ABSTRACT

SAFETY PERFORMANCE COMPARISON BETWEEN LIGHT RAIL TRANSIT AND SUBWAY

by
Nehemie Jasmin

Along with the expansion and addition of guide way transit systems, such as light rail and subway, there came the need to compare the safety performance of each mode. The multimodal transportation systems with many different technologies, operating characteristics and diversified environments made it more difficult to compare their safety.

In order to evaluate the potential for intermodal comparison of safety performance measures, the thesis has focused on the subway and Light Rail Transit (LRT) modes at the national level. Starting with clear definitions of each safety category, the analysis utilizes mostly the National Transit Database (NTD) from recent years to estimate the impact and implications of various safety performance measures. A series of comparisons between LRT and subway on various fatality, injury and property damage categories demonstrates that accident rates may be unstable and easily distorted when the operational base is small. With increasing number of operations, the accident rate may become more predictable even if the simple numbers of accidents/incidents may still appear random.

SAFETY PERFORMANCE COMPARISON BETWEEN LIGHT RAIL TRANSIT AND SUBWAY

by
Nehemie Jasmin

A Thesis
Submitted to the Faculty of
New Jersey Institute of Technology
in Partial Fulfillment of the Requirements for the Degree of
Master of Science in Civil Engineering

Department of Civil and Environmental Engineering

January 2013

Blank Page

APPROVAL PAGE

SAFETY PERFORMANCE COMPARISON BETWEEN LIGHT RAIL TRANSIT AND SUBWAY

Nehemie Jasmin

Dr. Rongfang Liu, Thesis Advisor Date
Associate Professor of Civil and Environmental Engineering, NJIT

Dr. Janice R. Daniel, Committee Member Date
Associate Professor of Civil and Environmental Engineering, NJIT

Dr. Jian Yang, Committee Member Date
Associate Professor of Management Science and Information Systems, Rutgers- Newark

BIOGRAPHICAL SKETCH

Author: Nehemie Jasmin

Degree: Master of Science

Date: January 2013

Undergraduate and Graduate Education:

- Master of Science in Civil Engineering,
  New Jersey Institute of Technology, Newark, NJ, 2013

- Bachelor of Science in Civil Engineering,
  Florida Agriculture & Mechanical University, Tallahassee, FL, 2011

Major: Transportation Engineering

I would like to dedicate this master thesis to my father, Daniel Jasmin, and my mother, Josette Jasmin, without their continuous encouragement I could not have completed this process and been in this stage in my life and to my brother, Ken Jasmin, for cooking for me during the past years.

ACKNOWLEDGMENT

With a deep sense of appreciation, I would like to express my sincere thanks to my advisor, Dr. Rongfang Liu, for her immense help in planning and executing this work. Her support, encouragement and reassurance are greatly acknowledged. Heartfelt thanks to my committee's members, Dr. Janice R. Daniel and Dr. Jian Yang, for their valuable suggestions and guidance which helped me in completing this work.

I would like to thank Sheralde Jean-Mary and Rolande Jean for reviewing this work and providing me with important suggestions.

I would like to express profound gratitude to my family and friends for uncomplaining patience, perennial support, and enormous encouragement during my studies. I wish I would never forget the company I had from my friends in New Jersey. I am thankful to Borgella's family for their countless cooperation, help and encouragement.

Partial support for this master program was provided by the HBCU Fellowship. I am very thankful to the HBCU Fellowship foundation for the financial support.

TABLE OF CONTENTS

TABLE OF CONTENTS

(Continued)

LIST OF FIGURES

LIST OF FIGURES

(Continued)

Chapter **Page**

LIST OF TABLES

Chapter **Page**

CHAPTER 1

INTRODUCTION

1.1 Objective

This study examines the safety performance of light rail and subway in the U.S. Increases in traffic volumes, in light rail, have made the operating environment for rail transit more difficult in recent years, leading to increased safety concerns and heightened levels of risk. Examples of the types of transportation and land use factors influencing transit safety include higher levels of pedestrian and bicycle traffic, increases in population and employment density, and various “smart growth” design elements. Previous transit industry safety research has provided considerable insights into the effects of human, physical and environmental conditions on safety. Recent efforts to examine the influence of operating environment on rail accident likelihood have been limited. As a result, the relationship between operational characteristics and safety performance of rail transit systems is not well understood.

Following are the objectives set out by the researcher for the present study:

1) To compare the safety performance of the light rail system and the subway system (heavy rail) in USA

2) To examine and discuss the factors causing accidents in both systems

3) To suggest measures for preventing the occurrence of accidents in both light and heavy rail

The purpose of this study is to examine the safety performance of Light Rail and Subway in the U.S. The analysis of this study is designed to offer insights into potential operations policies and practices that may be used or changed to improve rail operator safety performance. Previous studies on this topic have specifically addressed the effects of operator demographics, factors contributing to operator stress and fatigue, various measures of safety risk exposure (e.g., related to time and/or distance, passenger volumes served), and route or vehicle characteristics representing potential safety hazards.

1.2 Problem Statement

Concerns about safety are central to transit system planning and delivery of service. The incidence of transit crashes in the US has continued to rise steadily since 2003 and the trend does not seem to show any signs of slowing down (FTA, 2009). The consequences of injuries, fatalities and property damage resulting from crashes are serious problems that continue to affect both the general public and transit agencies in the United States. Over the last few years, transit ridership has been at or near 50-year highs primarily due to increasing petroleum prices and a renewed focus on environmental sustainability. During this time, many transportation service areas have also seen great levels of economic development in the form of new housing, employment, and business centers. For example, in 2012, the National Transit Database Safety and Security Module have recorded more than 4000 collisions, 229 fatalities and more than 9000 injuries in 2011for all transit combined (FTA, 2012). The historical trends of total fatality, injury and incidents for the transit systems are increasing as shown in Figure 1.1.

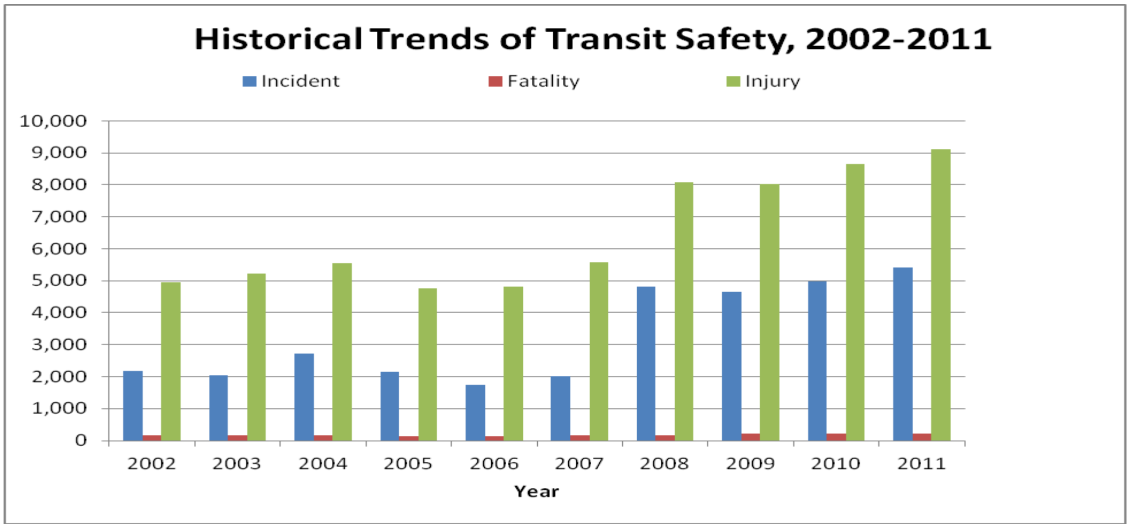


Figure 1.1 Historical trends of transit safety, 2002-2011.

In recent years, the choice between light rail and heavy rail has been one of the heated topics of debate on transport development, on which the present study focuses. The proponents of heavy rail argue that heavy rail is more cost-effective as it carries more passengers. According to 2009 estimates of American Public Transportation Association (APTA), the subway based heavy rail carried around 3.5 billion trips for around 16.8 billion passenger miles (APTA, 2011 Public Transportation Fact Book). In contrast, light rail carried passenger on only 465 million trips for 2.2 billion passenger miles (APTA, 2011 Public Transportation Fact Book). On the other hand, the supporters of light rail system held that it is more costly to build a subway system than to start a light rail system as the light rail system can run on existing roadways or cast-off rail networks (Garrett 2004). Also, many light rail systems are automated which further reduces the cost of an operator.

The most recent FTA report indicates that while ridership has grown annually at a relatively steady pace, the rail industry's accident rate has risen at a greater rate (FTA, 2009). Similarly, the total value of property damaged in collisions has also continued to rise steadily. An analysis of risk management and risk financing practices for a select number of transit properties by Chaney and Derr (1996) found that accident losses characterized as property damage or bodily injury to passengers, pedestrians or other motorists were responsible for about 50% of the total risk cost. Similarly, Abacus Technology Corporation (1996) also found that losses related to traffic accidents involving collisions and passenger accidents accounted for about 51 percent of the total risk cost and, on average, the total risk cost was 4.85 percent of a transit agency's operating expenses. The historical trends of fatality, injury and incident rate for the transit systems are increasing as shown in Figure 1.2. The rate is per million PMT for all the transit system combined.

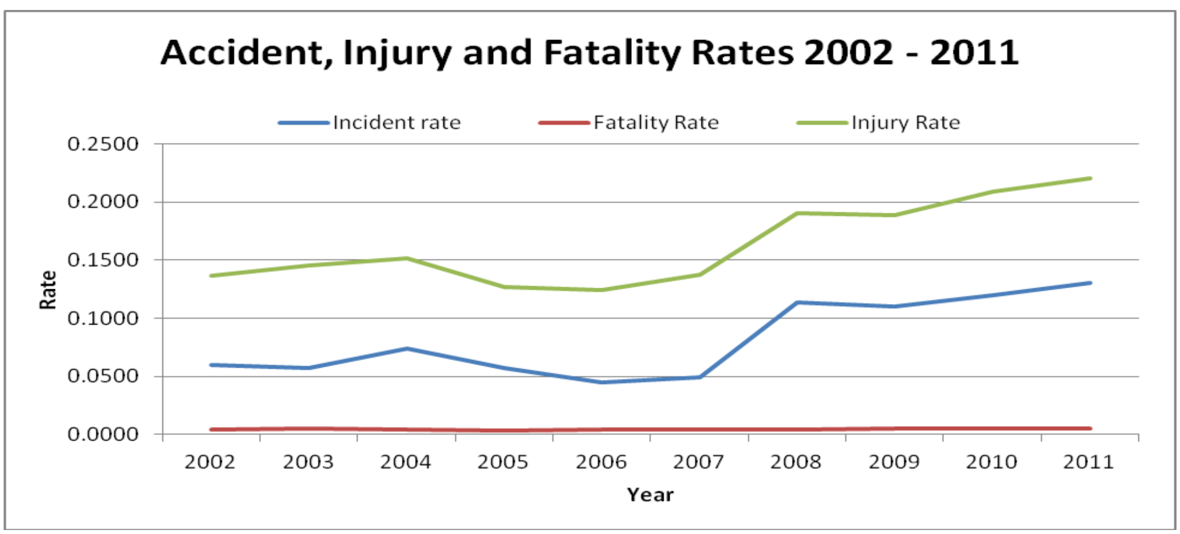


Figure 1.2 Accident, injury and fatality rates 2002 – 2011.

The rising costs of property in metropolitan cities have forced individuals to relocate to the suburbs in order to find greater value in real estate. With the relocation of families to the suburbs, more individuals rely on commuter rail or rapid transit as a means to commute to work. Empirical data revealed when new transit lines are brought to suppressed areas, property value increases (APTA, 2006). A number of other factors may influence individuals to consider heavy rail transit as their primary form of transportation.

Economic factors include the rising cost of parking, major roadwork or repair, serving the needs of economically disadvantaged individuals who cannot afford to procure a motor vehicle, insurance premiums, and car maintenance. This includes both the young and mature populations who do not operate a motor vehicle. As individuals continue to move to the suburbs, many come to depend on public transportation due to environmental concerns or because they belong to the aging population (APTA, 2006). Since many patrons rely on heavy rail transit as their primary form of transportation, the transit system needs to function optimally, reliably, and economically. The increase in demand requires longer or additional trains for frequent service. Increasing train length or frequency of service on any line requires that trains be more reliable to minimize any failure during revenue service. The added service translates into higher maintenance costs that must be controlled. Maintenance must optimally and efficiently be performed in order to minimize failure during revenue service.

A careful review of data on safety performance of major surface transportation modes reveal that US transit systems are relatively safe when compared to automobile travel. Given the increasing trend of accident rates, there is a need for transit providers and other agencies such as the FTA to take a more concerted and unified approach toward slowing down and possibly reversing this upward trend. The common approach would be to undertake safety investment programs, but the challenge is ascertaining where the focus should be and what level of safety resources to allocate.

Research has indicated that the nature of the accident, the causation and the effect vary with respect to the mode of transportation (APTA, 2011 Public Transportation Fact Book). Since the rail transit system does not operate on a single mode of transportation, safety performance of different types of rails are expected to vary. Light, commuter and heavy rails are the three modes of transportation present in the US rail industry. Some initial data comparing the number of accidents, the causation factors as well as the injuries and economical loss in the accidents of these different modes of rail transit is available (FTA, Safety Action Plan 20). However, a more detailed and comprehensive inquiry is yet missing. The present study fills this knowledge gap by focusing on the safety performance of light rail versus heavy rail. The study not only compares the frequency of accidents, injuries and human and financial loss caused by these accidents but also looks into the specific factors, with respect to both, within rail systems that cause occurrence of these accidents. Furthermore, recommendations for the avoidance of such accidents for both rail systems are also made.

1.3 Scope

The present study is focused on the comparison between safety performances of light rail system versus subway system of the USA only. The findings produced in this thesis are applicable directly to the rail transit system of USA but important lessons can be learnt from it to apply in the rail transit system of other countries, as well. The accident data analyzed in this study is from 2002-2011; and the frequency of incidents and their causes are identified for the accidents occurring only within this time period. With the time constraint for this thesis, this is the analysis that the author has been used:

1. Prepare graphs comparing total number of accidents including all types of incidents, fatalities, injuries.
2. Determine rate of incidents, fatalities, injuries, suicides and trespassers.
3. Determine rate of accidents/Passenger Miles Traveled (PMT) in millions.
4. Analyze the data, draw conclusion, and make policy recommendations.

1.4 Thesis Structure

The remainder of this thesis is structured as follows. Chapter 2 presents a review on Light Rail and Subway system. This is followed by a complete Literature Review in Chapter 3. In Chapter 4 the safety incident frequency analysis are discussed. This is followed with results, description and development of the preventability analysis model in Chapter 5. In addition, this Chapter also presents and discusses factors that influence the likelihood of preventable incident involvement and provides the concluding remarks, highlighting the policy or management implications.

CHAPTER 2

LIGHT RAIL/ SUBWAY SYSTEM

2.1 Introduction

Rail transit system in USA can be divided into three types with respect to the design and capacity. These types include heavy rail, commuter rail and light rail. Heavy rail operates through the subway system which is mostly available in big cosmopolitan cities like New York City, Boston and Chicago. It operated on completely exclusive guideway, with no grade crossings for vehicles or pedestrians. Systems often support long trains of 6-8 cars, and typically have level-platform boarding. Commonly called "subways" or "rapid rails" while Commuter rail operates through rail-road tracks and connects the suburbs to the main city centers. On the other hand, light rails can either use main roads as a trolley or tram or can have a separate roadway as a multi-car train. It operates on local routes with relatively frequent stops, and one or more grade crossings for vehicles or pedestrians. Systems often use shorter trains of 2-4 cars, and are typically powered by overhead wires. Light Rail includes both streetcars, and rapid light rail systems which may have extensive stretches of exclusive guideways, including tunnels/subways (Garrett 2004).

2.2 Background

The public transportation system in the USA originated in the early 1800s. According to Middleton, a famous urban transportation historian, the first public transport system in USA consisted of horse-drawn carriages, called omnibuses that started transporting public in New York City in 1827. However, soon the bad condition of the streets as well as the growing traffic congestion made the ride on these horse stagecoaches a difficult one (Iles 2005). To solve this issue a transporter came with the idea of using rails instead of streets for moving these horse cars (Middleton 2003). This led to the start of rail-transit system in the USA. By the mid-19th century these horse-driven street or rail cars were the only public transportation system in the USA (Middleton 2003). According to an estimate, in 1880s there were around 400 rail-transit companies in the USA that were providing services to around 180 million passengers annually using 6000 miles rail track (Garrett 2004). The two other public transit systems that started in USA in the late-1880s were cable car and electric streetcars (Garrett 2004)

Middleton reported that despite this phenomenal development in transit system within the USA, the growing population in the main urban centers particularly New York City was so high that omnibuses and streetcars failed to meet the public transit requirements. In 1867, an entrepreneur Alfred Beach put forward the idea of elevated train system in the New York City to resolve the congestion problem (Marten 2010). By this time, subways system had already been started in many cities of Europe and inspired from this system a number of innovators came up with the different subway's or elevated trains' models, none of them got much attention or government approval. Later, the same Alfred Beach succeeded in starting a pneumatic subway system in New York City but again failed to finish it with success due to financial constraints. The attempts continued until 1897, when the first electric underground street railway line was spread in the Boston area (Marten 2010). In New York City, the elevated train system started in 1870 while the subway system started operation as late as 1904 (Garrett 2004). Table 2.1 represented numbers of cities in the U.S. in 2000 that have a rail system operated in them.

Table 2.1 Rail-Transit Cities in the USA in 2000

Cities	**Population in millions (2000 estimates)****	**Rail-transit System**
Atlanta	4.11	Heavy
Baltimore	2.55	Heavy, Light
Boston*	3.40	Heavy, Light, Commuter
Charlotte, N.C.*	1.50	Light
Chicago	8.27	Heavy, Commuter
Cleveland	2.25	Heavy, Light
Dallas	3.52	Light
Denver*	2 .11	Light
Detroit*	4.44	Light
Los Angeles	9.52	Heavy, Light, Commuter
Memphis, Tenn.*	1.14	Light
Miami	2.25	Heavy, Commuter
Minneapolis*	2.97	Light
New Orleans*	1.34	Light
New York City	9.31	Heavy, Commuter
Philadelphia*	5 .10	Heavy, Light, Commuter
Pittsburgh	2.36	Light
Sacramento, Calif.	1.63	Light
St. Louis	2.60	Light
San Diego*	2.81	Light, Commuter
Seattle*	2.42	Light
Washington, D.C.	4.92	Heavy, Commuter

Source: *Light Rail Transit Association (www.lrta.org/index.html#top) and city transit web sites, as quoted in Garrett 3*
** All or part of the city's light-rail system consists of streetcars.*
*** Population is for the Primary Metropolitan Statistical Area (PMSA) and comes from the U.S. Census.*

Light rail transit came in the USA a little late. By 1972, North Americans were not aware of this term, though some references to this concept have been made in 1960s (Thompson 2012). The invention of the automobile in 1910s considerably reduced the demand for streetcars in the 20^{th} century and the only choice left for the transporters was the heavy rail system. However, that option was much more costly and was not feasible for many. A number of articles were published in the late 1990s in favor of transforming the street car system with a rapid-transit system but it was not earlier than 1970s that practical work started on the developed of light rail system (Thompson 2012). It was also 1972 when the term "light rail" was coined (Thompson 2012). It was 1981 when the first light rail system started operating in the USA in San Diego (Thompson 2012). By now, the two rail-transit systems are simultaneously operating in many cities of USA and is a popular means of public transportation in these cities.

2.3 Advantages and Disadvantages for Having a Light Rail or Subway in Your City

The advantages of the light and heavy rail system can be understood well by seeing the reasons that caused their advent. As described above, the subway system started in the United States much earlier than the start of light-rail system. In the early 1990s, cities like New York and Chicago faced serious traffic congestion problem due to the rapidly growing population and increasing use of motor vehicles. When it became evident that the city roads and streets did not have the capacity to hold the growing traffic, subway system was introduced (Middleton 2003). The result was the transfer of traffic load from the streets to underground subway system. People in those cities not only got more transportation options through the advent of this system but were also be able to reach their destination in much less time with no congestion delays and parking issues.

Light-rail system, however, did not start in the main cities of USA but in the suburbs, for the same reason of congestion. The reasons why the authorities did not build subway system in those cities were both political and financial. Subway system had been in operation since early 1900s but light-rail system made their debut in 1960s. Garrett (2004) explained that public at that time was more environmentally conscious and was aware of the pollution issues related to heavy rail system. Light rail system could relieve not only the congestion issues but also the pollution. In addition, as explained by Thompson (2003), development of light-rail system was more economical and thus, more suiting for a wider application.

Marten (2012) has outlined a number of benefits of rapid transit system without differentiating between the light and heavy rail system. According to Marten, the rapid transit system is an economical option for transportation as the fuel prices are continuously increasing. In addition, due to the growing property prices, people cannot afford to live in metropolitan cities and are forced to relocate to the suburban areas. These relocated people use rapid transit system to go to work. Other important benefits of using public transportation are saving of parking and motor maintenance cost, saving of time due to congestion and road repairs, and reduction in pollution. He also pointed out that the these rapid transit systems offer an excellent transportation option for individuals who cannot operate motors like disabled individuals, children and older citizens (Marten 2010).

Litman (2012) conducted a comprehensible study on this subject. He found that the cities in which rail transit is the main component of public transportation, the cost of congestion per capita is substantially lower than in other cities (Litman 2012). He also reported high transit ridership low, traffic death rates, low consumer expenditure on transportation and high transit service cost in cities with rail systems as compared to cities with none or less-developed rail system. The walking to the station is also found to positively affect the health of individuals and cities as cities with established rail system have improved individual health status. In terms of cost-efficiency, a number of scholars have criticized the rail transit system because it utilizes a large sum from public subsidies but Litman held that when considered with the inclusion of congestion cost, parking cost, roadway cost, and consumer cost, the rail-transit system appears to be more cost-efficient.

However, the main disadvantage of using a rail transit system instead of a private automobile is the loss of independence and privacy. Garrett argued that if people are willing to pay extra cost on fuel, car registration, maintenance, parking and others, it clearly shows that people value their independence and privacy more than the costs associated with car ownership. Also, the rail transit system is not much flexible as it operates on a defined route and following particular time schedule (Garrett 2005). Also, the time spent on walking to the rail station and waiting has been criticized as one big disadvantage that balances the time saved from congestion delays (Litman 2012).

2.4 Operating Cost

The operating cost of a rail transit system in terms of the type of activity or function performed includes cost of vehicle operation and maintenance, salaries of car operator and other administrative staff and purchase of new vehicles. A comparison of operating cost of light and heavy rail by type of function performed is shown in the table 2.2 below,

Table 2.2 Operating Costs of Heavy and Light Rails by Type of Activity Performed

Type of Operating Expense	**Heavy Rail**	**Light Rail**
Vehicle Operation	2775.7	549.7
Vehicle Maintenance	1133.2	260.5
Non-vehicle Maintenance	1552.0	221.4
General Administration	788.5	266.9
Purchased Transportation	61.2	111.4
Total	6310.5	1409.9

Source: *APTA, 2011 Public Transportation Fact Book 21*

- *All costs are in millions of dollar*

In terms of the type of goods and services performed, the operating cost includes salaries, fringe benefits, cost of services, cost of materials and supplies, and others. According to Garrett the salaries account for the highest operating cost in the light rail system. APTA (2011 Public Transportation Fact Book) also reported the same results that the salaries and other incentives for employees of transit agencies account for around two-third of the total operating cost. The results of APTA’s 2011 report are shown in Table 2.3.

Table 2.3 Operating Costs of Heavy and Light Rails by Type of Goods or Service Purchased

Type of Operating Expense	**Heavy Rail**	**Light Rail**
Salaries and Wages	3160.5	528.7
Fringe Benefits	2467.4	361.2
Services	363.9	196.1
Materials and Supplies	421.7	91.1
Utilities	580.5	100.8
Casualty and Liability	128.3	22.9
Purchased transportation	61.2	111.4
Other	-873.1	-2.2
Total	6310.5	1409.9

Source: APTA, 2011 Public Transportation Fact Book21

- All costs are in millions of dollar

The revenue to cover this operation cost comes either from the passenger fares or from the federal or local government funding. Garrett held that most of the operating cost is covered through public tax and only 30% of the revenue is generated by the fares. (APTA 2011 Public Transportation Fact Book) reported the figure of 37% which is almost same. The 2009 estimates of annual passenger fares for heavy rail were $3,801 million and for light rail were $390.6 million (APTA, 2011 Public Transportation Fact Book). Therefore, on average, passenger fare covers around 60% of operating cost in heavy rail and only 27% in light rail system. Thus, light-rail system appears to be less cost-efficient as compared to heavy rail system.

The operating cost of a rail system depends considerably on the size of system and the area of operation and consequently there are marked differences in the operating costs of different rail systems of USA. A better approach to use operating cost as a measure of efficiency is to compare the operating cost per passenger or per vehicle mile. Table 2.4 below compares the efficiency of the heavy and light rail system using this approach.

Table 2.4 Cost-Efficiency of Light Rail and Heavy Rail

	Light Rail	**Heavy Rail**
Operating Cost	6310.5	1409.9
Passenger Miles	16,805	2,199
Vehicle Miles	684.6	90.7
Operating Cost per Passenger Miles	0.38	0.64
Operating Cost per Vehicle Miles	9.22	15.54

- APTA's 2011 Public Transportation Fact Book

2.5 Transit Safety Management and Safety Performance Measurement

According to the report of National Transportation Safety Board (NTSB), one important cause of rail accidents is the limitation in the safety management system of rail agencies (GAO 2011). The important limitations in the safety management system, identified in the report, were problems in the safety rule and procedure defined by the transit agencies and the inadequacy of proper system to ensure that the defined rules and procedures are followed by the employees. For instance, in one incidence it was found that the agency' rules and procedures lacks details of wayside personal security that led to the fatality of one employee while working on a track (GAO 2011). Similarly, in another incidence, it was found that the train operator failed to follow the controlling signal indication as he was napping at that moment (GAO 2011).

FTA has recently taken action to ensure the development of effective safety management system in all urban transit agencies. In 2006, FTA prepared a Rail Transit Safety Action Plan with the purpose to identify the most common causes of rail transit accidents and to find ways to deal with these common causes (Safety Action Plan 3). Analysis of rail accidents that occurred from 2005 to 2005 showed that the most common type of accidents was collisions, of which the most common category was the collision of rail with the motor vehicle at rail grade crossing (FTA 2006). It was found that of the 371 total accidents, the probable cause of 225 accidents was not identifiable due to the lack of information (FTA, 2006 Safety Action Plan 20). This clearly shows the weakness in the accident reporting and data management system of transit agencies.

Different causes were identified for the collision accidents in light rail and heavy rail. In light rail collision, most common cause was the “illegal, inappropriate or risky actions” of motor vehicle’s driver and pedestrians. Although, for around 12% of incidents the rail operator was found responsible while for 5% cases there was clear violation of operating rules. In heavy rail collisions, the violation of operating rules was more frequent and most of the collisions occurred due to this factor. Operator fatigue and inattentiveness was found to cause five of the 36 heavy rail collisions. Violation of operating rules and procedures was also found to cause derailments and rail fires.

Based on these finding FTA proposed a plan in which the first priority was given to the reduction of collision accidents (The Top ten priorities for the Safety Action Plan are listed in Table 2.5). For reduction of collision, FTA planned to improve the rail grade crossing and to use research finding of FTA and other agencies for improving the safety of pedestrians and trespassers. As incompliance with operating rules was found to be an important cause, FTA revised the State Safety Oversight rule to ensure that all rail transit agencies integrate the compliance with operating and maintenance rules in their respective System Safety Program Plans (FTA, Safety Action Plan 41).

APTA has also taken steps for the establishment of effective safety management system for the urban rail transit industry of USA. It has recently published a Manual as a guidebook for the development of effective safety management system for urban rail transit. The objective of this manual is not only to assist the transit agencies that are member of APTA in developing their safety management system but it also defines the criteria for the APTA safety management audit program.

According to this manual, the first step for the development of safety management system is to fulfill the administrative requirements for safety management that include planning a specific course of action for safety management process and timely review of the process to ensure that the safety goals are being met (APTA, Manual for Urban Transit Safety Management System Section 3.0). APTA held that in this initial phase of planning and organization for safety management system, the rail transit agency should give explicit information about the operational structure of urban rail system along with its specific safety requirements, an approved and attested safety policy statement, identify the administrative body having authority to manage and monitor the safety management system, define goals and objectives for safety management, and develop a strategic plan for achieving that specified goals and objectives (Section 3.0).

The second phase of safety management system development, according to APTA's Manual for Urban Transit Safety Management System (Section 4.0), is the implementation of the safety program. One important element of this implementation process is the maintenance of rail infrastructure by assuring the access and availability of safety-related equipment and frequent inspection of equipment to report the defective or missing items. The inspection and repair of the vehicle is another important feature for assuring the safety of the transit system. The operating and administrative staff should be trained for safety management and the safety policies should be reviewed on regular basis. The safety management program should include an emergency management program as well as a workplace safety program. For contracted service, there should be safety-related clauses in the contract. In addition the rail transit agencies should also take measure for assuring the safety of passengers and trespassers. APTA Manual also held that the safety of operating rail corridor is the most important element of safety management program due to the increasing number of accidents on rail grade crossing and of roadway workers and trespassers. The manual also proposed measures for prevention of suicide accidents. Furthermore, APTA also consider the recent issues of environmental safety and sustainable development to be important and held that the rail transit agencies should be held accountable for the environmental impacts of their transit operations (Section 4.0).

The third and very important section of safety management system is related to the engineering practices and analysis (APTA, Manual for Urban Transit Safety Management System Section 5.0). The identification of system risk, their measurement and control is at the core of safety management system and should be given important considerations. APTA identified five important elements related to engineering technique and analysis namely, risk reduction, hazard management, accident reporting and investigation system, reliable data collection and authentic analysis, and loss prevention and control mechanism including the analysis of fire safety and causality management (Section 5.0).

The last important area that ought to be covered by the safety management system of the rail transit agency is the safety assurance by adoption of change management and performance measurement systems (APTA, Manual for Urban Transit Safety Management System Section 6.0). APTA suggested the use of configuration management for analyzing the impact of change along with reference to FTA safety standards, regular inspection and timely system modification, and use of existing quality control program for safety assurance. Transit agencies should also obtain certification for their security management systems from FTA and should also review the safety performance in case of any system modification. There should also be a proper document management system in the rail transit agencies. Most importantly, the transit agencies should adopt a reliable safety performance measurement system including both internal and external audit programs (Section 6.0).

CHAPTER 3

LITERATURE REVIEW

In order to have an understanding of transportation safety performance, performance management, as well as our choice for case study, series of literature reports analyzed and provided a great deal of information needed to begin building our comparative analysis. A detailed literature search revealed uneven coverage on the safety performance measures and research. That is, there are a large number of research papers, data sources, and methodologies for highway safety /crash analyses but very limited research and data sources for transit safety performance measures.

3.1 Public Transportation Ridership Trends

Heavy rail transit systems have grown in popularity for several reasons (APTA, 2006). Patrons rely on public railway transit systems primarily because of the increasingly high cost of automobile fuel, traffic congestion, escalating property costs, and environmental concerns, as well as the systems' convenience and efficiency (APTA, 2006; *Capital Corridor*, 2007; Celik & Yankaya, 2006). The public transportation ridership trend illustrated in Figure 1 clearly illustrates the trends and importance of transit to the United States since the early 1900s (APTA, 2006).

According to APTA (2006), various social and economic factors have affected the popularity of public transportation. In the beginning of the 20th century, ridership grew at a steady rate until the Great Depression. Between 1929 and 1939, ridership declined

(APTA), which was directly attributed to the loss of jobs and lack of money. The patron ridership increased again during World War II, when public transport became the main mode of transportation in many urban areas. Ridership peaked in 1946 with more than 23.4 billion trips reported on trains, buses, and trolleys.

3.2 The Conceptual / Theoretical Frameworks

Human capital theory has empirically been tested and supported by a number of rail industry safety studies (Rodriguez et al. 2006; Rodriguez et al. 2003; Monaco and Williams, 2000). For example, Rodriguez et al. (2003) found that human capital, occupational and compensation factors were important predictors of crash frequencies.

A careful review of empirical studies in the large area of safety reveals that application of human capital theory has been used in rail industry safety analysis only to a limited scale. In general, there seems to be no consensus on one unified theory of accident occurrences. However, it is also evident that the traditional subway–based empirical framework has most often been adapted and applied to rail transit safety research at both industry and firm levels.

The conventional subway-based empirical approach treats occurrences of subway or commercial vehicle accidents as being the result of the interaction between the driver, vehicle, and environmental conditions (Jovanis, 1989; Jovanis, 1986). Evidence suggests that empirical studies that have used this approach have had a driver focus, in part because human error is recognized as the key determinant of commercial vehicle accidents (Jovanis, 1989). Whereas this empirical framework is useful, still it cannot directly be applied to rail transit accident analysis because of the complications that are inherent and specific in the transit industry.

There are features which are unique to rail transit and have no parallel structure in the traditional subway safety field. First, there is the risk of an accident in rail transit which is affected in part by transit service characteristics and by agency policy environment in addition to the traditional factors of human, vehicle, subway and environmental conditions, such as, weather and lighting factors. Second, passenger injuries resulting from non-collision incidents are also a major concern in the transit industry. In particular, injuries to transit passengers occur in non-collision incidents, especially while the vehicle is accelerating or decelerating (Wahlberg, 2007), and during boarding and alighting processes (Morlok et al., 2004; Hudenski, 1992).

Prior research on rail safety performance has mainly been examined at two-levels of analysis; system and route–levels. The system level approach is used where the goal of the analysis is to investigate factors that are important in safety and to provide broad level indicators of safety performance (Chang and Yeh, 2005; Jovanis et al. 1991). Beyond the big picture or safety performance indicators, route level designs are used in determining geometric and other non-behavioral factors that contribute to crash incidents (Jovanis et al. 1991; Chimba et al. 2010). Data in route-level design are organized around the individual routes or network facility segments. As observed in the studies by Jovanis et al. and Chimba et al., the route-based design approach is limited to the sample of operators who are involved in incidents and consequently, information on those without incidents is not recovered. In addition, behavioral factors are not captured in the route based designs.

In contrast to earlier safety research, the present study examines the contributing factors to rail safety using the operator signup based approach. This approach is consistent with Evans (2004) perspective that efforts to improve safety should focus on human behavior. Similarly, FTA (2009) policy paper on rail safety improvement strategies recommends that the focus should be to identify and assess effects of factors that are within transit agency control.

3.3 Urban Transportation in America

The history of rapid transit began with the first transit system, which consisted of stagecoaches pulled by horses. Over time, horses were replaced with other motive sources such as pneumatic, steam, cable, and electricity. Middleton (2003), a rapid transit historian, reported that the first urban transit system in North America appeared in New York City in 1827, consisting of horse-drawn stagecoaches.

By 1832, the New York City stagecoaches were replaced by horse-drawn streetcars. The congestion on the street from the horse-drawn streetcars, pedestrians, and private stagecoaches, became a concern for the growing city (IIes, 2005). Middleton reported that an innovator named Alfred Beach, in 1867, proposed to resolve the congestion problem on New York City streets with a pneumatic subway, which he subsequently designed and built. His pneumatic subway used air to power the trains under street level, avoiding the use of conventional steam engines. Beach's innovation used 10-foot fans located at each end of the subway to propel the train along the subway line. Middleton (2003) went on to report that in 1866, William Hemstreet built a transit system that was elevated 30 feet above the busy streets of New York City. The elevated railway transit system operated for the next two decades. Middleton posited that since the introduction and subsequent abandonment of the pneumatic subway in 1870, other innovators proposed, designed, and built different configurations of railway transit systems.

Since the 1900s, several transit designs have used subway, elevated tracks, and at-grade guide ways. Designs incorporated pneumatic, steam, complex cable, and electricity to propel the trains. While each of the propulsion systems offer advantages and disadvantages, pneumatic and steam solutions have been largely abandoned, while cable remains suitable for limited situations.

Since the introduction of Beach's rapid transit system, many forms of underground (e.g., subway) and elevated railway transit systems have been constructed. After 1900, railway rapid transit increased in popularity and eventually replaced the horse- and mule-drawn carriages.

3.4 The Empirical Findings

Turning to the specific factors and how they are related to accident rates and frequencies, evidence is clear that numerous factors play roles in accident occurrences. These factors have been well identified in the empirical framework conceptualized by Jovanis et al. (1991) and they are consistent with the human capital theoretical framework (Rodriguez et al. 2003; Monaco and Williams, 2000).

In general, traffic safety literature has found negligent driver behavior to be the principal cause of crashes. Evans (2004), for example, summarizes the findings of two large independent studies undertaken in the U.S. and U.K. Analyzing the details of thousands of crash records, both studies found driver behavior to be either the sole or contributing cause of over 90% of crashes. The principal causes of the remaining crashes were identified as vehicle failures (e.g., brakes and tires), environmental factors (e.g, weather and lighting), and roadway factors (e.g., design and condition).

3.5 Safety Culture in Rail Transit System

Rail transit system is relatively safer than travelling through other modes of transport (Nelson and Streit 2011). Statistics shows the probability of accident in motor vehicles is much higher than the probability of in rail (Bureau of Transportation Statistics 2011). In 2009, some 5,505,000 accidents occur on the road while 3,807 accidents occur on the railroad (Bureau of Transportation Statistics 2011). However, the loss of life and property in the recent rail incidents has called for the need to make necessary action so this loss can be avoided in future. National Transportation Safety Board (NTSB) has conducted investigation on these accidents and has outlined a number of factors that contributed to these rail accidents (Government Accountability Office 2011).

One important contributing factor, mentioned by the NTSB, is the lack of safety culture in the transit agencies, which according to Government Accountability Office (GAO) is a “challenge that largest transit agencies face”. One very basic problem regarding the establishment of safety culture in the rail transit agencies is that there is no universally accepted definition of safety culture. Reason has explained that the literature on safety culture has defined it usually in two ways: “as something an organization is (the beliefs, attitudes and values of its members regarding the pursuit of safety), and as something that an organization has (the structures, practices, controls and policies designed to enhance safety).” Thus, safety culture is a combination of the organizational values, policies and practices regarding the establishment of safety. In the APTA Manual for Urban Rail Safety Management System, safety culture has been defined as:

“The product of individual and group values, attitudes, perceptions, competencies, and patterns of behavior that can determine the commitment to and the style and proficiency of an organization’s Safety Management System” (APTA, 2011 Manual for Urban Transit Safety Management System).

The safety culture has been reported to vary in different rail transit agencies (GAO 2011). However, all in all, the degree of safety culture in transit agencies is considered as low and there is need to bring changes in the behavior and commitment of employees as well as values and culture of organization to develop the safety culture in the rail transit industry as a whole (GAO 2011). APTA has recently set the development of safety culture in the urban rail transit agencies to be one of its prime goals (APTA, 2011 Manual for Urban Transit Safety Management System).

One important element of the safety culture that has been found missing in the rail transit system of USA is the reporting culture, which is claimed by Reason (1998) to be the most difficult to achieve. In a report by Federal Railroad Administration (FRA 2005), it was found that among the 543 reportable grade crossing accidents that occurred from May 2003 to December 2004 and caused 116 fatalities, only 115 (21%) were immediately reported. The delay in the required immediate reporting to FRA resulted in the difficulty for FRA to decide whether or not to conduct investigation on that accident.

Reason (1998) identified that the main reason for the lack of reporting culture is because the driver and other employee of rail transit agencies are fearful of reporting their own mistakes. Thus, when FRA (2005) investigated the issue, it was found that in many cases employees were actually confused due to the unclear regulation regarding the reporting of rail road accidents. It was noted that most of such unreported cases involved fatalities of non-passengers. As per FRA regulation, railroads are not required to immediately inform FRA about the occurrence of accidents that involves injury of non-passengers. However, if any of the non-passengers died after accidents, they are required to report the matter immediately. They noted that in many cases the non-passengers died when they had been taken from the accident scene to the hospital and as a result, railroad, unaware of the fatality, did not report the accident immediately (FRA 2005).

The different measures suggested by FTA officials for improvement of safety culture are giving proper safety training to staff, evaluation of the current status of safety management system, and reliable and valid measurement of safety performance (GAO 2011). According to APTA, development of safety culture in an organization can be achieved through three stages

1. "Stage 1: Safety is based on rules and regulations.
2. Stage 2: Safety is considered as an organizational goal.
3. Stage 3: Safety can always be improved" (Manual for Urban Transit Safety Management System Sec 3.3.2)

To find out at which stage of safety culture development a transit agency is at present, multiple methods, including employee surveys and interviews, focus group discussion, observation of the process employed for handling of conflicts and focus on the safety defense, should be used (APTA, 2011 Manual for Urban Transit Safety Management System Sec 3.3.3).

3.6 Factors beyond Transit Management Control

Turning to factors specifically related to design and other related conditions, there is clear evidence indicating that the effect of these factors on crash activity depends in part on the type of the variable and how the given variable is entered in the estimation model. Railway segments or zones with higher average posted speed limits are consistently associated with fewer accident occurrences (Jovanis et al. 1991).

This relationship is, however, counter-intuitive and has been explained in various ways. Some authors have argued that high speed railway tracks are likely to be well designed, carry small traffic volumes and have fewer stations and are therefore relatively safer (Jovanis et al. 1991). The challenge is that such routes allowing faster travel may be safer but might not be preferred for transit operations if fewer patrons exist. Alternatively, higher speed limit may mean lower spacing between intersections and thus less opportunity for conflicts.

Shoulder width and travel lane width have mixed effects on accident occurrence. The effect and magnitude of each of these variables depend on whether the factor is entered in the estimation model as a continuous or as a dummy variable. For example, Shankar et al. (1997) showed that when defined as categorical or dummy variables, travel lane and shoulder width have positive and significant effects on crash frequency.

In the organizational safety literature, human factors are widely studied using psychology and engineering perspective. However, in some recent studies, this human factors approach has been adopted to study the public safety issues with regard to road and rail traffic accidents (Baysari *et al.* 2009; Greig & Hopkins 2011; Petridou & Moustaki 2000).

With regard to the road accidents, a recent study was conducted in Britain in which it was highlighted that human factors such as drivers' or passengers' human errors play a vital role in the occurrence of road accidents (Greig & Hopkins 2011). The study further found that the age of driver is significantly associated with certain factors that cause these accidents (Greig & Hopkins 2011). After reviewing the studies on human factors association with traffic accidents, Petridou & Moustaki reached the conclusion that in Europe around 90% of traffic accidents are caused by human factors.

In the research related to rail accident, there was little attention to these human factors. It is just few years back when researcher started realizing the importance of these factors and inspired from the convincing findings of studies on other modes of transport, conduct studies on finding rail human factors (Wilson & Norris 2006). One important area of research with regard to human factors in rail accident causation is on the rail operator's behavior. Baysari (2009) adopted the human factors approach to analyze 19 rail accidents in Australia and found that the main human factor related to these accidents was the "slip of attention of rail operators." Driver's lacks of motivation or fatigue due to over workload or low compensation are also highlighted in a number of studies (Cotteril & Jones 2005; Gouin *et al.* 2006). Ashton and Fowler (203) suggested using human friendly roosters for the reduction of the impact of fatigue (Kecklund *et al.* 2006) believed that the one important way to reduce the driver error is by giving attention to the details of driving job like wage, workload, job aids etc. They held that the workload on the rail drivers should be kept at a moderate level as high or low workload can increase the probability of driver error.

Petridou & Moustaki (2000) have classified the human factors related to drivers into two main branches, first the factor that affect the driving ability of the driver and second the factors that led to risky and careless behavior of the driver. They further divided these two types of factors with respect to the long-term and short-term impact. According to their review, the factors that produce long term impact on the drivers' ability to drive safely include their lack of experience, old age, any disability or disease, accident proneness, and alcoholism and drug abuse (Petridou & Moustaki 2000). The factors that produce short-term or temporary impact on driving ability are fatigue, high alcohol intoxication, temporary drug effects, overeating, acute psychological stress, and temporary distraction (Petridou & Moustaki 2000). Similarly, overconfidence on driving abilities, habit of over-speeding, law-breaking habit, indecent driving attitude, wrong sitting posture while driving, disuse of seat belt or helmet, accident proneness and alcoholism are factor that produce long-term impact on risk-taking behavior of driver while moderate intake of ethanol, intake of psychotropic drugs, motor vehicle crimes, attraction to suicide and other compulsive acts are responsible for short-term risky behavior of drivers (Petridou & Moustaki 2000).

Another important area of research is related to the response of driver to the danger signals. Studies have attempted to find better signals system to grab attention of driver and to ensure his timely recognition and response to these transmitted signals

(Collis & Schmid 2001; Pasquini *et al.*2004). Tools have also been developed to identify the risk of accidents due to the single passing at danger (SPADs) (Holywell 2005; Lowe & Turner 2005).

With the improvement of technology used in the rail operation, the nature of rail human factors will be changed. Moreover, as identified by Wilson and Norris, there is growing centralization in the rail functions which will also influence the role of drivers and their responsibilities. Another important change that has been witnessed in past few years is the increase in ridership (APTA, 2011 Public Transportation Fact Book 10) because of which rail transit agencies want to increase the number of rails (Wilson & Norris 2006). With the increase in the rail number the information about their route and time schedule will become more complex and research will have to examine the human factors associated with management of complex and large amount of information.

3.7 Need for Safety Performance Measurement

GAO reported that the main reason why transit agencies are facing difficultly in developing safety culture is their inability to measure the safety performance of their agency. The safety performance data collected by them and the analysis conducted by them is often flawed which make it difficult to identify the main causes of safety hazards (GAO 2011). The report mentioned that the data present in the FTA's Safety Database is not reliable as there are unsubstantiated figures, repeated entries, entries that were not matching with each other, and other issues with measurement.

The report clearly highlighted the importance of having an effective and reliable safety performance measurement system as without it, it is difficult for FTA to decide the level of improvement in the agencies as well as to identify and curtail the issues that can breach the safety measures (GAO 2011). Safety performance can also enable FTA to set specific safety performance goals for the rail transit agencies and make informed decision for reducing the rail accidents in future (GAO 2011).

APTA also consider safety performance measurement to be an important factor and have defined the phase of safety performance measure and assessment to be one of the main stages for the development of safety management system suggested by them for the urban rail transit agencies (Manual for Urban Transit Safety Management System Section 2.2.3). The report held that safety performance measurement help in benchmarking the safety performance of rail transit agencies and in identifying the pattern and level of progress of different rail transit agencies.

3.8 Summary

The literature review also reveals a number of limitations to prior studies on rail transit accident analysis. First, there are no studies that have comprehensively examined the operational determinants of rail transit accidents at the operator signup level. Second, the influence of employment status, assigned work, work performance abilities and customer feedback on the expected frequencies of bus collision and non-collision has not been quantitatively determined. Third, there is no study that has used data recovered from Transit ITS technologies and related systems to develop an operator-based safety incident model that can help in identifying and assessing the effect of factors that contribute to the likelihood of preventable incident involvement and occurrence of transit bus safety incidents.

The findings from the empirical literature review reveal that prior empirical studies specifically examining rail crashes primarily addressed the effects of operator demographics, factors contributing to operator stress and fatigue, various measures of safety risk exposure and route or vehicle characteristics representing potential safety hazards. The importance of operational characteristics has also been recognized by researchers (Jovanis et al., 1991). Due to data limitations and research design issues, these studies could not directly model the likelihood of preventable incident involvement and crash frequencies at the operator level.

CHAPTER 4

DATA ANALYSIS

4.1 Transit Safety Data Sources

The primary data source for this paper is from National Transit Database (NTD) report. NTD is the Federal Transit Administration's primary national database for statistics on the transit industry (National Transit Database, 2011). It was established by Congress to be the nation’s primary source for information and statistics on the transit system of the United State. Basically, our data includes operating information of number of vehicles, passenger miles traveled, vehicle revenue miles, vehicle revenue hours and incidents information on total incidents, total fatalities and injuries, etc. The database provides us information from 2002 to 2011 which include all kinds of transportation modes in the US. For this research purpose, Subway and Light Rail’s data has been used for the entire United State.

According to National Transit Database, there are some limitations that need to consider before using the data. Data quality and completeness have improved significantly over time. The safety & security data collection was introduced as a pilot program in 2002. Over time, most transit properties developed new internal data collection and processing methods to meet the new requirements. These developments, combined with the implementation of more sophisticated validation checks by FTA, have resulted in more complete and accurate data in more recent years.

These data have created an opportunity to explore a new dimension of safety- the transit operating environment. Previous research could not systematically and comprehensively address this dimension due to data limitations and research design complications.

After the close of a month, transit properties have one month to compile and submit data to the NTD. Upon submission, NTD Analysts review submissions for data completeness and reasonableness and request revisions where appropriate. To allow for this validation process, this Time Series includes a 90 day lag before publishing reported safety and security data. Therefore, January data is not published until the May release of the Safety & Security Time Series File. Additionally, transit properties may revise their data at any time during the calendar year reporting cycle, which lasts through March 1 of the subsequent year. These changes may be done unilaterally by the transit property, as the transit property collects additional data on its operations and these changes will be reflected in subsequent release of the Safety & Security Time Series.

This Time Series includes service data collected through the NTD Annual Module. Because closeout of the Annual Module occurs after closeout for the Safety & Security Module, the Time Series file may incorporate the previous years' service data for 1 or 2 of the most current Time Series data sheets. The Time Series data sheets will include a notation if such an adjustment has been made.

A transit agency that directly operates some of its motorbus service and contracts out for the rest of its motorbus service will have two separate lines for motorbus service, one for the directly operated component and another for the purchased transportation component. The same principle holds true for a transit agency that contracts out its service that was previously directly operated. The service will appear on two different lines, depending on whether it was directly operated or purchased transportation.

4.2 Safety Management Information Statistics Database (SMIS)

Transit agencies have been collecting safety-related data for more than three decades. Over 750 of the nation's public transportation providers submit safety data to the National Transit Database (NTD) program routinely by service mode These data are used by the FTA to construct metrics and track trends of the overall safety performance of the transit industry (FTA, 2012).

The quality and completeness of accident/incident data reported by transit agencies affect the understanding of the safety of the U.S. transit industry and consequently how safety resources are targeted. The reported data usually come from accident, incident, or police reports and are used to complete the major incident report form (S&S-40) and the non-major incident summary report form (S&S-50) required by the FTA. The information contained in these forms is entered into the National Transit Database (NTD), which also contains financial and operating data for public transportation systems in the U.S.

The NTD underwent a major redesign for calendar year 2002 (FTA, 2005). The NTD now incorporates a web-based, monthly, and two-tiered safety and security incident collection mechanism. The injury definition was changed for the 2002 revision of the NTD to coincide with other USDOT modes. A redesign of the NTD for calendar year 2002 resulted in the Federal Railroad Administration's (FRA) Rail Accident/Incident Reporting System (RAIRS) now the source of commuter rail safety data (FTA, 2005).

For NTD electronic reporting purposes, transit operators collect data on four major categories of transit accidents:

1. collisions,
2. derailments/buses going off the road,
3. personal casualties, and
4. fires.

These major categories are divided into subcategories. For example, the collisions category comprises collisions with vehicles, objects, and people except suicides. Transit agencies report fatalities, injuries, accidents, incidents, and property damage in excess of a specified dollar amount.

4.3 State Safety Oversight Agency Data

In response to Congressional concern regarding the potential for accidents and incidents on rail transit systems, the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) added Section 28 to the Federal Transit Act, codified at 49 U.S.C. Section 5330. This section requires the FTA to issue a regulation creating the first state-managed oversight program for rail transit safety.

State Safety Oversight Agency (SSO) agencies are required to submit data annually to the FTA on transit accident and hazard investigations including date, type of accident, number of injuries, number of fatalities, probable cause, property damage, and type of individuals injured, such as passenger or worker. These annual data submissions are manually entered into a template that the SSO agencies submit to the FTA. The FTA recommends, but does not require, SSO agencies to provide internal tracking numbers assigned to each accident; not all SSO agencies do so.

To allow for the individuality of reporting agencies, the FTA allows each agency to develop its own reporting format, including items such as accident cause classifications. Some agencies have indicated that they would prefer to report using a standardized form. In response, the FTA has developed the SSO Annual Reporting Template, which is fully acceptable for Annual Certification and may help streamline the process.

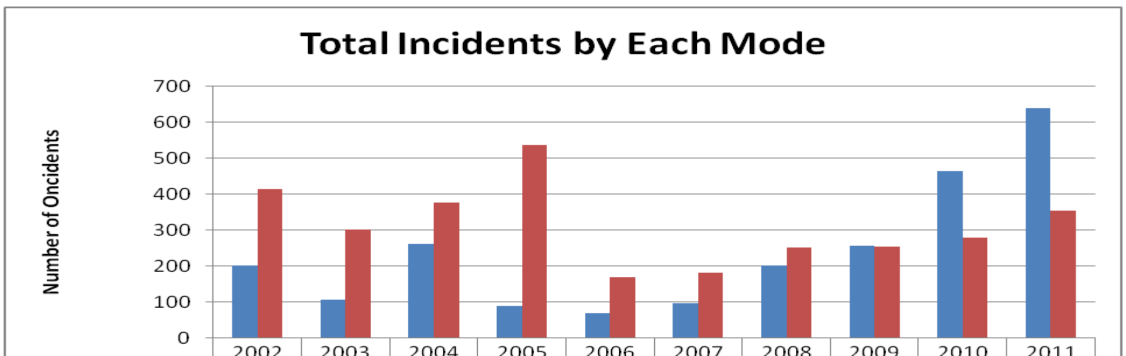
In addition to the two primary sources, other entities, such as departments of public safety, police departments, city/county/state transportation and traffic departments, and universities, may also provide some of the necessary data. For instance, local public works departments and state departments of transportation are good sources of traffic data (traffic volumes, traffic speeds, inventories of traffic control devices, traffic signal timing information, and so forth). The geographic information systems (GIS) maintained by local planning organizations can be very helpful in analyzing data spatially.

4.4 Comparative Analysis

The total number of incidents, injuries and fatalities for Subway (HR) and Light rail (LR) from 2002 to 2011 are included in historical trends for subway and light rail below. 4.1 show the incident data comparison between Subway and light rail. From 2002 to 2008, incidents related to Light Rail are of much larger amount than incidents related to Subway; however, incidents from Subway from 2009 to 2011 has been increase to the point that it surpasses Light Rail. For light rail, the average amount of incidents during these 10 years is 312 per year. However, the average amount of incidents related to Subway is 239 per year.

Figure 4.2 illustrates the difference in injuries from Subway and Light Rail from 2002 to 2011. Total injuries data shows that Light Rail had caused far more injuries than Subway, with around 274 a year compared to around 232 a year for Subway. From 2007 to 20011, the injuries caused by Light Rail and Subway increase and the injuries caused by Subway is almost double the one caused by Light Rail from 2020 to 2011.

Figure 4.3 analyzes how the fatalities caused by Subway are related to Light Rail. Total fatalities caused by Subway are far greater than fatalities caused by Light Rail. For light rail, the average of fatalities during these 10 years is 20 per year, but the average amount of fatalities related to Subway is 59 per year.



	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Subway (HR)	202	108	261	89	71	97	202	257	464	639
Light Rail (LR)	414	301	378	538	171	181	252	254	279	355

Figure 4.1 Total incidents from 2002 to 2011 for light rail and subway.

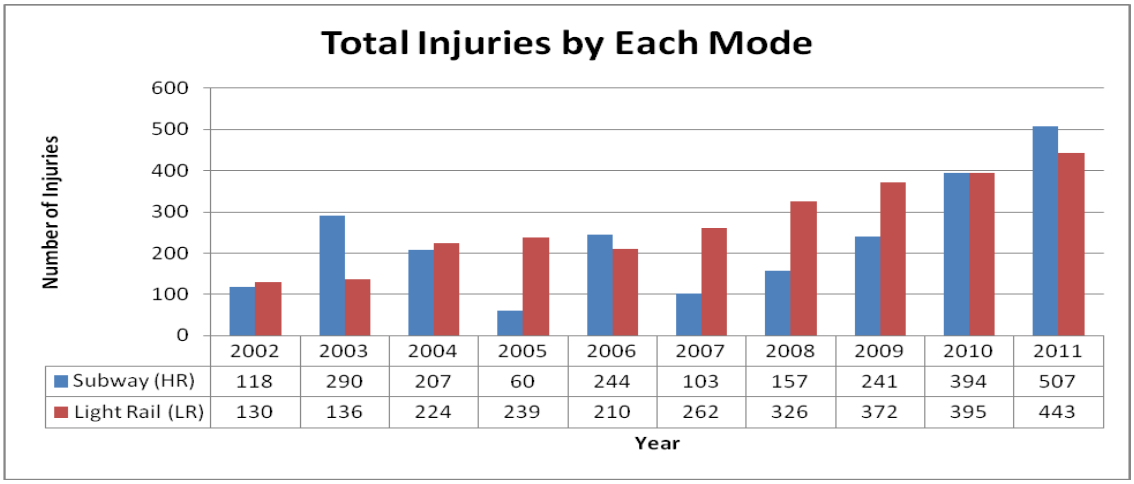


Figure 4.2 Total injuries from 2002 to 2011 for light rail and subway.

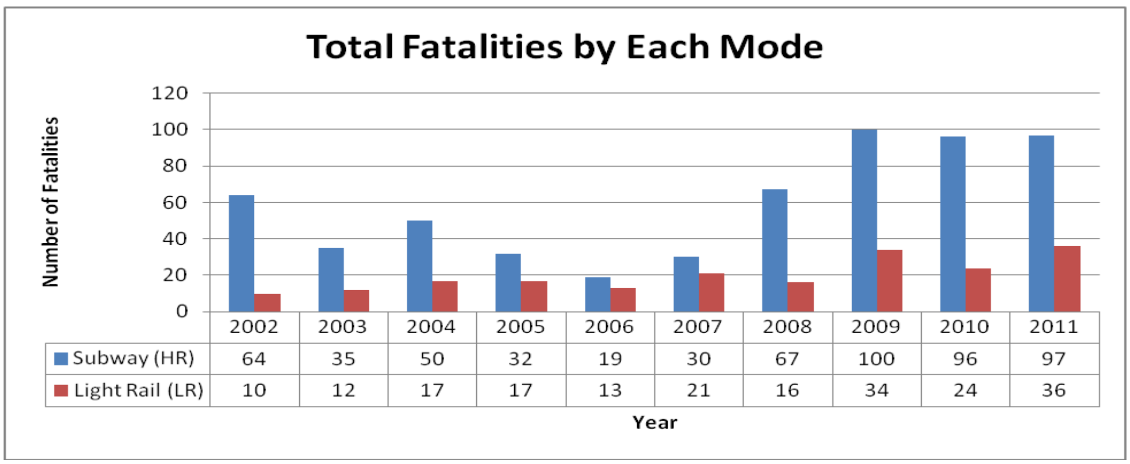


Figure 4.3 Total fatalities from 2002 to 2011 for light rail and subway.

The operating statistics of each mode shows total passenger miles traveled (PMT), total vehicle revenue miles (VRM) and total vehicle revenue hours (VRH) for each mode respectively. The author can conclude from these figures that from 2002 to 2011, numbers for each category have increased. On the other hand, for the three factors above, Subway had far more than light rail. The average PMT per year for Subway is

15,019,416,633 and 1,857,140,694 for Light Rail; the average VRM per year for Subway is 89 Million and 44 Million for Light Rail; and the average VRH per year for Subway is 15 Million and 4 Million for Light Rail. According national transit database (NTD), the data used to count the VRH as train (train revenue hours) prior to 2008 (all vehicles in one train), but after 2008, NTD started to count it as vehicle revenue hours. Each train has in average 8 vehicles so that is why after 2008 the VRH is so high. Despite the much safer performance, public transit has not been cast in a positive light when it comes to safety measures (see Figures 4.4 to 4.6). One simple explanation is that VRM is not the proper conversion to measure safety performance for all modes. One transit vehicle may carry 20 to 100 riders while the average occupancy rate for private vehicles in the US is less than two (2). The Passenger Miles Traveled (PMT) may be a better conversion unit but not all modes collect such data. For example, the metrics collected by the official source, Bureau of Transportation Statistics, US Department of Transportation, measure the fatality rate for air travel per 100 million aircraft miles, for waterborne mode numbered boats and train miles for railroad mode.

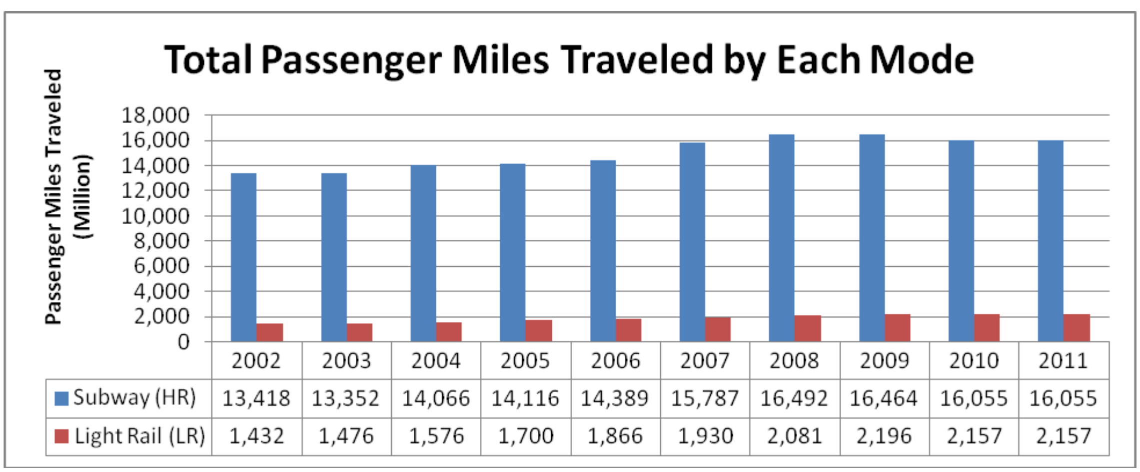


Figure 4.4 Total passenger miles traveled by each mode between 2002 and 2011.

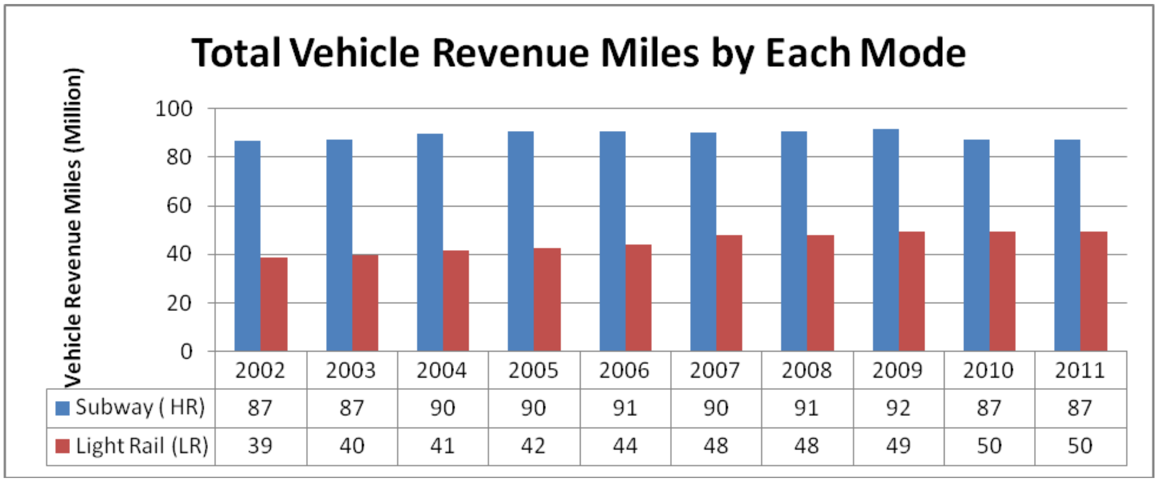


Figure 4.5 Total revenue miles traveled by each mode between 2002 and 2011.

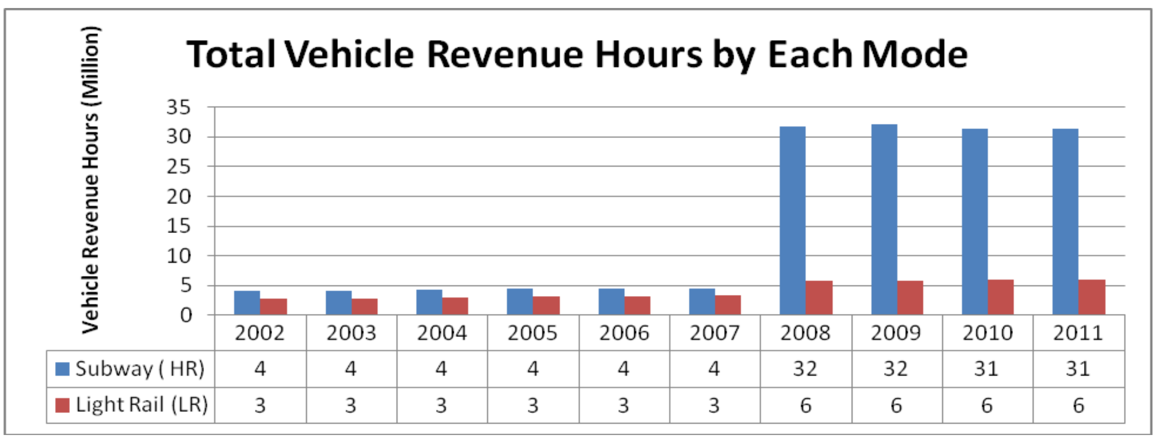


Figure 4.6 Total vehicle revenue hours by each mode between 2002 and 2011.

It is clear that when compared to other modes, particularly automobiles, the safety performance of public transportation is often distorted due to inadequate unit conversions or calculation bases. This arises, in part, because of the differences in how safety performance is defined and measured among transportation modes and because of the inherent differences in the operating environments of the different modes. In addition, some of the comparisons of aggregate national safety statistics and performance measures of different transportation modes can be misleading and may, in fact, distort the safety performance record of a particular mode.

The disparity between the safety performance and public perceptions of various transportation modes may have hampered the viability of transit services. Given the discrepancies and misperceptions of existing safety performance measures, the public transit industry is in urgent need of recognizing, addressing, and improving a safety performance comparison among transportation modes.

Transit incidents, fatalities and injuries vary considerable from year to year, especially when viewed alone, without consideration to the volume of ridership. Figure 4.7 shows the incidents rate per million passenger miles traveled; we figure out that from 2003 to 2005 there was an increase in the incident rate for Light Rail; thus, it was decreased from 2005 to 2006. From 2007 to 2011, the incident rate for Light Rail increased. The incidents rate for Subway was relatively low, but started to increase in 2008**.**

The true pictures of transit safety for various modes start to emerge when the simple accident or fatality numbers are converted into various operating contexts. For example in Figure 4.8, the injuries rate per million PMT for Light Rail is much higher than the rate for Subway. From 2003 to 2005, the injury rate increased for Light Rail; the rate started to decrease between 2005 and 2006. However, the injury rate started to increase after 2006 and now passengers have the highest rate of getting injured ever before and it was at his highest peak in 2011. For the Subway, the injury rate went up and down almost every year until 2007 where it started to increase every year but at a lower rate than the Light Rail.

As shown in Figure 4.9, the fatality rate per PMT for Light Rail is higher than the Subway. From 2002 to 2004, there were an increase in passenger fatality rate for Light Rail but started to decrease from 2004 to 2006. Since 2006, the fatality rate went up and down but at a higher rate than the previous year. From 2004 to 2006, the fatality rate for subway decreased, but it started to increase in 2007.

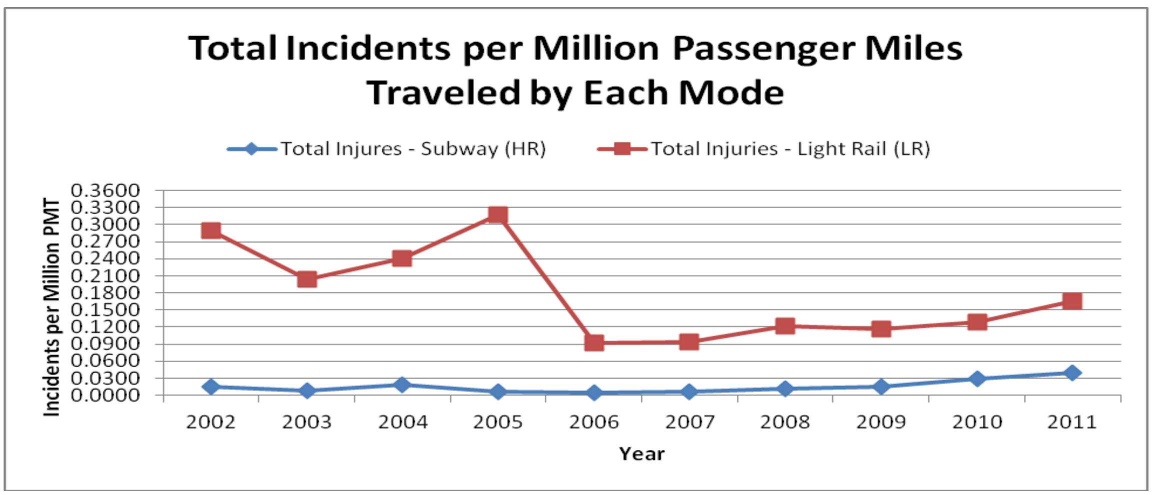


Figure 4.7 Total incident rate for subway and light Rail from 2002 to 2011.

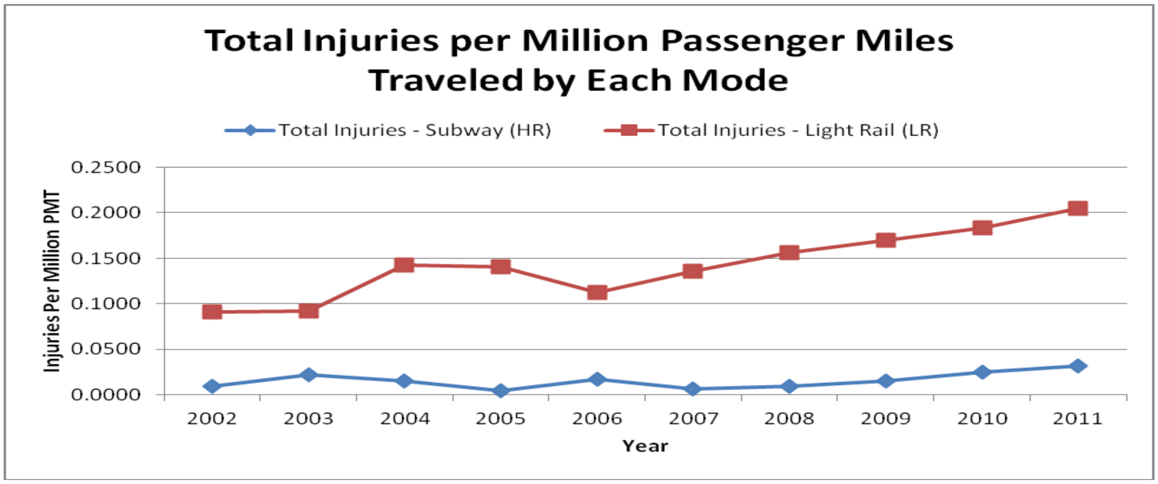


Figure 4.8 Total injury rate for subway and light rail from 2002 to 2011.

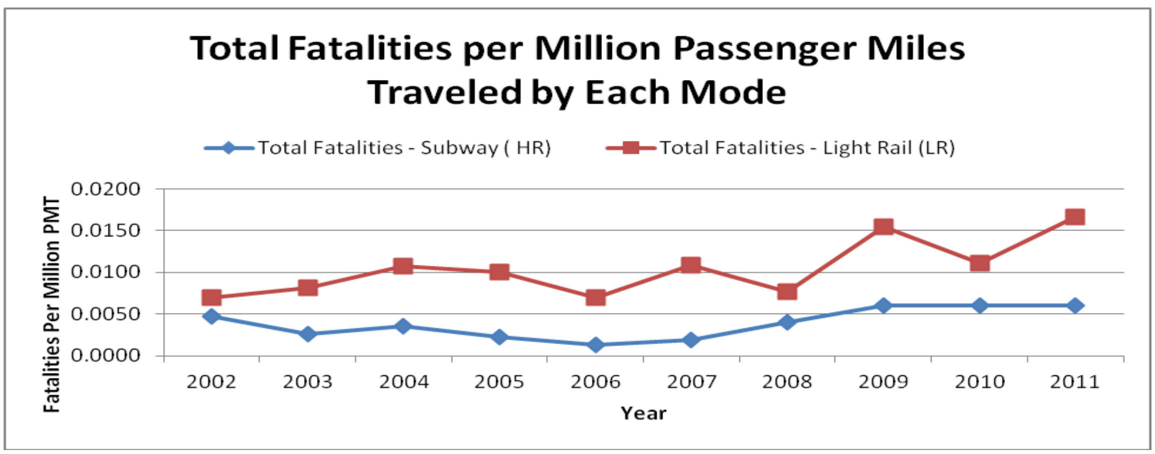


Figure 4.9 Total fatality rate for subway and light rail from 2002 to 2011.

For figure 4.10, the passenger injuries rate per million PMT for Light Rail is much higher than the rate for Subway. From 2003 to 2005, the passenger injury rate increased for Light Rail; the rate started to decrease between 2005 and 2006. However, the passenger injury rate started to increase after 2006, and now passengers have the highest rate of getting injured ever before. For the Subway, the injury rate was almost constant until 2007 where it started to increase but at a lower rate than the Light Rail.

For Figure 4.11, the passenger fatality rate per PMT for Light Rail is higher than the Subway. From 2003 to 2006, there were a big jump the in passenger fatality rate for Light Rail but come to be lower than Subway after 2006 and stay lower until 2011. It means that from 2006 to 2011, passengers had higher risk of getting killed by the Subway than the Light Rail; however, the average passenger fatality rate per Million PMT per year for Light Rail was 0.0004 while the average rate for Subway was 0.0003 per year.

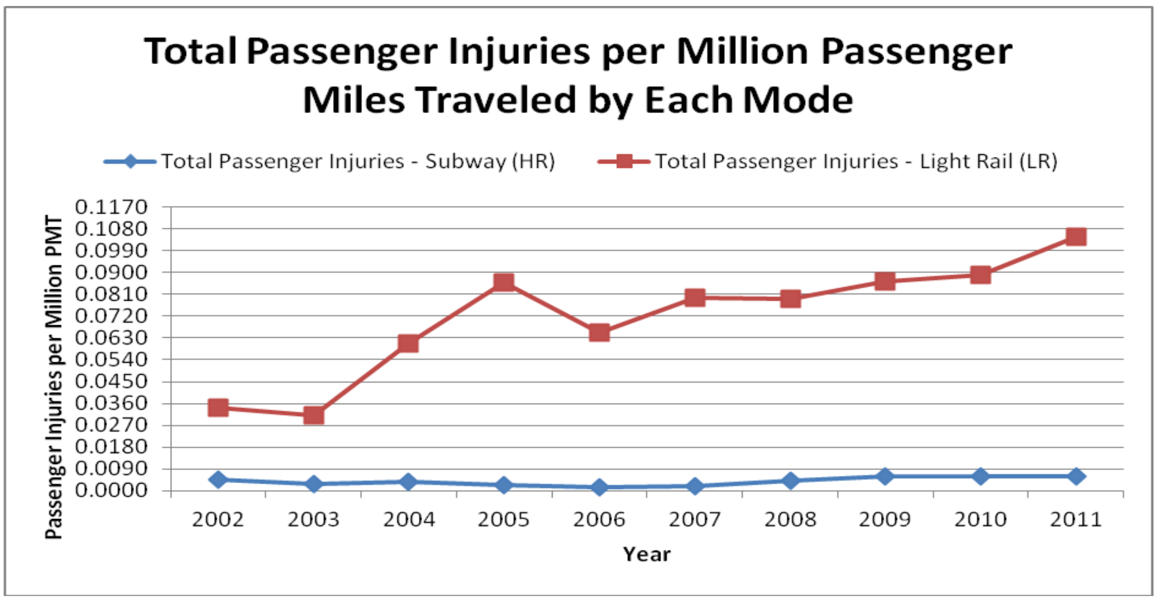


Figure 4.10 Total passenger injury rate for subway and light rail from 2002 to 2011.

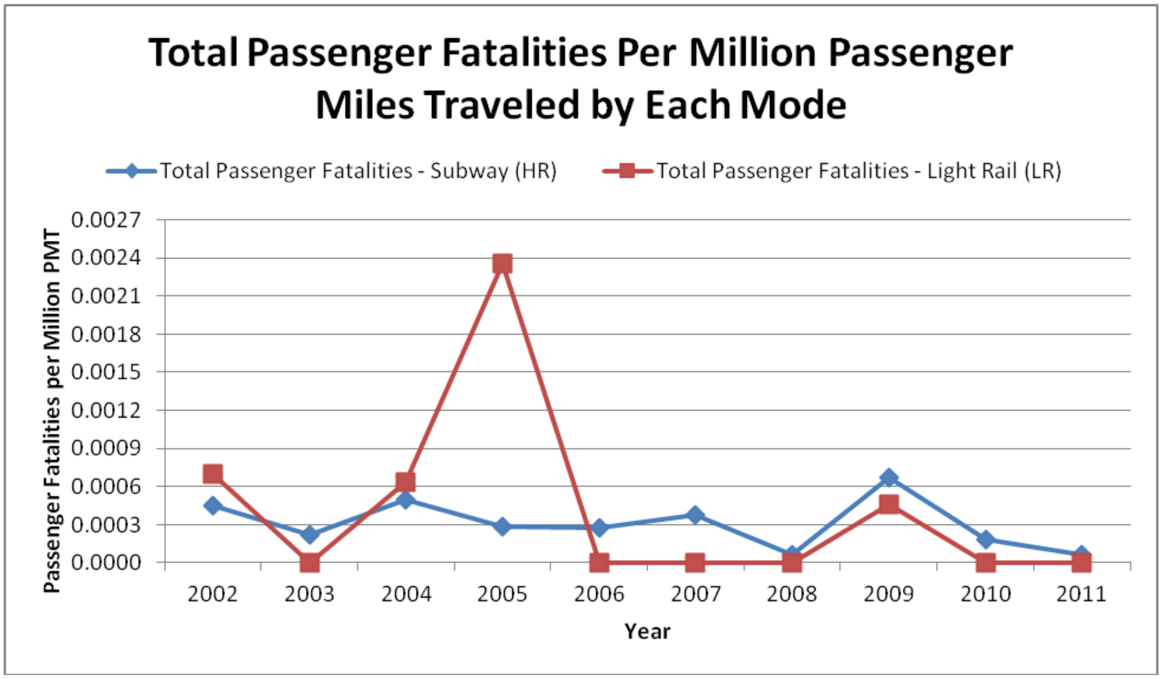


Figure 4.11 Total passenger fatality rate for subway and light rail from 2002 to 2011.

The Suicide rate plays a big part of the fatalities for the Subway system. For over 10 years in these analyses we found that 173 people commit suicide from Subway compare to 21 people from Light Rail. It is a little bit over 8:1 ratio. The suicide that caused injuries from 2002 to 2011 is still higher for Subway compare to Light Rail. It is important to notice that National Transit Database, there are no reports for suicide from 2002 to 2007. It is arguable that the increased number of fatalities due to suicide in the subway might represent an anomaly. It is difficult to mitigate against a potential suicide, nor is that the sole determinant of safety policy.

Suicide has been reported as an important cause of rail accidents. According to FTA (2009), suicide is a major cause of heavy rail accidents but is not a major cause of accident in light rail system. Between 2003 and 2005 some 200 suicide accidents occurred in the heavy rail but only 24 suicide accidents occurred in light rail system

(FTA 2006). The possible reason is the speed of heavy rail that attracts the suicide attempters.

When comparing the suicide rate that end up in injury and fatality, the author concluded that NTD did not start to pay attention to it until 2008. Figure 4.12 illustrated that between 2008 and 2009 the suicide injury rate for light rail decreased but there were a big increase from 2009 to 2010. There was a small decrease from 2010 to 2011. The subway suicide injury rate increased from 2008 to 2010 but started to decrease from 2010.

For Figure 4.13, the suicide fatality for light rail has been increased since 2008, but it increased from 2008 to 2009, decreased from 2009 to 2010 and increased again from 2010 to 2011 for subway. Prior to 2008, the transit agencies did not have to report the number of suicide. Based on the accident, the agencies reported suicide as trespasser or other. After 2008 the system changed on how suicide needed to report. The agencies started reporting suicide as suicide. But when NTD gets the information, the data has to be clear. If the information is not clear, the agencies would need to have witnesses on site that can testify the accident is actually a suicide otherwise NTD would report it as other.

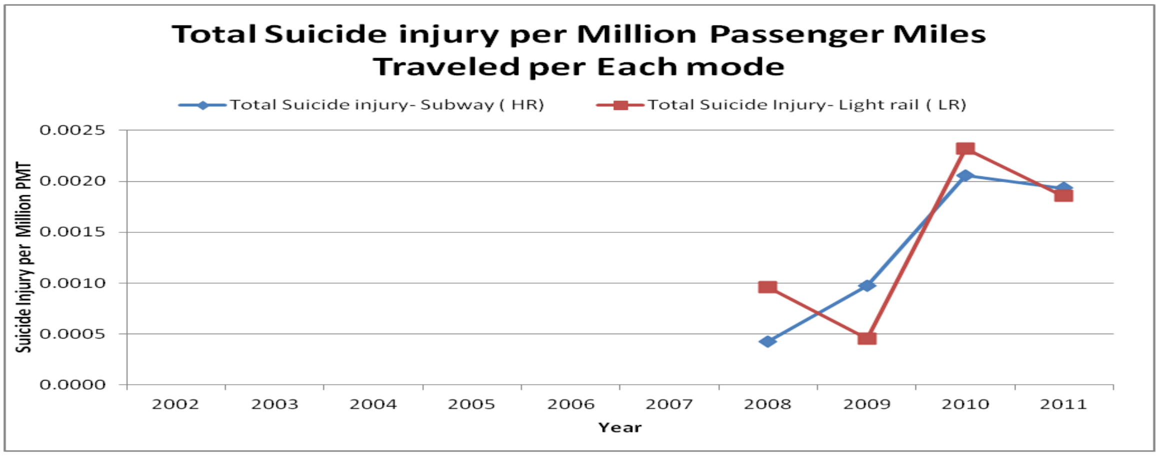


Figure 4.12 Total suicide injury rate for subway and light rail from 2002 to 2011.

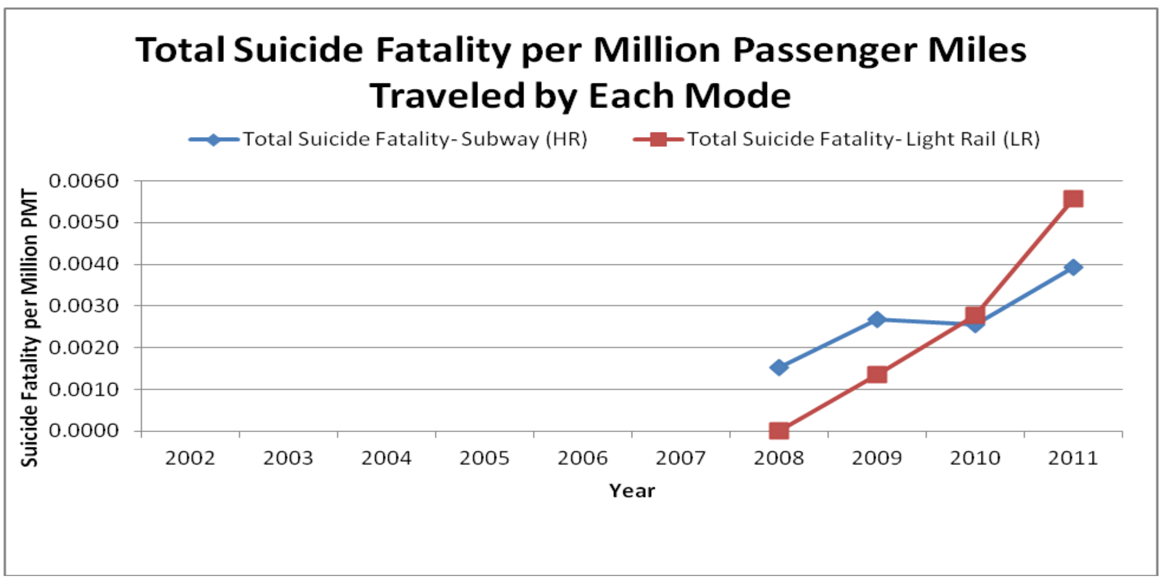


Figure 4.13 Total suicide fatality rate for subway and light rail from 2002 to 2011.

One of the major issues in the rail system is trespasser. From 2003 to 2004 the trespasser injury rate for light rail was doubled. It decreased in 2005 and increased again from 2005 to 2007. For subway, the trespasser rate decreased from 2002 to 2004; it stayed at a low rate since 2004 until it reached zero in 2008. The trespasser fatality rate went up and down from 2002 to 2008 for both systems. It came to the author's attention that from 2008 to 2011, the trespasser rate for both systems was zero but the suicide rate was up. (See Figures 4.14 and 4.15)After 2008, the way, that the trespasser used to reported, has changed. The transit agencies started to report trespassers as other or pedestrians crossing the tracks or walking along the tracks.

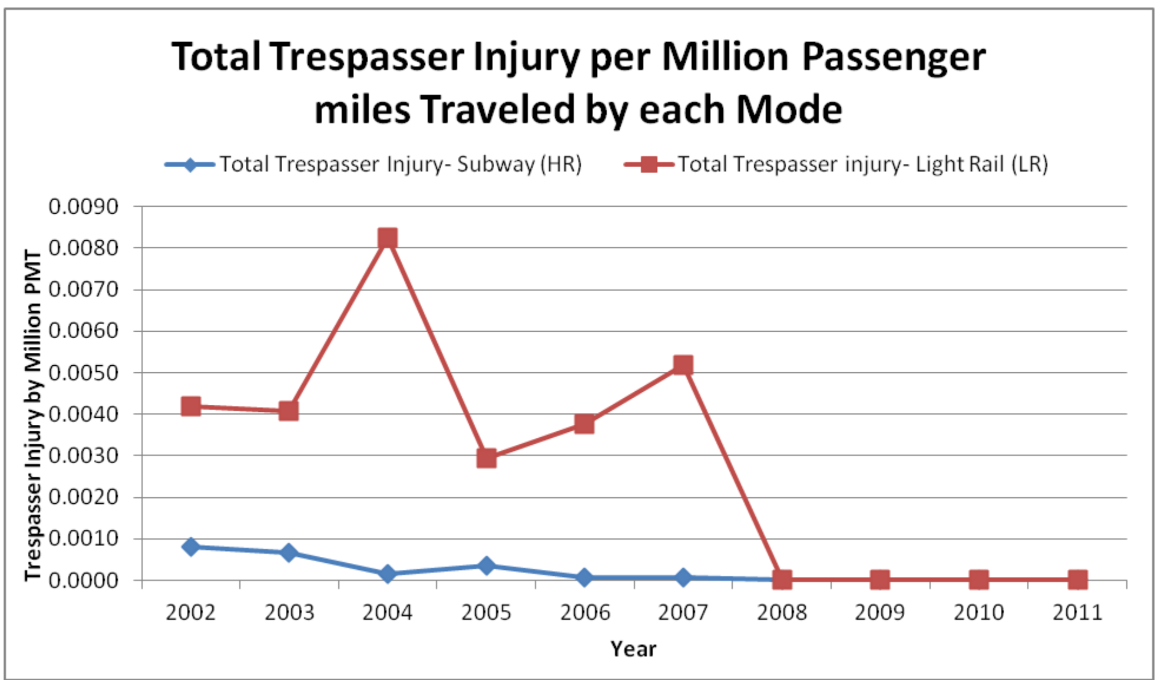


Figure 4.14 Total trespasser injury rate for subway and light rail from 2002 to 2011.

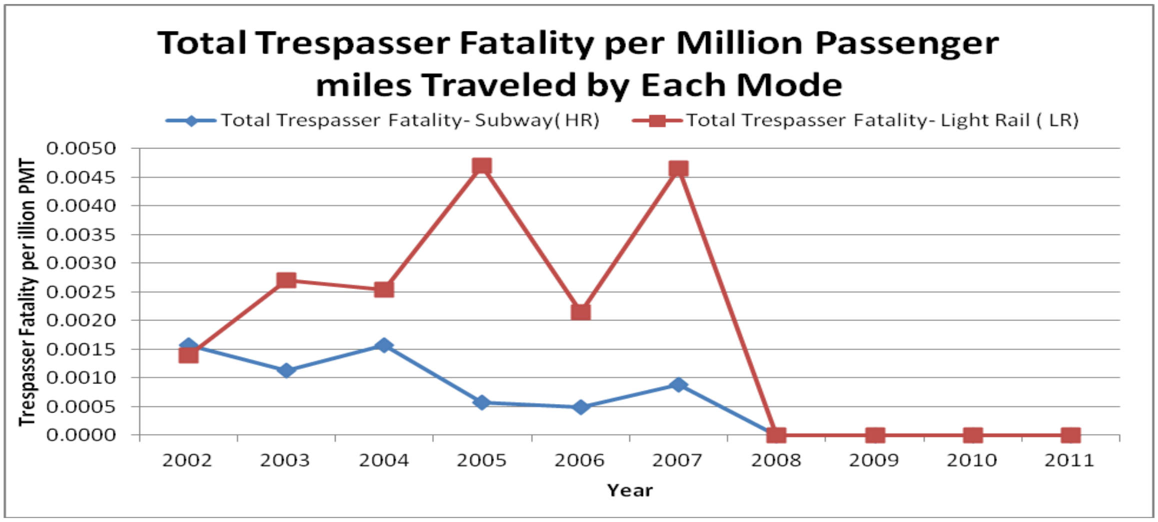


Figure 4.15 Total trespasser fatality rate for subway and light rail from 2002 to 2011.

CHAPTER 5

CONCLUSIONS

5.1 Summary Analysis

Transit incidents, fatalities and injuries vary considerably from year to year, especially when viewed alone, without consideration of the volume of ridership. However, the true pictures of transit safety for various modes start to emerge when the simple accident or fatality numbers are converted into various operating contexts. As shown in Figure 4.7, the accident rate, injury rate and fatality rate per million PMT for LRT are consistently higher than those of subway. The clear difference is highlighted by converting the total number of accidents, injuries and fatalities into a unique platform or consistent unit. This conclusion is also consistent with general expectations as subway usually operates in exclusive right-of-way but LRT is in mixed traffic, which has higher risk exposure. The simple process presented in this manuscript demonstrates that it is possible to derive reasonable and consistent safety performance measures in order to compare different transportation, especially transit, modes. It is clear that the total number of accidents or injuries may vary from year to year and the operations may grow at different rates. When a common denominator, such as an accident rate per million PMT, is used, it is much easier to compare the safety performance of different modes.

From the figures of total incidents, fatalities and injuries per million passenger miles traveled by each mode, there is a trend that can be found. Though passenger fatality rate caused by subway and light rail were closely similar which 0.0004 average passenger fatality rate per year for light rail and 0.0003 average passenger fatality rate per year for subway, total incident rate, passenger injury rate, total injury rate and total fatalities rate caused by light rail were much higher than the one caused by the subway**.** From 2006 to 2011, in Figure 4.7 shows that when there is an incident happened related to light rail or subway, the risk that it will lead to death to passengers is higher in subway compared to light rail.

Overall, subway is much safer than light rail in the aspects of risk of incidents, injuries and fatalities rate. The number of total incidents injuries and fatalities for subway are much higher than the ones for light rail, but when you compare their rate, the subway has the lower risk. This analysis proves that when comparing the two dominant modes of transportation in the US that subways are safer than Light Rail. Subways have dedicated rights of ways, signal dedication and infrastructure that is totally separate from any other mode of transport. Subways do have an overall higher fatality number but, that is due part to subways having larger capacities for users. When an accident occurs, the probability of injury or fatality will be higher.

Most light rail fatalities tend to be not passengers, but individuals in other categories, such as illegal trespassers, suicide and motorists that violate safety laws or regulations. Also, though the passenger injury is a major component of all injuries, passenger fatalities caused by subway does not take a big part in total fatalities. To some extent, it shows that subway passengers face a lower risk of death and incidents and injuries per Million PMT compared to light rail passengers

As a result of accidents, injuries and fatalities, various controls have been put in place to minimize as much as possible the probabilities of accidents occurring. Safety training, safety commissions, safety campaigns, awareness training, periodic workshops for continuous improvement are some of the ways United State Transit is working to ensure that their employees and passengers are engrained with a culture of safety. Through fundamental positive changes in safety performance, the transit agency can adapt and grow and continue to enhance their reputation.

5.2 Safety Performance of Light Rail versus Subway

To compare the safety performance of light rail and subway system, it is important to take into account a number of factors defining safety performance. One very popular way of defining safety performance is to examine the frequency of accidents. In the present study, when comparison was made between total accidents of subway and light rail system two very important trend were observed. From 2002 to 2005, there were a lot of accidents occurring in the light rail system, but 2006 saw a remarkable decline in accident occurrence and from that year, though there is continuous increase in the total number of light rail accidents, the situation is not as bad as was earlier. The decline in the accident rate in 2006 can be attributed to the safety action plan introduced by FTA in the same year that placed the reduction of collision to be its first priority. A closer view on the number of accidents from 2003 to 2008 with respect to accident type is shown in Figure 5.1 below. As can be seen, the decline in the number of accident in 2006 was mainly due to the decline in the number of collisions (FTA 2009).

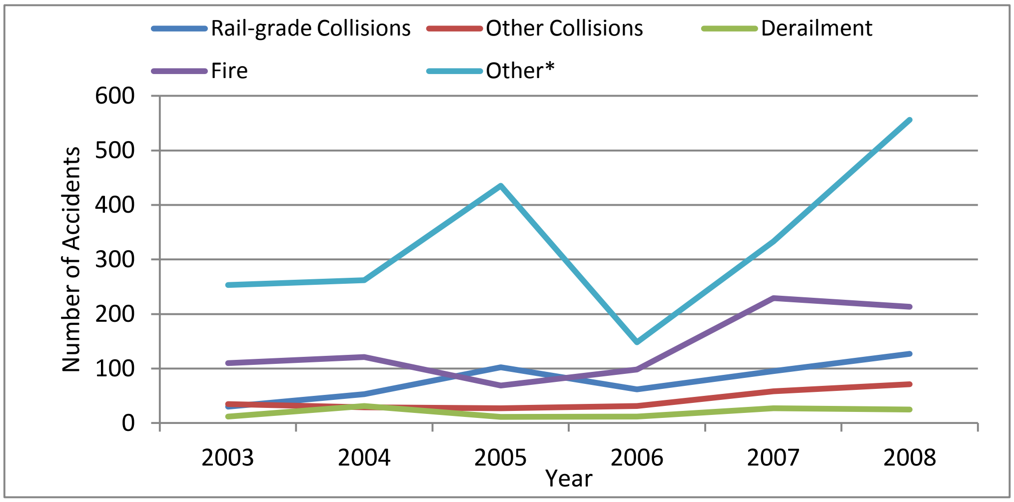


Figure 5.1 Number of accidents by accident type (2003-2008).

Source: FTA, 2009, p. 4
** Other accidents include suicide and trespassing-related fatalities; homicides; non-fire -related evacuations; and other fatality or multiple-injury accidents that are not considered Collisions, Derailments, or Fires*

Also, the data on frequency of accidents clearly shows that the increase in the number of heavy rail accidents is at much higher level than the increase in the number of light rail accidents. This might be due to the higher capacity of the heavy trains and its high speed because of which the chances of injuries and fatalities in an incident increases. After reviewing the data from 2003 to 2008, FTA (2009) reported that in total some 348 people died in heavy rail accidents while only 139 died in rail road accidents, showing that there were more than double deaths caused by heavy rail accidents than by light rail accidents despite the fact that the number of accidents in light rail (2747) was much higher than the number of accidents in heavy rail (918).

The major cause of these accidents was found to be suicide (FTA 2009). Also, the large number of fatalities in heavy rail accidents is mainly due to suicide. Table 5.1 below shows the number of fatalities and injuries caused by traffic accidents that occurred due to suicide. It clearly shows the increase in the suicide rates in past few years. This explains the growing rate of accidents as well as fatalities of heavy rail accidents in past few years.

Table 5.1 Fatalities and Injuries in Traffic Accidents due to Suicide

Year	**Total number of fatalities**	**Total number of injuries**
2002	15	18
2003	15	11
2004	16	0
2005	7	0
2006	12	27
2007	23	16
2008	27	15
2009	49	23
2010	52	39
2011	79	38

The present study has also compared the number of fatalities or injuries occurred in the accidents of these two rail systems from 2002 through 2011. This measure can be used to benchmark the severity of accidents. According to the data reported by NTA, light rail is safer mode of transport as there are very few fatalities in light rail accidents, though the number of injuries is quite equal in both mode of transport. Thus, when taken into account the large capacity of users in subway system, it appears to have much lesser safety risk then in light rail system. According to FTA (2009), most of the people that die in these accidents are non-passenger publics including the motorists, trespasser and patrons.

Turning to the specific factors with respect to both rail system and their relationship with the accident rates and frequencies, evidence is clear that numerous factors play roles in accident occurrences. Some of these factors are equally applicable to both light and heavy rail system but some factors are specifically associated with the accident occurrence in either light rail or heavy rail system.

According to “2009 Rail Safety Statistical Report” (FTA 2009), there is noticeable difference in the accidents rates of light rail and heavy rail system with respect to the type of accidents. In heavy rail system the rate of rail grade collision is very low and remained below 0.02 throughout 2003-2008. However, rail grade crossing collisions is the most common cause of accidents in light rail system and there is a significant rise in the rail grade collisions from 2003 to 2008 (16.78 to 26.32). In comparison, the rate of accidents caused by suicide, trespassing-related fatalities, homicides and other factors not including collisions, derailments and fires is very high in heavy rail system, reaching around 1.03 in 2007. Such factors play not much important role in the light rail accidents where rail grade collision or non-rail grade collisions are the main type of accidents. A previous report by FTA (2006) has also reported collision to be the major cause of accidents, deaths and injuries in light rail system.

Several reasons have been identified leading to such accidents. In general, traffic safety literature has reported negligence from the rail operator’s side to be the prime cause of traffic accidents. Evans (2004), for example, summarizes the findings of two large independent studies undertaken in the U.S. and U.K. In both studies driver behavior was found to be either the sole or contributing cause of more than 90% of crashes. Wilson and Norris (2006) reviewed a number of studies specifically on rail accidents and also reported rail operator's behavior including attentiveness, care, recognition of signals, and ability to make right decision with respect to the signals as important factors related to rail accidents. Similarly Hursh, Fanzone and Raslear (2011) found a strong and significant relationship between the level of rail operator's fatigue and the frequency and severity of rail accidents.

Studies not only focused on the behavior of rail operators and other workers of rail agencies but found passenger behavior to be another important cause of such accidents. FTA (2009) reported that in all the passenger fatalities between 2003 to 2008 in rail accidents were due to the factors associated with either passenger-behavior, of which some 43% accidents were due to medical problems with the passenger and 21% were found to be slip and fall accidents. However, it is important to note that all these passenger fatalities were caused by the heavy rail accidents except one in which case a passenger died by slipping from the light rail. Passenger behavior was also found to be one major cause of accidents that led to public (non-passenger) fatalities (FTA 2009)

Risky action taken by motorists is found to be one of the major causes of rail grade crossing collisions and, in many of these accidents, it is the motorists who die. Private automobiles drivers and public bus drivers must understand that by doing anything risky around a heavy rail line or light rail can led to their death.

The other important causes were identified as vehicle failures (e.g., brakes and tires), environmental factors (e.g, weather and lighting), and roadway factors (e.g., design and condition). The vehicle-specific attributes that are known to influence rail accident risk include vehicle age, model year, and configuration. Older vehicles and old models have been reported to be over- represented in crashes relative to the newer models (Zeeger*et al.* 1994; Chang &Yeh 2005). Failure of safety equipment is another important cause of rail accidents, in particular derailment and fire accidents. According to FTA (2009) some 80 derailment accidents and some 89 fire accidents in rail were occurred due to equipment failure.

Change in weather or climate condition can also led to rail road traffic accidents but it is a relatively less important factor because the number of accident caused by this factor are relatively very low. From 1995 to 2005 only 861 railroad accidents, including all modes or rail traffic, occurred due to weather condition (Rossetti, n.d.). However, indirectly these weather conditions can play a significant role in accident causation. For instance, floods and flash floods produce damage on rail tracks, high temperature in summer can develop heat kinks in railroad tracks, cold temperate can result in blockage of train lines, thunderstorm can cause damage to safety equipment, and other similar issues (Rossetti 2002)

Rossetti (n.d.) also looked into the frequency of the rail accidents with respect to the time of day and found that in all rail accidents that occurred between 1995 to 2005, most of the accidents occurred from early afternoon to evening (Around 2:00 p.m. to 6 p.m., as shown in Figure 5.2). In most of these cases the reason was found to be high temperature.

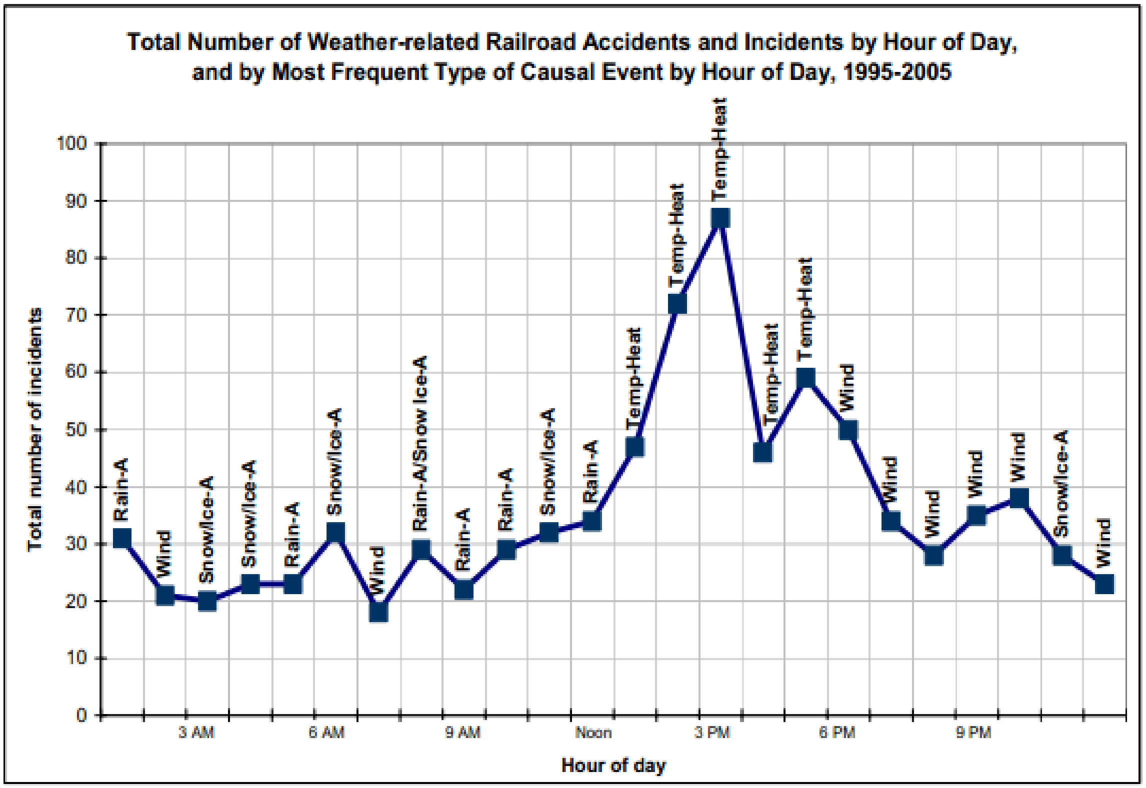


Figure 5.2 Effect of Time of day on the cause and frequency of occurrence of rail accidents in US during 1995-2005

Source: Rossetti, M.A. (n.d.). Analysis of Weather Events on US Railroads. Cambridge, MA: Volpe National Transportation System Center

Railroad crossings are reported to the main site of collision accidents. A recent study has found that the main cause of collisions at railroad crossing in the light rail system is the illegal and abrupt turns made by the motor vehicle drivers in front of approaching light rail (Ogden *et al.* 2007). It was found that the turning traffic is often controlled through left and right turn arrow signal which might not be an appropriate way to inform them about the approaching light rail. The study suggests a number of measures like flashing light signals, automatic gates, and audible signals in form of bell or horn (as light rail are not much noisy) for motorists safety. Also, the study gives importance to the safety of pedestrians and suggests use of fencing, swing gates, pedestrian barriers, pavement markings and texturing, refuge areas, and fixed message signs for pedestrian safety. However, BNSF (n.d.) reported that more than half of grade crossing collisions on BNSF in 2010 were on the grade collision where there were active flashing light signals as well as automatic doors. This indicates the need of more measures like a system to ensure the compliance of motor vehicle rules in these crossing and reduction of at-grade crossings.

The data indicate continual increase after 2007 in the frequency of accidents, injuries and fatalities in both mode of system, though at different rates. A particular reason for this has not yet been identified but it could be due to the increase in the number of passenger and vehicles miles as well as vehicle revenue hours. All these factors show increase in the railroad operation indicating the need to analyze the rail safety taking into consideration the number of passenger as well as miles travel by each mode of rail transport.

5.3 Policy Implications

From this extensive and detailed review of statistical and research data on the safety performance of light and heavy rails system, it can be concluded that both modes of transport pose a different type of threat. Light rail that has been reported in previous studies to be a safer mode of transport is found to be more risky than subway system. Although the number of fatalities and injuries are much lesser in light rail system, it is mainly because of the low speed and low capacity for passengers. With limited number of passengers travelling in light rail, it is not surprising that in case of accident there is low probability of fatality or injury.

Collision between light rail and other automobiles have been found to be the major type of accidents in light rail. One main cause of such collisions in the light rail system is because it does not have its own right of way and it travels along with other vehicles on the road. Also, many of these collisions occur at rail road crossing. Safety policies for ensuring the decrease in number of collision can make the light rail the safest mode of travelling in future.

The policy makers must understand that the chances of fatality are much higher in the subway system as compared to light rail system due to high speed of heavy rail and the higher capacity for passengers. Although with the large number of passengers travelling through heavy rail system made the percentage of fatalities with respect to total number of passenger quite low, it is important to understand that the life of every single person is important and efforts must be made to make the heavy rail system even more secure for passengers and for public.

The study has found that the human factor particularly driver and passenger risky behavior and worker fatigue critically affect the occurrence of accidents. Important measures to be taken for reducing the workers behavioral problems causing rail accidents were found to be reduction in the work load over employees of rail agencies, development of official training program on safety and security particularly for rail operators, selection of rail operator after their behavioral analysis, and development of safety culture in the organizations. Public education program needs to be introduced as well to make general public aware of the safety measures they should take while travelling through rail or crossing the rail line.

The present study has created new directions for the future research on safety performance of rail system. First, it highlights the importance of human factor and encourages the future researcher to compare different modes of rail system or traffic to see the relative importance of human factors in occurrence of accidents. Second, the study has compared the safety performance of just mode of transportation. Future comparative studies should include commuter rail as well as other mode of transport to find out the safety performance of transport in USA. It is also important to note that the previous method of measuring safety performance through number of accidents, injuries and fatalities is proved by the present study to give only partial view on safety performance. A comprehensive view including rate of accident, injuries and fatalities with respect to, capacity, passenger and vehicle miles and other similar factors gives more reliable findings on the subject.

5.4 Recommendations

The researcher has gained a lot of knowledge about the factors causing the occurrence of accidents in both light rail system and in subway system. In this section, suggestions have been made to avoid those causal factors to ensure safety and security for railway workers and passengers as well as general public.

For light rail safety plan, there should be increased emphasis on the reduction of railroad grade crossing – the main site of accident occurrence. One very important recommendation for reducing the collision between light rail and other vehicles is to install necessary signs on the road for informing the motor driver in advance about the approaching railroad crossing or light rail line. Since light rail shares the road with other vehicles, it is important that the route of light rails should be developed in a way that the motorist or pedestrian coming from the side roads can see the approaching light rail. Also, some laws need to be made for reducing the number of rail road crossings. The study also recommends development of a rail grade crossing safety management system that not only takes care of the maintenance of railroad crossing safety equipment but also ensures the enforcement of traffic rules in such crossings. Measures needs to be taken at community level to make people, particularly motor drivers, understand the importance of following traffic rules at rail grade crossing for their own safety. Some public education program should specifically focus on how a motorist can confirm that it will be safe to cross the road when there is a light rail approaching.

Since subway system poses higher risk of death or injury in case of accidents, it is important that the any safety management plan must give priority to the reduction of heavy train accidents. For reduction of derailment accidents, proper and timely maintenance of vehicle as well as safety management equipment is needed. However, one important cause of growing fatalities in heavy rail accidents are suicide relating to the growing suicide rates in the country. Reduction of suicide rate is beyond the control of rail agencies but they can take measure to reduce the use of heavy rail system for suicide. The study recommends that for reduction of suicide heavy rail accidents, a thorough research must be conducted to determine the most common ways these suicide attempts were made in the past and then take practical measures to reduce the probability of occurrence of those common methods of suicide. For instance, if most of the suicide accidents occurred when a person jumped in front of train, the agencies must add fences around rail line. Fences can also reduce the occurrence of collisions accidents.

REFERENCES

Abacus Technology Corporation. (1996). Liability Cost and Risk Analysis Studies: Bus Liability Review for Six Transit Systems. Report No. DOT-T-96-13. US Department of Transportation, Washington, D.C.

American Public Transit Association [APTA]. (2009). *2009 Public Transportation Fact Book, 60th Edition.* Washington, DC.

American Public Transportation Association [APTA].*2011 Public Transportation Face Book*, 62nd ed. Washington, DC.

American Public Transportation Association [APTA]. (2012). *Manual for Urban Transit Safety Management System.* Washington, DC.

Ashton, Rebecca, & Abigail Fowler. (2005).“Human Friendly Roosters: Reducing the Risk of Fatigue” *Rail Human Factors: Supporting the Integrated Railway*. Ed. John R. Wilson and Beverley Norris, University of Nottingham, UK, Theresa Clarke, Network Rail, UK and Ann Mills, Rail Safety and Standards Board, UK. Burlington,VT: Ashgate Publishing.

Becker, G. (1962). *Investment in Human Capital: A Theoretical Analysis*. Journal of Political Economy, 70, 9-44.

Baysari, Melissa T. *et al.* (2009). “*Classification of errors contributing to rail incidents and accidents: A comparison of two human error identification techniques*” Safety Science, 47.7: 948-957.

Burlington Northern Santa Fe [BNSF] (n.d.). *Grade Crossing Safety*. Available from: http://www.bnsf.com/communities/pdf/GradeCrossingSafety.pdf [Accessed 22 October 2012]

Bureau of Transportation Statistics.*National Transportation Statistics 2011*.Washington, DC: Bureau of Transportation Statistics.

Chaney, V., & Derr, K. (1996). *Liability cost and risk analysis studies- task 1: Assess liability expense and claims experience for selected bus transit Agencies* (No. FTA-94-3115). U.S. Department of Transportation. Washington, DC

Chang, H., & Yeh, C. (2005). *Factors affecting the safety performance of bus companies: The experience of Taiwan bus deregulation*. Safety Science, 43, 323- 344.

Chimba, D, Santo, T. and Kwigizile, V. (2010). *Effect of bus size and operation to crash occurrences*. Journal of accident analysis and prevention, 42, 2063-2067

Collis, Lynne, & Felix Schmid. (2001). "Human-centered design for railway applications." *People in Control: Human Factors in Control Room Design.* Jan Noyes & Matthew Bransby. London, UK. Halcrow Group. 273-291

Cotterill, Rob, & Helen Jones. (2005). "The HSE revised fatigue index in the rail industry: From application to understanding." *Rail Human Factors: Supporting the Integrated Railway.* Ed. John R. Wilson, Beverley Norris, Theresa Clarke & Ann Mills. Burlington,VT: Ashgate Publishing, 215-223

Carson J, Mannering F. (2001) *The effect of ice warning signs on ice-accident frequencies and severities*. Accident Analysis and Prevention. 33(1):99–109

Ekeila, W. (2005). *Vancouver's Streetcar Microsimulation Report*. University of British Columbia & City of Vancouver, BC, Canada.

Ekeila, W .(2006) *Dynamic Transit Signal Priority*. Master of Applied Science, thesis, University of British Columbia. Vancouver, BC, Canada

Evans, L. (2004). Traffic Safety. Bloomfield Hills, MI: Science Serving Society.

Federal Transit Administration [FTA]. (2002). *Safety Management Information Statistics (SAMIS) 2002 Annual Report.* Cambridge, MA: John A. Volpe National Transportation Systems Center.

Federal Transit Administration [FTA]. (2009). Industry accident and incident trend update. *Bus Transit Safety and Security, Quarterly Newsletter.* Winter Issue, 4-5.

Federal Transit Administration. [FTA]. *2009 Rail Safety Transit Report.* Available from: *http://transitsafety.fta.dot.gov/publications/RailSafety/Rail_Safety_Statistics_Report 2009-FINAL.pdf* [Accessed 22 October 2012]

Federal Transit Administration. *Rail Transit Safety Action Plan*. Washington, DC: FTA

Federal Transit Administration [FRA] (2005). Audit of oversight of highway-rail grade crossing accident reporting, investigations, and safety regulations (Report Number: MH-2006-016). Available from: http://www.oig.dot.gov/sites/dot/files/pdfdocs/mh2006016.pdf [Accessed 8 November 2012]

Gerken, Jeff and Tracy, Sara.Analysis of traffic impact at isolated light rail transit. Available from: http://www.docstoc.com/docs/26713444/analysis- of-traffic- impacts-at-isolated-light-rail-transit [Accessed 22 October 2012]

Garrett, Thomas A.(2004). *Light-Rail Transit in America: Policy Issues and Prospects for Economic Development.* Federal Reserve Bank of St. Louis, MO.

Gouin, V. *et al.* (2006) "*Train drivers' fatigue during a seven hour daytime trip, engineering psychology and cognitive ergonomics."Aerospace and Transportation System* .Ed. D. Harris. Burlington, VT : Ashgate Publishing. 455-462 .

Government Accountability Office. (2011)"*FTA Programs are Helping Address Transit Agencies' Safety Challenges, but Improved Performance Goals and Measures Could Better Focus Efforts*" Highlights. Washington, DC.

Greig, Neil & Jean Hopkin. (2011). *"Contributory Factors in Road Accidents: Great Britain 2005-2009*" ITE Journal, 81.7:34-39.

Hollywell, Paul. (2005)."ORAM: a structured method for integratinghuman factors into SPAD risk assessment" *Rail Human Factors: Supporting the Integrated Railway*. Ed. John R. Wilson, Beverley Norris, Theresa Clarke & Ann Mills. Burlington: Ashgate Publishing. 189-200.

Hadayeghi A, Shalaby AS, Persaud BN. (2003) *Macro level accident prediction models for evaluating safety of urban transportation systems.* Transportation Research Record: Journal of the Transportation Research Board, No. 1840. 2003:87–95.

Hursh, S.R., Fanzone, J.F., &Raselear, T.G. (2011).*Analysis of the Relationship between Operator Effectiveness Measures and Economic Impact of Rail Accidents.* Washington, DC: Office of Railroad Policy and Development, U.S. Department of Transportation.

Hundenski, R. (1992). *Public transport passenger accidents: An analysis of the structural and functional characteristics of passenger and vehicle.* Accident Analysis and Prevention, 24, 133-142.

Iles, Richards. (2005) *Public Transportation in Developing Countries.* San Diego, CA. Elsevier.

Jovanis , P., & Chang. H. (1986). *Modeling the relationship of accidents to miles traveled*. Transportation Research Record, 1068, 42-52.

Jovanis, P. P., & Chang, H.L. (1989). *Disaggregate model of highway accidents occurrence using survival theory.* Accident Analysis and Prevention, 21(5), 445-458.

Krass, A. (1993). *Impact of the U.S. motor carrier act of 1980 on road safety in California: An econometric policy evaluation*. Logistics and Transportation Review, 29, 179-192.

Kecklund, Lena, *et al.* (2003).“The TRAIN-project: effects of organizational factors, automatic train control, work hours and environment: suggestions for safety enhancing measures.” *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, 47.16: 1835-1839.

Litman, Todd. (2012).*Rail Transit in America*: A comprehensive evaluation of benefits. Victoria Transport Policy Institute. Victoria, BC, Canada

Lowe, Emma, & Claire Turner. (2005). “A human factor SPAD checklist.”*Rail Human Factors: Supporting the Integrated Railway.* Ed. John R. Wilson, Beverley Norris, Theresa Clarke & Ann Mills. Burlington: Ashgate Publishing.182-188 .

Monaco, K., & Williams, E. (2000). *Assessing the determinants of safety in the truck industry*. Journal of Transportation and Statistics, 3, 69-80.

Morlok, E., Nitzberg, B., & Lai, L. (2004). *Boarding and alighting injury experience with different station platform and car entranceway designs on US commuter railroads.* Accident Analysis and Prevention, 36, 261-271

Marten, Felix A. Jr. (2010). *Reliability centered maintenance: A case study of railway transit maintenance to achieve optimal performance.* San Jose, CA: Mineta Transportation Institute.

Middleton, William D. (2003) *Metropolitan Railways: Rapid Transit in America.* Bloomington, IN: Indiana University Press.

Nelson, David O. and Adamson E. Streit. (2011). “Rail Transit Safety: A Real Difference Between Cities?” *Transportation Research Record: Journal of the Transportation Research Board,* 22.19:42-49. Print.

Ogden, B.D. &Korve Engineering, a Division of DMJM+Harris(2007). *Railroad-Highway Grade Crossing Handbook - Revised Second Edition 2007*. Washington, DC: Federal Highway Administration.

Pasquini A., A. Rizzo, L. Save. (2004). *“A methodology for the analysis of SPAD.”* Safety Science, 42.5:437–455.

Petridou, Eleni, & Maria Moustaki. (2000)“*Human factors in the causation of road traffic crashes*.”European Journal of Epidemiology, 16: 819-826.

Reason, James. (1998). “Achieving a safety culture: theory and practice” *Work & Stress,* 12.3: 293-306.

Rodriguez, D., Rocha, M., Khattack, A., & Belzer, M. (2003). *Effects of truck driver wages and working conditions on highway safety: Case study*. Transportation Research Record: Journal of the Transportation Research Board, 1833, 95- 102.

Rodriguez, D.A., Targa, F., & Belzer, M.H. (2006). *Pay incentives and truck driver safety: A case study*. Industrial and Labor Relations Review, 59 (2), 205-225.

Rossetti, M.A. (2002).Potential Impacts of Climate Change on Railroads. In:*The Potential Impacts of Climate Change on Transportation: Workshop Summary*, U.S. Department of Transportation, Workshop, 1-2 October, 2002.

Rossetti, M.A. (n.d.). *Analysis of Weather Events on US Railroads.*Cambridge, MA: Volpe National Transportation System Center.

Shankar VN, Chayanan S, Sittikariya S, Shyu MB, Juvva NK, Milton JC.(2010). *Marginal impacts of design, traffic, weather, and related interactions on roadside crashes.* Transportation Research Record: Journal of the Transportation Research Board, No. 1897. 2004:156–163.

Thompson, Gregory L. "Defining an alternative future: Birth of the light rail movement in North America." *Transportation Research E-Circular*, E-C058 (2003): 25-36. Available from: http://onlinepubs.trb.org/onlinepubs/circulars/ec058/03_01_Thompson.pdf [Accessed 8 October 2012]

Wael Ekeila, Research Assistant, University of British Columbia, Development of a Dynamic Transit Signal Priority Strategy. Available from: www.tac-atc.ca/english/resourcecentre/readingroom/conference/conf2009/pdf/Ekeila.pdf [Accessed 8 October 2012]

Wahlberg, A. (2007). *Effects of passengers on bus driver celebration behavior and incident prediction*. Journal of Safety Research, 38, 9-15.

Wilson, John R., & Beverley J. Norris. (2006). "Human factors in support of a successful railway: a review." *Cognition Technology & Work*, 8: 4-14.