	0.2	1.1
Chloropicrin	1583	6.1	0.3	0.5	1.2	2.2
Cyanogen chloride	1589	2.3	0.4	1.8	2.7	6.3
Dymethyl sulfate	1595	6.1	0.1	0.1	0.3	0.5
Ethylene dibromide	1605	6.1	0.1	0.1	0.2	0.4
Hexaethyl tetraphosphate	1612	2.3	0.5	1.7	2.2	5.1
Hydrocyanic acid	1613	6.1	0.1	0.1	0.3	0.8
Hydrogen cyanide, anhydrous	1614	6.1	0.1	0.4	0.3	1.1
Ethylene dibromide methyl bromide	1647	6.1	0.1	0.1	0.2	0.4

Name of Hazardous Material	Emergency Response ID Number	Classification (49CFR172.101)	US DOT ERG Protective Action Distance			
			Small Spills		Large Spills	
			Day (mi)	Night (mi)	Day (mi)	Night (mi)
Nitric oxide	1660	2.3	0.1	0.5	0.4	1.7
Perchloromethyl mercaptan	1670	6.1	0.1	0.2	0.4	0.8
Potassium cyanide	1680	6.1	0.1	0.3	0.6	2.4
Sodium cyanide	1689	6.1	0.1	0.4	0.8	3.0
Chloroacetone	1695	6.1	0.1	0.2	0.5	0.9
Acetyl bromide	1716	8	0.1	0.2	0.5	1.4
Acetyl chloride	1717	3	0.1	0.3	0.7	2.2
Allyl chlorocarbonate	1722	6.1	0.2	0.5	1.2	2.4
Allyltrichlorosilane	1724	8	0.1	0.5	1.2	3.4
Aluminum bromide, anhydrous	1725	8	0.1	0.3	0.4	1.6
Aluminum chloride, anhydrous	1726	8	0.1	0.5	0.7	2.8
Amyltrichlorosilane	1728	8	0.1	0.1	0.3	1.2
Antimony pentafluoride	1732	8	0.1	0.6	1.2	3.4
Boron trichloride	1741	2.3	0.1	0.2	0.4	1.1
Bromine	1744	8	0.3	1.1	2.1	4.6
Bromine pentafluoride (land)	1745	5.1	0.2	0.9	1.7	4.3
Bromine pentafluoride (water)	1745	5.1	0.1	0.6	1.4	4.1
Bromine trifluoride (land)	1746	5.1	0.1	0.4	1.1	3.0
Bromine trifluoride (water)	1746	5.1	0.1	0.6	1.2	3.6
Butyltrichlorosilane	1747	8	0.1	0.2	0.4	1.3
Chlorine trifluorde	1749	2.3	0.3	1.3	1.8	5.1
Chloroacetyl chloride (land)	1752	6.1	0.2	0.4	0.9	1.6
Chloroacetyl chloride (water)	1752	6.1	0.1	0.1	0.3	1.0
Chlorosulfonic acid (land)	1754	8	0.1	0.1	0.2	0.3
Chlorosulfonic acid (water)	1754	8	0.1	0.4	0.5	1.7
Chlorosulfonic acid sulfur trioxide (land)	1754	8	0.2	0.6	1.5	4.0
Chlorosulfonic acid sulfur trioxide (water)	1754	8	0.1	0.4	0.5	1.7
Sulfur trioxide chlorosulfonic acid (land)	1754	8	0.2	0.6	1.5	4.0
Sulfur trioxide chlorosulfonic acid (water)	1754	8	0.1	0.4	0.5	1.7
Chromium oxychloride	1758	8	0.1	0.1	0.2	0.8
Cyclohexyltrichlorosilane	1763	8	0.1	0.2	0.5	1.9
Dichlorophenyltrichlorosilane	1766	8	0.1	0.6	1.3	3.6
Diethyldichlorosilane	1767	8	0.1	0.1	0.3	0.8
Diphenyldichlorosilane	1769	8	0.1	0.1	0.2	0.8
Dodecyltrichlorosilane	1771	8	0.1	0.1	0.3	1.2
Fluorosulfonic acid	1777	8	0.1	0.3	0.6	2.1
Hexyltrichlorosilane	1784	8	0.1	0.3	0.7	2.4
Nonyltrichlorosilane	1799	8	0.1	0.2	0.4	1.6
Octadecyltrichlorosilane	1800	8	0.1	0.2	0.5	1.8
Octyltrichlorosilane	1801	8	0.1	0.2	0.4	1.6
Phenyltrichlorosilane	1804	8	0.1	0.6	1.4	4.0
Phosphorus pentachloride	1806	8	0.1	0.3	0.5	1.9
Phosphorus trichloride (land)	1809	6.1	0.1	0.3	1.0	2.2
Phosphorus trichloride (water)	1809	6.1	0.1	0.4	1.0	3.0
Phosphorus oxychloride (land)	1810	8	0.2	0.3	0.7	1.4
Phosphorus oxychloride (water)	1810	8	0.1	0.6	1.5	3.9
Propyltrichlorosilane	1816	8	0.1	0.3	0.8	2.6
Silicon tetrachloride	1818	8	0.1	0.4	1.0	2.9
Sulfur chlorides (land)	1828	8	0.1	0.1	0.6	1.1
Sulfur chlorides (water)	1828	8	0.1	0.4	0.9	3.0
Sulphur chlorides (land)	1828	8	0.1	0.1	0.6	1.1
Sulphur chlorides (water)	1828	8	0.1	0.4	0.9	3.0
Sulfur trioxide	1829	8	0.2	0.6	1.5	4.0
Sulfuric acid, fuming	1831	8	0.2	0.6	1.5	4.0
Sulfuryl chloride (land)	1834	8	0.1	0.1	0.2	0.5
Sulfuryl chloride (water)	1834	8	0.1	0.2	0.5	1.8
Sulphuryl chloride (land)	1834	8	0.1	0.1	0.2	0.5
Sulphuryl chloride (water)	1834	8	0.1	0.2	0.5	1.8
Thionyl chloride (land)	1836	8	0.2	0.5	0.6	1.4
Thionyl chloride (water)	1836	8	0.2	1.1	2.8	6.5
Titanium tetrachloride (land)	1838	8	0.1	0.1	0.3	0.5
Titanium tetrachloride (water)	1838	8	0.1	0.3	0.7	2.3
Silicon tetrafluoride	1859	2.3	0.1	0.1	0.3	0.5
Ethyldichloroarsine	1892	6.1	0.1	0.2	0.4	0.7
Acetyl iodide	1898	8	0.1	0.2	0.4	1.1

Name of Hazardous Material	Emergency Response ID Number	Classification (49CFR172.101)	US DOT ERG Protective Action Distance			
			Small Spills		Large Spills	
			Day (mi)	Night (mi)	Day (mi)	Night (mi)
Diborane	1911	2.3	0.2	1.0	1.1	3.4
Calcium dithionite	1923	4.2	0.1	0.1	0.3	0.8
Zinc dithionite	1931	9	0.1	0.1	0.3	0.8
Compressed gas, flammable, poisonous, nos (hazard zone A)	1953	2.1	0.8	3.2	5.4	7.0
Compressed gas, flammable, poisonous, nos (hazard zone B)	1953	2.1	0.2	0.8	2.5	6.7
Compressed gas, flammable, poisonous, nos (hazard zone C)	1953	2.1	0.1	0.5	1.5	4.0
Compressed gas, flammable, poisonous, nos (hazard zone D)	1953	2.1	0.1	0.1	0.5	1.5
Compressed gas, flammable, toxic, nos (hazard zone A)	1953	2.1	0.8	3.2	5.4	7.0
Compressed gas, flammable, toxic, nos (hazard zone B)	1953	2.1	0.2	0.8	2.5	6.7
Compressed gas, flammable, toxic, nos (hazard zone C)	1953	2.1	0.1	0.5	1.5	4.0
Compressed gas, flammable, toxic, nos (hazard zone D)	1953	2.1	0.1	0.1	0.5	1.5
Compressed gas, poisonous, flammable, nos (hazard zone A)	1953	2.1	0.8	3.2	5.4	7.0
Compressed gas, poisonous, flammable, nos (hazard zone B)	1953	2.1	0.2	0.8	2.5	6.7
Compressed gas, poisonous, flammable, nos (hazard zone C)	1953	2.1	0.1	0.5	1.5	4.0
Compressed gas, poisonous, flammable, nos (hazard zone D)	1953	2.1	0.1	0.1	0.5	1.5
Compressed gas, toxic, flammable, nos (hazard zone A)	1953	2.1	0.8	3.2	5.4	7.0
Compressed gas, toxic, flammable, nos (hazard zone B)	1953	2.1	0.2	0.8	2.5	6.7
Compressed gas, toxic, flammable, nos (hazard zone C)	1953	2.1	0.1	0.5	1.5	4.0
Compressed gas, toxic, flammable, nos (hazard zone D)	1953	2.1	0.1	0.1	0.5	1.5
Liquified gas, flammable, poisonous, nos (hazard zone A)	1953	2.1	0.8	3.2	5.4	7.0
Liquified gas, flammable, poisonous, nos (hazard zone B)	1953	2.1	0.2	0.8	2.5	6.7
Liquified gas, flammable, poisonous, nos (hazard zone C)	1953	2.1	0.1	0.5	1.5	4.0
Liquified gas, flammable, poisonous, nos (hazard zone D)	1953	2.1	0.1	0.1	0.5	1.5
Liquified gas, flammable, toxic, nos (hazard zone A)	1953	2.1	0.8	3.2	5.4	7.0
Liquified gas, flammable, toxic, nos (hazard zone B)	1953	2.1	0.2	0.8	2.5	6.7
Liquified gas, flammable, toxic, nos (hazard zone C)	1953	2.1	0.1	0.5	1.5	4.0
Liquified gas, flammable, toxic, nos (hazard zone D)	1953	2.1	0.1	0.1	0.5	1.5
Compressed gas, poisonous, nos (hazard zone A)	1955	2.3	3.7	7.0	7.0	7.0
Compressed gas, poisonous, nos (hazard zone B)	1955	2.3	0.3	1.3	4.9	7.0
Compressed gas, poisonous, nos (hazard zone C)	1955	2.3	0.2	0.8	1.5	4.0
Compressed gas, poisonous, nos (hazard zone D)	1955	2.3	0.1	0.4	0.8	2.4
Compressed gas, toxic, nos (hazard zone A)	1955	2.3	3.7	7.0	7.0	7.0
Compressed gas, toxic, nos (hazard zone B)	1955	2.3	0.3	1.3	4.9	7.0
Compressed gas, toxic, nos (hazard zone C)	1955	2.3	0.2	0.8	1.5	4.0
Compressed gas, toxic, nos (hazard zone D)	1955	2.3	0.1	0.4	0.8	2.4
Liquified gas, poisonous, nos (hazard zone A)	1955	2.3	3.7	7.0	7.0	7.0
Liquified gas, poisonous, nos (hazard zone B)	1955	2.3	0.3	1.3	4.9	7.0
Liquified gas, poisonous, nos (hazard zone C)	1955	2.3	0.2	0.8	1.5	4.0
Liquified gas, poisonous, nos (hazard zone D)	1955	2.3	0.1	0.4	0.8	2.4
Liquified gas, toxic, nos (hazard zone A)	1955	2.3	3.7	7.0	7.0	7.0
Liquified gas, toxic, nos (hazard zone B)	1955	2.3	0.3	1.3	4.9	7.0
Liquified gas, toxic, nos (hazard zone C)	1955	2.3	0.2	0.8	1.5	4.0
Liquified gas, toxic, nos (hazard zone D)	1955	2.3	0.1	0.4	0.8	2.4
Organic phosphate mixed with compressed gas	1955	2.3	0.7	2.1	2.7	6.0
Insecticide gas, poisonous or toxic	1967	2.3	0.7	2.1	2.7	6.0
Dinitrogen tetroxide and nitric oxide mixture	1975	2.3	0.1	0.5	0.4	1.7
Iron pentacarbonyl	1994	6.1	0.2	0.4	1.0	1.9
Magnesium diamide	2004	4.2	0.1	0.3	0.4	1.8
Magnesium phosphide	2011	4.3	0.4	1.5	4.7	7.0
Potassium phosphide	2012	4.3	0.3	1.1	2.9	7.0
Strontium phosphide	2013	4.3	0.2	1.1	2.9	7.0
Nitric acid, fuming	2032	8	0.1	0.2	0.4	0.8
Hydrogen chloride, refrigerated liquid	2186	2.3	0.1	0.3	2.2	6.5
Arsine	2188	2.3	0.4	1.9	2.6	5.9
Dichlorosilane	2189	2.3	0.1	0.6	2.5	6.7
Oxygen difluoride	2190	2.3	3.7	7.0	7.0	7.0
Sulfuryl fluoride	2191	2.3	0.1	0.2	0.8	2.4
Germane	2192	2.3	0.1	0.6	0.5	1.9
Selenium hexafluoride	2194	2.3	0.5	2.0	2.7	5.6
Tellurium hexafluoride	2195	2.3	0.6	2.5	3.7	7.0
Tungsten hexafluoride	2196	2.3	0.1	0.7	0.6	2.3
Hydrogen iodide, anhydrous	2197	2.3	0.1	0.2	0.8	2.3
Phosphorus pentafluoride	2198	2.3	0.2	1.0	1.0	2.9
Phosphine	2199	2.3	0.4	1.9	2.7	6.0
Hydrogenselenide, anhydrous	2202	2.3	0.8	3.2	5.4	7.0

Name of Hazardous Material	Emergency Response ID Number	Classification (49CFR172.101)	US DOT ERG Protective Action Distance			
			Small Spills		Large Spills	
			Day (mi)	Night (mi)	Day (mi)	Night (mi)
Carbonyl sulfide	2204	2.3	0.1	0.4	1.9	5.0
Chloroacetaldehyde	2232	6.1	0.1	0.2	0.5	1.0
Allylamine	2334	6.1	0.1	0.3	0.7	1.5
Phenyl mercaptan	2237	6.1	0.1	0.1	0.2	0.4
Dimethylhydrazine	2282	6.1	0.1	0.1	0.4	0.8
Isopropyl chloroformate	2407	6.1	0.1	0.2	0.5	0.9
Carbonyl fluoride	2417	2.3	0.1	0.7	0.6	2.3
Sulfur tetrafluoride	2418	2.3	0.4	2.0	2.9	6.6
Hexafluoroacetone	2420	2.3	0.2	0.8	4.5	7.0
Nitrogen trioxide	2421	2.3	0.1	0.3	0.3	1.2
Methylphenylchlorosilane	2437	8	0.1	0.1	0.3	0.7
Trimethylacetyl chloride	2438	6.1	0.1	0.1	0.3	0.5
Trichloroacetyl chloride	2442	8	0.2	0.5	0.8	1.4
Thiophosgene	2474	6.1	0.5	1.5	2.3	4.2
Methyl isothiocyanate	2477	6.1	0.1	0.1	0.3	0.7
Methyl isocyanate	2480	6.1	0.3	1.2	3.3	7.0
Ethyl isocyanate	2481	3	0.4	1.3	3.9	7.0
n-Propyl isocyanate	2482	6.1	0.7	1.6	5.6	7.0
isopropyl isocyanate	2483	3	0.7	1.8	7.0	7.0
tert-Butyl isocyanate	2484	6.1	0.6	1.5	5.2	7.0
n-Butyl isocyanate	2485	6.1	0.5	1.0	2.9	5.0
Isobutyl isocyanate	2486	3	0.5	1.0	3.0	4.8
Phenyl isocyanate	2487	6.1	0.2	0.3	1.0	1.8
Cyclohexyl isocyanate	2488	6.1	0.2	0.2	0.6	1.0
Iodine pentafluoride	2495	5.1	0.1	0.6	1.2	3.6
Diketene	2521	6.1	0.1	0.1	0.2	0.3
Methylchlorosilane	2534	2.3	0.1	0.5	1.5	4.0
Chlorine pentafluoride	2548	2.3	0.2	1.1	1.5	4.6
Carbon monoxide and hydrogen mixture	2600	2.3	0.1	0.1	0.4	1.5
Methoxymethyl isocyanate	2605	3	0.2	0.4	1.0	1.6
Methyl orthosilicate	2606	6.1	0.1	0.1	0.3	0.4
Methyl iodide	2644	6.1	0.1	0.1	0.2	0.5
Hexachlorocyclopentadiene	2646	6.1	0.1	0.1	0.3	0.3
Chloroacetonitrile	2668	6.1	0.1	0.1	0.2	0.3
Stibine	2676	2.3	0.3	1.4	1.7	4.7
Phosphorus pentabromide	2691	8	0.1	0.4	0.4	1.7
Boron tribromide (land)	2692	8	0.1	0.3	0.4	0.8
Boron tribromide (water)	2692	8	0.1	0.3	0.5	1.6
n-Propyl chloroformate	2740	6.1	0.1	0.2	0.5	0.9
sec-Butyl chloroformate	2742	6.1	0.1	0.1	0.3	0.4
Isobutyl chloroformate	2742	6.1	0.1	0.1	0.2	0.3
n-Butyl chloroformate	2743	6.1	0.1	0.1	0.2	0.3
Lithium nitride	2806	4.3	0.1	0.2	0.4	1.6
Poisonous liquid, nos (hazard zone A)	2810	6.1	0.8	2.2	7.0	7.0
Poisonous liquid, nos (hazard zone B)	2810	6.1	0.3	1.1	2.1	4.6
Poisonous liquid, organic, nos (hazard zone A)	2810	6.1	0.8	2.1	7.0	7.0
Poisonous liquid, organic, nos (hazard zone B)	2810	6.1	0.2	0.6	1.6	3.5
Toxic liquid, nos (hazard zone A)	2810	6.1	0.8	2.2	7.0	7.0
Toxic liquid, nos (hazard zone B)	2810	6.1	0.3	1.1	2.1	4.6
Toxic liquid, organic, nos (hazard zone A)	2810	6.1	0.8	2.1	7.0	7.0
Toxic liquid, organic, nos (hazard zone B)	2810	6.1	0.2	0.6	1.6	3.5
Ethyl chlorothioformate	2826	8	0.1	0.1	0.4	0.6
Ethyl phosphonous dichloride, anhydrous	2845	6.1	0.2	0.5	1.2	2.2
Methyl phosphonous dichloride	2845	6.1	0.3	0.8	1.9	3.7
Bromine chloride	2901	2.3	0.2	0.6	1.5	3.9
Ethyl phosphonothioic dichloride, anhydrous	2927	6.1	0.1	0.1	0.1	0.2
Ethyl phosphorodichloridate	2927	6.1	0.1	0.1	0.2	0.2
Poisonous liquid, corrosive, nos (hazard zone A)	2927	6.1	0.5	1.5	3.9	7.0
Poisonous liquid, corrosive, nos (hazard zone B)	2927	6.1	0.3	1.1	2.1	4.6
Toxic liquid, corrosive, organic, nos (hazard zone A)	2927	6.1	0.4	1.3	3.9	7.0
Toxic liquid, corrosive, organic, nos (hazard zone B)	2927	6.1	0.2	0.4	1.0	1.8
Poisonous liquid, flammable, nos (hazard zone A)	2929	6.1	0.8	2.2	7.0	7.0
Poisonous liquid, flammable, nos (hazard zone B)	2929	6.1	0.2	0.6	1.6	3.5
Poisonous liquid, flammable, organic, nos (hazard zone A)	2929	6.1	0.8	2.1	7.0	7.0
Poisonous liquid, flammable, organic, nos (hazard zone B)	2929	6.1	0.2	0.6	1.6	3.5

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			Small Spills		Large Spills	
			Day (mi)	Night (mi)	Day (mi)	Night (mi)
Toxic liquid, flammable, nos (hazard zone A)	2929	6.1	0.8	2.2	7.0	7.0
Toxic liquid, flammable, nos (hazard zone B)	2929	6.1	0.2	0.6	1.6	3.5
Toxic liquid, flammable, organic, nos (hazard zone A)	2929	6.1	0.8	2.1	7.0	7.0
Toxic liquid, flammable, organic, nos (hazard zone B)	2929	6.1	0.2	0.6	1.6	3.5
Radioactive material, uranium hexafluoride, fissle	2977	7	0.1	0.4	0.5	2.1
Radioactive material, uranium hexafluoride	2978	7	0.1	0.4	0.5	2.1
Chlorosilanes, flammable, corrosive, nos	2985	3	0.1	0.3	0.8	2.4
Chlorosilanes, corrosive, flammable, nos	2986	3	0.1	0.3	0.8	2.4
Chlorosilanes, corrosive, nos	2987	8	0.1	0.3	0.8	2.4
Chlorosilanes, nos	2988	4.3	0.1	0.3	0.8	2.4
2-Methyl-2-heptanethiol	3023	6.1	0.1	0.1	0.3	0.5
Aluminum phosphide pesticide	3048	6.1	0.4	1.7	5.6	7.0
Metal alkyl halides	3049	6.1	0.1	0.1	0.2	0.8
Aluminum alkyl halides	3052	4.2	0.1	0.1	0.2	0.8
Trifluoroacetyl chloride	3057	2.3	0.2	0.8	4.9	7.0
Methacrylonitrile	3079	3	0.1	0.2	0.5	1.0
Perchloryl fluoride	3083	2.3	0.1	0.4	2.2	5.5
Poisonous liquid, oxidizing, nos (hazard zone A)	3122	6.1	0.8	2.2	7.0	7.0
Poisonous liquid, oxidizing, nos (hazard zone B)	3122	6.1	0.2	0.9	1.7	4.3
Toxic liquid, oxidizing, nos (hazard zone A)	3122	6.1	0.8	2.2	7.0	7.0
Toxic liquid, oxidizing, nos (hazard zone B)	3122	6.1	0.2	0.9	1.7	4.3
Poisonous liquid, water-reactive, nos (hazard zone A)	3123	6.1	0.8	2.2	7.0	7.0
Poisonous liquid, water-reactive, nos (hazard zone B)	3123	6.1	0.3	1.1	2.1	4.5
Poisonous liquid, flammable gases in water (hazard zone A)	3123	6.1	0.8	2.2	7.0	7.0
Poisonous liquid, flammable gases in water (hazard zone B)	3123	6.1	0.3	1.1	2.1	4.6
Toxic liquid, water-reactive, nos (hazard zone A)	3123	6.1	0.8	2.2	7.0	7.0
Toxic liquid, water-reactive, nos (hazard zone B)	3123	6.1	0.3	1.1	2.1	4.6
Toxic liquid, flammable gases in water (hazard zone A)	3123	6.1	0.8	2.2	7.0	7.0
Toxic liquid, flammable gases in water (hazard zone B)	3123	6.1	0.3	1.1	2.1	4.6
Liquified gas, poisonous, flammable, nos (hazard zone A)	3160	2.3	0.8	3.2	5.4	7.0
Liquified gas, poisonous, flammable, nos (hazard zone B)	3160	2.3	0.2	0.8	2.5	6.7
Liquified gas, poisonous, flammable, nos (hazard zone C)	3160	2.3	0.1	0.5	1.5	4.0
Liquified gas, poisonous, flammable, nos (hazard zone D)	3160	2.3	0.1	0.1	0.5	1.5
Liquified gas, toxic, flammable, nos (hazard zone A)	3160	2.3	0.8	3.2	5.4	7.0
Liquified gas, toxic, flammable, nos (hazard zone B)	3160	2.3	0.2	0.8	2.5	6.7
Liquified gas, toxic, flammable, nos (hazard zone C)	3160	2.3	0.1	0.5	1.5	4.0
Liquified gas, toxic, flammable, nos (hazard zone D)	3160	2.3	0.1	0.1	0.5	1.5
Liquified gas, poisonous, nos (hazard zone A)	3162	2.3	3.7	7.0	7.0	7.0
Liquified gas, poisonous, nos (hazard zone B)	3162	2.3	0.3	1.3	4.9	7.0
Liquified gas, poisonous, nos (hazard zone C)	3162	2.3	0.2	0.8	1.5	4.0
Liquified gas, poisonous, nos (hazard zone D)	3162	2.3	0.1	0.4	0.8	2.4
Liquified gas, toxic, nos (hazard zone A)	3162	2.3	3.7	7.0	7.0	7.0
Liquified gas, toxic, nos (hazard zone B)	3162	2.3	0.3	1.3	4.9	7.0
Liquified gas, toxic, nos (hazard zone C)	3162	2.3	0.2	0.8	1.5	4.0
Liquified gas, toxic, nos (hazard zone D)	3162	2.3	0.1	0.4	0.8	2.4
Methanesulfonyl chloride	3246	6.1	0.2	0.4	1.0	1.6
Nitriles, poisonous, flammable, nos	3275	6.1	0.1	0.2	0.5	1.0
Nitriles, poisonous, liquid, nos	3276	6.1	0.1	0.2	0.5	1.0
Organophosphorus compound, poisonous, liquid, nos	3278	6.1	0.3	0.8	1.9	3.7
Organophosphorus compound, poisonous, flammable, nos	3279	6.1	0.3	0.8	1.9	3.7
Organoarsenic compound, liquid, nos	3280	6.1	0.1	0.4	1.3	3.2
Metal carbonyls	3281	6.1	0.5	2.2	2.9	6.1
Poisonous liquid, inorganic, nos (hazard zone A)	3287	6.1	0.6	2.2	3.3	6.9
Poisonous liquid, inorganic, nos (hazard zone B)	3287	6.1	0.3	1.1	2.1	4.6
Toxic liquid, inorganic, nos (hazard zone A)	3287	6.1	0.6	2.2	3.3	6.9
Toxic liquid, inorganic, nos (hazard zone B)	3287	6.1	0.3	1.1	2.1	4.6
Poisonous liquid, corrosive, inorganic, nos (hazard zone A)	3289	6.1	0.6	2.2	3.3	6.9
Poisonous liquid, corrosive, inorganic, nos (hazard zone B)	3289	6.1	0.3	1.1	2.1	4.6
Toxic liquid, corrosive, inorganic, nos (hazard zone A)	3289	6.1	0.6	2.2	3.3	6.9
Toxic liquid, corrosive, inorganic, nos (hazard zone B)	3289	6.1	0.3	1.1	2.1	4.6
Hydrogen cyanide solution in alcohol	3294	6.1	0.1	0.2	0.4	1.3
Carbon dioxide and ethylene mixture	3300	2.3	0.1	0.1	0.5	1.5
Compressed gas, poisonous, oxidizing, nos (hazard zone A)	3303	2.3	3.7	7.0	7.0	7.0
Compressed gas, poisonous, oxidizing, nos (hazard zone B)	3303	2.3	0.3	1.3	2.2	5.5
Compressed gas, poisonous, oxidizing, nos (hazard zone C)	3303	2.3	0.2	0.8	1.5	4.0

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			Small Spills		Large Spills	
			Day (mi)	Night (mi)	Day (mi)	Night (mi)
Compressed gas, poisonous, oxidizing, nos (hazard zone D)	3303	2.3	0.1	0.4	0.8	2.4
Compressed gas, poisonous, toxic, nos (hazard zone A)	3303	2.3	3.7	7.0	7.0	7.0
Compressed gas, poisonous, toxic, nos (hazard zone B)	3303	2.3	0.3	1.3	2.2	5.5
Compressed gas, poisonous, toxic, nos (hazard zone C)	3303	2.3	0.2	0.8	1.5	4.0
Compressed gas, poisonous, toxic, nos (hazard zone D)	3303	2.3	0.1	0.4	0.8	2.4
Compressed gas, poisonous, corrosive, nos (hazard zone A)	3304	2.3	3.7	7.0	7.0	7.0
Compressed gas, poisonous, corrosive, nos (hazard zone B)	3304	2.3	0.3	1.3	4.5	7.0
Compressed gas, poisonous, corrosive, nos (hazard zone C)	3304	2.3	0.2	0.8	1.5	4.0
Compressed gas, poisonous, corrosive, nos (hazard zone D)	3304	2.3	0.1	0.4	0.4	1.4
Compressed gas, toxic, corrosive, nos (hazard zone A)	3304	2.3	3.7	7.0	7.0	7.0
Compressed gas, toxic, corrosive, nos (hazard zone B)	3304	2.3	0.3	1.3	4.5	7.0
Compressed gas, toxic, corrosive, nos (hazard zone C)	3304	2.3	0.2	0.8	1.5	4.0
Compressed gas, toxic, corrosive, nos (hazard zone D)	3304	2.3	0.1	0.4	0.4	1.4
Compressed gas, poisonous, flammable, corrosive, nos (hazard zone A)	3305	2.3	3.7	7.0	7.0	7.0
Compressed gas, poisonous, flammable, corrosive, nos (hazard zone B)	3305	2.3	0.1	0.6	2.5	6.7
Compressed gas, poisonous, flammable, corrosive, nos (hazard zone C)	3305	2.3	0.1	0.5	1.5	4.0
Compressed gas, poisonous, flammable, corrosive, nos (hazard zone D)	3305	2.3	0.1	0.1	0.5	1.5
Compressed gas, toxic, flammable, corrosive, nos (hazard zone A)	3305	2.3	3.7	7.0	7.0	7.0
Compressed gas, toxic, flammable, corrosive, nos (hazard zone B)	3305	2.3	0.1	0.6	2.5	6.7
Compressed gas, toxic, flammable, corrosive, nos (hazard zone C)	3305	2.3	0.1	0.5	1.5	4.0
Compressed gas, toxic, flammable, corrosive, nos (hazard zone D)	3305	2.3	0.1	0.1	0.5	1.5
Compressed gas, poisonous, oxidizing, corrosive, nos (hazard zone A)	3306	2.3	3.7	7.0	7.0	7.0
Compressed gas, poisonous, oxidizing, corrosive, nos (hazard zone B)	3306	2.3	0.3	1.3	2.2	5.5
Compressed gas, poisonous, oxidizing, corrosive, nos (hazard zone C)	3306	2.3	0.2	0.8	1.5	4.0
Compressed gas, poisonous, oxidizing, corrosive, nos (hazard zone D)	3306	2.3	0.1	0.4	0.4	1.4
Compressed gas, toxic, oxidizing, corrosive, nos (hazard zone A)	3306	2.3	3.7	7.0	7.0	7.0
Compressed gas, toxic, oxidizing, corrosive, nos (hazard zone B)	3306	2.3	0.3	1.3	2.2	5.5
Compressed gas, toxic, oxidizing, corrosive, nos (hazard zone C)	3306	2.3	0.2	0.8	1.5	4.0
Compressed gas, toxic, oxidizing, corrosive, nos (hazard zone D)	3306	2.3	0.1	0.4	0.4	1.4
Liquified gas, poisonous, oxidizing, nos (hazard zone A)	3307	2.3	3.7	7.0	7.0	7.0
Liquified gas, poisonous, oxidizing, nos (hazard zone B)	3307	2.3	0.3	1.3	2.2	5.5
Liquified gas, poisonous, oxidizing, nos (hazard zone C)	3307	2.3	0.2	0.8	1.5	4.0
Liquified gas, poisonous, oxidizing, nos (hazard zone D)	3307	2.3	0.1	0.4	0.8	2.4
Liquified gas, toxic, oxidizing, nos (hazard zone A)	3307	2.3	3.7	7.0	7.0	7.0
Liquified gas, toxic, oxidizing, nos (hazard zone B)	3307	2.3	0.3	1.3	2.2	5.5
Liquified gas, toxic, oxidizing, nos (hazard zone C)	3307	2.3	0.2	0.8	1.5	4.0
Liquified gas, toxic, oxidizing, nos (hazard zone D)	3307	2.3	0.1	0.4	0.8	2.4
Liquified gas, poisonous, corrosive, nos (hazard zone A)	3308	2.3	3.7	7.0	7.0	7.0
Liquified gas, poisonous, corrosive, nos (hazard zone B)	3308	2.3	0.3	1.3	4.5	7.0
Liquified gas, poisonous, corrosive, nos (hazard zone C)	3308	2.3	0.2	0.8	1.5	4.0
Liquified gas, poisonous, corrosive, nos (hazard zone D)	3308	2.3	0.1	0.4	0.4	1.4
Liquified gas, toxic, corrosive, nos (hazard zone A)	3308	2.3	3.7	7.0	7.0	7.0
Liquified gas, toxic, corrosive, nos (hazard zone B)	3308	2.3	0.3	1.3	4.5	7.0
Liquified gas, toxic, corrosive, nos (hazard zone C)	3308	2.3	0.2	0.8	1.5	4.0
Liquified gas, toxic, corrosive, nos (hazard zone D)	3308	2.3	0.1	0.4	0.4	1.4
Liquified gas, poisonous, flammable, corrosive, nos (hazard zone A)	3309	2.3	3.7	7.0	7.0	7.0
Liquified gas, poisonous, flammable, corrosive, nos (hazard zone B)	3309	2.3	0.1	0.6	2.5	6.7
Liquified gas, poisonous, flammable, corrosive, nos (hazard zone C)	3309	2.3	0.1	0.5	1.5	4.0
Liquified gas, poisonous, flammable, corrosive, nos (hazard zone D)	3309	2.3	0.1	0.1	0.5	1.5
Liquified gas, toxic, flammable, corrosive, nos (hazard zone A)	3309	2.3	3.7	7.0	7.0	7.0
Liquified gas, toxic, flammable, corrosive, nos (hazard zone B)	3309	2.3	0.1	0.6	2.5	6.7
Liquified gas, toxic, flammable, corrosive, nos (hazard zone C)	3309	2.3	0.1	0.5	1.5	4.0
Liquified gas, toxic, flammable, corrosive, nos (hazard zone D)	3309	2.3	0.1	0.1	0.5	1.5
Liquified gas, poisonous, oxidizing, corrosive, nos (hazard zone A)	3310	2.3	3.7	7.0	7.0	7.0
Liquified gas, poisonous, oxidizing, corrosive, nos (hazard zone B)	3310	2.3	0.3	1.3	2.2	5.5
Liquified gas, poisonous, oxidizing, corrosive, nos (hazard zone C)	3310	2.3	0.2	0.8	1.5	4.0
Liquified gas, poisonous, oxidizing, corrosive, nos (hazard zone D)	3310	2.3	0.1	0.4	0.4	1.4
Liquified gas, toxic, oxidizing, corrosive, nos (hazard zone A)	3310	2.3	3.7	7.0	7.0	7.0
Liquified gas, toxic, oxidizing, corrosive, nos (hazard zone B)	3310	2.3	0.3	1.3	2.2	3.5
Liquified gas, toxic, oxidizing, corrosive, nos (hazard zone C)	3310	2.3	0.2	0.8	1.5	4.0
Liquified gas, toxic, oxidizing, corrosive, nos (hazard zone D)	3310	2.3	0.1	0.4	0.4	1.4
Ammonia solution woth 50+% ammonia	3318	2.2	0.1	0.1	0.4	1.4
Insecticide gas, poisonous, flammable, nos (hazard zone A)	3355	2.3	0.8	3.2	5.4	7.0
Insecticide gas, poisonous, flammable, nos (hazard zone B)	3355	2.3	0.2	0.8	2.5	6.7
Insecticide gas, poisonous, flammable, nos (hazard zone C)	3355	2.3	0.1	0.5	1.5	4.0

Name of Hazardous Material	Emergency Response ID Number	Classification (49CFR172.101)	US DOT ERG Protective Action Distance			
			Small Spills		Large Spills	
			Day (mi)	Night (mi)	Day (mi)	Night (mi)
Insecticide gas, poisonous, flammable, nos (hazard zone D)	3355	2.3	0.1	0.1	0.5	1.5
Insecticide gas, toxic, flammable, nos (hazard zone A)	3355	2.3	0.8	3.2	5.4	7.0
Insecticide gas, toxic, flammable, nos (hazard zone B)	3355	2.3	0.2	0.8	2.5	6.7
Insecticide gas, toxic, flammable, nos (hazard zone C)	3355	2.3	0.1	0.5	1.5	4.0
Insecticide gas, toxic, flammable, nos (hazard zone D)	3355	2.3	0.1	0.1	0.5	1.5
Poisonous by inhalation liquid, nos (hazard zone A)	3381	6.1	0.8	2.2	7.0	7.0
Poisonous by inhalation liquid, nos (hazard zone B)	3382	6.1	0.3	1.1	2.1	4.6
Poisonous by inhalation liquid, flammable, nos (hazard zone A)	3383	6.1	0.8	2.2	7.0	7.0
Poisonous by inhalation liquid, flammable, nos (hazard zone B)	3384	6.1	0.2	0.6	1.6	3.5
Poisonous by inhalation liquid, water-reactive, nos (hazard zone A)	3385	6.1	0.8	2.2	7.0	7.0
Poisonous by inhalation liquid, water-reactive, nos (hazard zone B)	3386	6.1	0.3	1.1	2.1	4.6
Poisonous by inhalation liquid, oxidizing, nos (hazard zone A)	3387	6.1	0.8	2.2	7.0	7.0
Poisonous by inhalation liquid, oxidizing, nos (hazard zone B)	3388	6.1	0.2	0.9	1.7	4.3
Poisonous by inhalation liquid, corrosive, nos (hazard zone A)	3389	6.1	0.5	1.5	3.9	7.0
Poisonous by inhalation liquid, corrosive, nos (hazard zone B)	3390	6.1	0.3	1.1	2.1	4.6
Aluminum alkyl halides, solid (water)	3461	4.2	0.1	0.1	0.2	0.8
Chlorine dioxide, hydrate, frozen (water)	9191	5.1	0.1	0.1	0.1	0.4
Fluorine, refrigerated liquid	9192	2.3	0.1	0.3	0.5	2.2
Carbon monoxide, refrigerated liquid	9292	2.3	0.1	0.1	0.4	1.5
Methyl phosphonic dichloride	9206	6.1	0.1	0.1	0.1	0.1
Chloropivaloyl chloride	9263	6.1	0.1	0.1	0.2	0.3
3,5-Dichloro-2,4,6-trifluoropyridine	9264	6.1	0.1	0.1	0.2	0.3
Trimethyloxysilane	9269	6.1	0.1	0.3	0.7	1.4

VITA

Name:	Craig Emmitt Roco
Address:	HNTB Corporation 301 Congress Avenue Suite 600 Austin, Texas 78701
Email Address:	croco@HNTB.com

Education:	B.S., Stephen F. Austin State University, 1987 B.S., Civil Engineering, Texas A&M University, 1995 M.S., Petroleum Engineering, Texas A&M University, 2000 M.S., Finance, Texas A&M University, 2007