ABSTRACT

PROBABILITY OF A HAZARDOUS MATERIAL TRUCK ACCIDENT IN NEW JERSEY

by
Mahesh Damodaran

Accident prediction modeling is a powerful tool for determining the frequency of accidents under certain circumstances. Nationwide, direct damages from highway hazardous material spills for the year 2000 were tallied at over $31billion. This thesis determines the probability of an accident involving hazardous materials on the roads of New Jersey. The methodology is based on a British predictive equation used by their Highways Agency to determine the probability of a hazardous spill over a section of a roadway. The parameters used by the British's Highways Agency, which is obtained from their accident data, were modified to reflect conditions that best fit the State of New Jersey.

Using the probability calculated from this method, the recurrence interval is determined. The recurrence interval represents the number of years it would take before a hazardous material accident would occur. Based on the recurrence interval, segments with higher chances of accidents involving hazardous materials are identified. Thus, by identifying the danger-prone segments, best suited engineering solutions that could be applied to those segments to either arrest spills due to such accidents, or divert them to appropriate places can be made available. This approach would not only benefit the environment efficiently, but would also create fewer disturbances to the public during any hazardous material truck accident.

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This thesis is dedicated to my beloved
Parents, Brothers, Teachers and Friends

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CHAPTER 1

INTRODUCTION

1.1 Overview

Accident prediction modeling is a powerful tool for determining the frequency of accidents under certain circumstances. This thesis determines the probability of an accident involving hazardous materials on the roads of New Jersey. The methodology is based on a British predictive equation used by their Highways Agency to determine the probability of a spill over a section of a roadway.

There is a strong relationship between the Nation's economy and travel on the Nation's highway system. Since the 1930s, growth in the Gross National Product (GNP) and vehicle-miles of travel (VMT) reflect strikingly similar patterns (with the exception of the World War II years). According to the Federal Highway Authority (FHWA), in the year 2000 there were about 2731 billion vehicle miles traveled on the United States highways and there were 220 million vehicles registered in the nation. Of these, truck miles alone contribute to about 200 million vehicle miles on highways with only about 8 million trucks registered. Passenger cars and other vehicles (excluding trucks), on average, only travel 12,000 miles per vehicle per year, whereas trucks travel over 25,000 miles per truck per year.

A significant percentage of the truck miles traveled involve hazardous materials (HAZMAT). According to the Research and Special Programs Administration (RSPA) Office of HAZMAT Safety, annually there are at least 300 million domestic shipments of hazardous materials in the United States. The United States Department of Transportation

(USDOT) currently lists approximately 3,000 shipping descriptions for various hazardous materials such as poisons, chemicals, pesticides, radioactive materials, explosives, oil, and gasoline. Ninety-four percent of hazardous materials shipments are moved by truck; five percent by air; and less than one percent by rail, water, and pipeline. Over 3.2 billion tons of hazardous materials, are shipped annually in domestic commerce. There are about 200,000 dedicated HAZMAT trucks and about 6.5 million of them are potential HAZMAT carrying trucks in the United States.

Spills of hazardous materials on our nation's highways create disturbances to the driving public, threaten surrounding communities, and degrade the environment. The USDOT Hazardous Materials Safety figures show that the number of such incidents has been increasing about ten percent a year since 1992, with an overall increase of almost 92% for the decade (HAZMAT). Ninety percent of all transportation related spills of hazardous materials in the United States occur on the highways. In 1993 there were about 11,080 highway incidents reported. However, in the year 2001, there were about 15,398 incidents involving hazardous materials on the highways. Of these, there were 343 incidents in New Jersey and accounted for $1,383,308 in direct costs alone. Nationwide direct damages from highway spills for the year 2000 were tallied at over $31billion. These costs do not include commuter costs, irreparable damage done to the environment, and the economic damage done to the neighborhood. New Jersey, because of its great industrial activity, proximity to major metropolitan areas and major and important ports in the east coast, has the most heavily traveled highways.

1.2 Research Motivation

Due to the increasing number of hazardous truck accidents in the State of New Jersey, it has become necessary to take proactive measures to eliminate and to mitigate the impacts of such accidents. The most widely accepted risk-assessment model for identifying preferred routes for hazardous materials (HAZMAT) transportation is presented in the U.S. Department of Transportation (DOT) guidelines. This model was first presented in the 1980 Federal Highway Administration (FHWA) publication "Guidelines for Applying Criteria to Designate Routes for Transporting Hazardous Materials" (Barber and Hildebrand 1980). The latest updated version is Criteria for Highway Routing of Hazardous Materials (Shaver and Kaiser 1998). However, the data obtained by the DOT comes from a federal database, which does not include accidents on state and local roadways. In spite of planning to avoid occurrence of hazardous materials accidents, accidents involving hazardous materials will continue to occur. The above reasons urge us to develop accident prediction models that could, approximately, predict the potential of accidents.

The prediction model developed in this research is simple and could be used to approximately determine the chance or probability of a hazardous material spill over a segment of a road. Depending on the probability over the segment, appropriate preventive or mitigative measures could then be taken. Given the probability, mitigative measures could be taken for a given roadway segment to reduce the potential for invaluable damage that would otherwise be incurred on the environment. So far, very little has been done to contain hazardous materials on the highways and before they are discharged to a watercourse, wetland or a detention basin, which is the usual course of storm water from the highways. The model would best fit in the State of New Jersey, since it was developed based on the accident statistics of the state.

1.3 Problem Statement

Unfortunately, due to hazardous material accidents, millions of dollars are lost due to clean up costs, construction costs, commuter costs, environmental damage and non-user costs. There are a number of engineering solutions available to either arrest these spills or to divert them to appropriate places. However, the problem has been in identifying the places best suited for each system based on economic conditions. A unique solution cannot be applied to all the segments of the highway. Even if it were applied the cost-benefit ratio would be much higher than 1.0, which means that the cost incurred would be more than the cost of such accidents. Hence, it is increasingly necessary to develop an accident prediction model, which could calculate the probability of a hazardous material accident over a segment of roadway. Most models developed to predict accidents in highways do not specify the probability of an accident over a given segment of the roadway. If the probability of an accident over a given segment is calculated, then an appropriate solution could be applied to reduce the impacts of a hazardous material truck accident. Hence, a general model with the flexibility of being able to apply to any stretch of roadway has to be developed. Therefore, based on the accident probability the most appropriate proactive step could be taken to mitigate the damage caused by any such devastating accidents in the future. The important problems encountered while developing this model were choosing the accident database to determine the number of accidents in New Jersey, the base and scale factors that have to be used while determining the truck miles traveled, and how an accident involving multiple trucks should be taken into account. The following chapters illustrate how the problems were approached.

1.4 Research Objectives

The objective of this thesis is to provide a modified British predictive equation, used to predict the probability of a serious accidental spillage, into one, which best fits, the State of New Jersey. The objective is accomplished by changing the parameters used by the British's Highways Agency, which is obtained from their accident data, into parameters obtained from New Jersey's recent accident data. The modified approach was also tested on various roadway segments to validate the ability of the model to determine the occurrence of a serious accidental spillage.

1.5 Research Outline

Chapter 2 discusses the research performed by various authors in this area of study or related area of study is discussed. It describes the various problems encountered while developing this model and how they are solved using solutions from other authors. Chapter 3 describes the methodology used in this study and also the methodology used by the British Highways Agency. Chapter 4 analyzes the model for various roadways of different functional classifications. It also demonstrates how the British Highways Agency had used the model to predict the probability of a hazardous material truck accident for existing and proposed roadways in England. Chapter 5 describes the conclusions made from the study and how the study could be further expanded to obtain a more accurate prediction model.

1.5 Summary

The chapter provides an overview of truck travel and hazardous material accidents experience for the nation. The number of trucks traveled in the nation's highways, the percentage of trucks carrying hazardous materials, the number of accidents involving hazardous materials are provided in the chapter. It cites the amount of money and material wasted due to such accidents every year. It also describes the necessity to prevent these accidents or at least provide mitigative measures to reduce the impact of such accidents to the environment. It outlines the hazardous material accident prediction model used by the federal agency and the necessity to provide a prediction equation that could approximately predict the potential occurrence of accidents. It later describes the objective of this thesis and what initiated this study. It finally describes the outline of this research.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The literature review is a survey of material addressing the existing models used to predict hazardous material accidents, truck accidents and review of other materials that helped to solve different technical problems encountered. The relative merits and demerits of different models are also discussed. The review starts with a report presented by Luke to the Research and Technology Division of the New Jersey Department of Transportation (Luke 2002). Since the model developed is similar to the British methodology of calculating spillage risks, enough time is devoted to its discussion. Then the various literature sources relevant to the work performed in this research are discussed. Finally, the models that were developed by different authors are then reviewed and described.

2.2 Background

The New Jersey Institute of Technology (NJIT) conducted a research project *Contaminant Arresting Systems* for the Research and Technology Division of the New Jersey Department of Transportation (NJDOT) to research the potential impacts of a truck accident involving spills (Luke 2002). One of the recommendations of the study was to provide an innovative method for detecting spills of hazardous materials, resulting from a highway accident, on umbrella sections of the highway, like the shoulders, and nearby landscapes. Also, the report recommended the need for a proactive measure to prevent or divert such spills before a potentially hazardous accident occurs in a neighborhood that could not recover easily from its effect. The report referred to a recently occurred devastating accident in New Jersey, which pointed to the devastating impacts a hazardous accident could cause. The report refers to an accident, which took place on Interstate 80 between exits 38 and 39 in Denville, NJ. A truck carrying 9000 gallons of gasoline spilled the entire load on the highway causing a fire to break out and destroying the tanker and two other trucks. To add to the severity, the burning gasoline flowed through the storm drains and later into the Denn Brook, which flowed under the roadway. The fire damaged the bridge over the brook, which was later replaced with a temporary one for a cost of $10 million. The user costs were estimated to be in the neighborhood of $35 million before a permanent bridge could be constructed.

The report describes that even with the immediate arrival of the firefighters to the accident location, a large amount of damage was done to the environment. Thus, had a proactive measure been taken at this location to prevent the flow of spilled material, a significant amount of damage could have been averted. The report suggests various measures that could be taken to stop or divert such a hazardous spill. The following methods were identified and discussed in the report:

1. Storm Drain Filters
2. Oil/ Water Separators
3. Swirl or Vortex Concentrators
4. Flow Balancing or Under Water Detention
5. Valves

6. StreamSaver
7. Interface with Intelligent Transportation Systems
8. Fiber Optic Technology to detect spills on Umbrella Section
9. Satellite relay of Sensor detection

However, due to various constraints only one or a combination of the above systems could be used to detect and respond to the spill. Thus, it was important to be able to predict a hazardous spill on New Jersey's roadways, so that the installation of these systems could be based on a credible methodological approach.

2.3 British Predictive Model

As part of the NJDOT study, the research team contacted various state and international agencies to find out if any contaminant arresting systems had been installed or if this problem was given significant importance. The research team found that due to the growing environmental concerns about construction and operation of roadways in England, the British Highways Agency had developed a guidance manual on the environment assessment of trunk roads including motorways. The manual describes guidance on methods for the assessment of the impact on the environment due to runoff from roads The manual also provides advice on the mitigation measures that may be used to reduce the impact of pollution from runoff, where it is found to be required.

One of the methods described was to calculate the probability that a spillage will cause a pollution incident. As part of this procedure, it was also necessary to calculate the probability of a serious accidental spillage. The serious accidental spillage is calculated using the road length, the serious spillage rates, annual average daily traffic and the percentage of heavy goods vehicles. The spillage rates are calculated from the historic data by dividing the total number of accidents involving spills in each type of junction by the vehicle miles traveled in terms of million heavy good vehicle kilometers per year.

In order to determine the probability that a spillage will pass through the drains, thereby causing a pollution incident in receiving waters, a formula involving serious spillage rates, risk reduction factor and the vehicle miles traveled by heavy vehicles is derived. However, the model only holds for Britain. Since the accidental spillage rates in the British model are calculated from the statistics of England, the same rates cannot be applied to obtain the probability of a serious accidental spillage for the State of New Jersey.

The serious accidental spillage rates in the British model expressed were as rate per million heavy good vehicle kilometers per year. The rates have been developed depending on the proximity to an intersection or a junction. Also, the rates have been developed based on the classification of the roadway and the type of junction or intersection being analyzed. The following chapters discuss the method in which the British Predictive Equation is converted to fit the American Standards or more appropriately to fit the State of New Jersey.

Based on the probability of a serious pollution incident occurring, the agency concludes if a containment facility is required. If it were found out that a facility is needed, then the agency would decide upon the suitable type of control facility to be installed. The facilities may include a simple single storm drain filter or a combined approach. Depending on the feasibility of land acquisition, bypass oil water separators can also be used with isolation valves in each outfall.

The manual recommends that if the spillage risk assessment is less than once in 100 years, then containment or control facilities are needed to prevent pollution arising from accidents on the road. It also recommends that it is usually not necessary to conduct any further investigation of risk indicating how strongly the agency considers the validity of the model.

2.4 Spillage Rates

Spillage rates were calculated for New Jersey based on the British Predictive Equation. The spillage rates were higher than those used in the British Model. The rates were calculated as accidents per million heavy goods vehicle miles per year. However, the most common American way of computing highway section accident rates is in terms of accidents per 100 million vehicle miles using the formula

$$\mathrm{RSEC} = \frac{100{,}000{,}000 \times \mathrm{A}}{365 \times \mathrm{T} \times \mathrm{V} \times \mathrm{L}} \qquad (2.1)$$

where,
RSEC = accident rate for the section, accidents per 100 million vehicle miles
A = number of reported accidents, accidents
T = time frame of the analysis, years
V = AADT, vehicles
L = length of the section, miles

Also, most of the federal agencies like the USDOT and FHWA represent the accident rates per 100 million vehicle miles. However, since the NJDOT calculates the accidents per million vehicle miles traveled, the same unit was used to represent the accident rates.

An accident prediction model is essential to determine the probability of an accident in any location. Thus, by determining the return period of an accident at any location, the appropriate systems could be installed. This method would be more practical and cost effective.

2.5 Other Prediction Models

2.5.1 Database Selection

In order to decide upon which source of data to be used in order to determine the rates, work performed by Hobeika et al. (1993) was referred. He involved a detail comparison of three databases, the Research and Special Programs Administration's (RSPA), hazardous material incident reports (HMIR), the Bureau of Motor Carrier Safety's (BMCS) truck accident database, and the accident database used at the state level by the Pennsylvania Department of Transportation (PennDOT). The study compares the BMCS and HMIR Databases, and then the BMCS and PennDOT Databases. The study concluded that it is better to rely on state level database for the analysis of HAZMAT accidents or incidents, since they report both interstate and intrastate HAZMAT transportation accidents. Even though the state database had a different approach in recording the accidents than other federal databases, it was reasonable to accept the fact that most states would include all the accidents occurred in the state involving hazardous materials in their database irrespective of the location of the accidents. Also, the conclusion included that the high quantity spills as a result of vehicular accidents produce the most fatalities and damages on highways, and are of great concern to the public and the responsible authorities. The study clearly explains the need for a state level reporting database, which is totally acceptable. Since the roadway network consists of all interstates, highways, arterials and collector roads, it is very important to obtain data from the state database, which would have more information and be more accurate.

2.5.2 Emprical Bayes Model

David et al. (1995) in their study described an empirical Bayes procedure for obtaining reliable accident rate estimates through use of an optimal compromise between the aggregate and the segment specific estimation methods. The aggregate method is one in which accident data from all available road segments are pooled, and the segment specific method is one in which separate accident rate estimates are obtained for each road segment. The segment specific historical rate method uses truck accident and truck traffic volume history of only the segment being analyzed. The advantage of such specificity is clear when the broad objective is to avoid routing trucks on roadways with high accident rates. This method is in sharp contrast to generic highway class models that aggregate similar information across large classes of highway types. These are very often state or national averages. Such aggregations are advantageous when little accident history is available. The researchers have applied the model to accident data from a regional network in northeast Ohio. The authors conclude that an empirical Bayes methodology strikes a balance between the aggregate and disaggregate methods and yet maintains continuity between the two estimation philosophies, whereby they had gained the advantages of each while minimizing their drawbacks. The paper clearly indicates that statewide data would be the best to formulate or apply to any model.

2.5.3 Truck Involvement

The literature review raised a question about whether the accident rates should be calculated by including the total number of trucks involved in the accident or just including the total number of accidents. Mohamedshah et al. (1992) had developed models for truck accidents on interstates and two lane rural roads using data obtained from the Highway Safety Information Systems which contained accident, roadway and traffic data. The principal objective of the paper was to identify the roadway variables that affect truck accidents and to develop mathematical models of their relationships. The authors found that the previous researchers calculated the truck accident rates by considering a truck accident as an accident involving at least one truck. The truck accident rate is determined by dividing the total number of truck accidents by truck annual daily traffic (ADT), resulting in artificially high truck accident rates because we are basically only concerned about the accidents involving trucks and not the number of trucks involved. The reason behind this is that multivehicle accidents involving trucks and nontrucks are only counted as truck accidents. Thus, the true rates are obtained by adding the total number of trucks involved in an accident divided by truck ADT. However, the number of trucks involving hazardous material is much less compared to the number of accidents involving trucks. Moreover, since the British model does not consider the truck involvement rate instead it only considered accidents involving trucks the theory developed by the authors is not considered valid for this study. Also when the accident data obtained from the NJDOT showed very few accidents involving two hazardous material trucks in the accident.

2.5.4 Poisson Distribution Model:

Menzie et al. (1979) approached estimating probabilities of transportation related spills of hazardous materials by first determining the accident rates for appropriate modes of transportation and then determining the fraction of accidents that result in spills using Poisson distribution. The author's objectives were almost the same as this thesis, hence the model is analyzed and described. The limitations of this model are also discussed. Since much data were not available, he collected the spill statistics for a chemical plant and estimated its probability. The author classifies each type of chemicals transported and their mode of transportation. He then determines the length of the route in which the raw materials or final products are transported and estimates the annual miles the materials are transported. Then based on the accident rate for each mode of transportation and the percentage of transportation related accidents resulting in spills causing more than $100 in property damage, both obtained from the USDOT, the author calculates the probability of transportation related spills of chemicals associated with operation of the hypothetical plant using Poisson distribution. The probability of a spill within a year, one or more spills in the lifetime of the plant and the most probable number of spills in its lifetime are also calculated.

The author estimates the probability based on the nationwide accident and spill rates, which does not guarantee to calculate the most accurate spill probability for the area under consideration. Since the statistics were obtained during a short duration and due to lack of knowledge of reporting spills, the accuracy of the data used could not be validated.

2.5.5 Hazmat Routing

Harwood et al. (1993) developed truck accident rates to assess risks in HAZMAT routing. The author's conclusions reinstate the fact that state accident database would produce more accurate results than the federal database. He studied the accident rates as a function of roadway type and area type (urban/rural) from the state data on highway geometrics, traffic volume and accidents. The study describes the procedure for developing truck accident rates and HAZMAT release probabilities for HAZMAT routing. The procedure is similar to the procedure used in this thesis. The study assesses the risk determined by the USDOT, which is given as;

$$\text{Risk} = \text{Accident Probability X Accident Consequences} \qquad (2.2)$$

The study suggests that the model has several weaknesses, which include factors like, incident rate, accident rate, and likeliness of a hazardous material accident. The study also compared the accident rates obtained from three state databases: California, Michigan and Illinois, categorized by rural and urban area and different types of roadway. The accident rates for each state were found to be different in every category. The authors show how the grouping accident rates of different states could change the accident rate. The study strongly encourages performing HAZMAT risk analyses to develop default accident rates from data obtained from the state for which the accident rate is determined. The accident rates were represented in accidents per million vehicle-kilometers, thus, justifying the accident rate to be used as discussed in previous sections.

The study also computed the HAZMAT release probabilities. The procedure used is similar to the British Methodology. The authors suggested that all accidents involving trucks carrying HAZMAT do not result in a spill. Therefore, they obtained the probability of release from the FHWA motor carrier accident reports, calculated by dividing the number of accidents involving HAZMAT spills by the total number of accidents involving hazardous material trucks. They finally revise the equation (2) to find out the risk probability more accurately. Finally, to choose the preferred HAZMAT transportation route, the authors also used a Chi-squared analysis to determine whether the accident frequency is sufficiently larger or smaller than the expected accident frequency to warrant replacement of the default truck accident rates by site-specific rates based on accident histories.

2.5.6 Network Routing

Kessler (1986) established a risk assessment model to determine the low risk route for transporting hazardous materials through the Dallas-Fort Worth area. A network of freeway segments were connected to identify the minimum risk route to transport HAZMAT so that any unexpected accident would cause little impact to the surrounding environment. The main objective of the selected route was to reduce the potential exposure of individuals to an accidental release of hazardous materials transported on public roadways. The study calculated the accident probability based on the FHWA guidelines. Using the following formula, the probability of an accident in a segment is calculated as:

$$\text{Probability of an accident on a given Segment} = \frac{\text{Annual number of truck accidents}}{(\text{Annual number of vehicles} \times \text{link length})} \quad (2.3)$$

FHWA recommends that the probability of a hazardous material accident could then be determined by multiplying the accident probability by 2.3 x 10^{-5}. This factor is based on the national ratio of hazardous materials accidents to all vehicle accidents for 1973 through 1978. However, the author does not use this factor. Instead the accident consequence rate, obtained by multiplying the population and total employment within 2 miles of the freeway segment with the length of the link segment, is used to determine the risk. The accident consequence rate is similar to the vehicle miles of travel in the accident probability equation. Then the total risk is calculated as,

Total Risk = Accident Probability x Sum of population and employment exposure miles

The total risk for each freeway segment is calculated and then the risks for each network are calculated. Comparing minimum risk paths and minimum travel distance paths, a performance report is generated. The ideal measure of this comparison is for a cost-benefit analysis based on dollar value, that is, for the amount of time and money consumed for a specific path, what are its benefits compared to other routes. After evaluating the cost benefit ratio, the best routes are selected which have a balance between risk and cost.

2.6 Summary

The chapter describes the background for initiating this theses and how this topic was important for protecting the environment. It explains the development of the theses from the British predictive model used in determining the probability of a serious accidental spillage in England. It later describes the spillage rate to be used in this thesis that is also used by the NJDOT. It later explains the various models that have already been developed and then cites some of their advantages and disadvantages. The chapter also describes how the various parameters in the equation thesis were considered.

CHAPTER 3

METHODOLOGY

As mentioned in the previous chapters, the thesis is based on the British predictive model hence the methodology is also similar to the ones used by the British Highways Agency. This chapter includes two sections, the first one explaining the steps and tables used by the Agency, and the second one describes the methodology used in this thesis for analysis.

3.1 British Methodology

The British methodology involves determining the probability of a serious accidental spillage calculated using the following equation:

$$P_{acc} = RL \times SS \times \ (AADT \times 365 \times 10^{-6}) \times (\%HGV \div 100) \tag{3.1}$$

Where:

P_{acc} = Probability of a serious accidental spillage in one year over a given road length

RL = Road Length in Kilometers

SS = Serious Spillage rates obtained from Table 3.1

AADT =Annual Average Daily Traffic

% HGV = Percentage of Heavy Goods Vehicles

This probability is then used in determining the probability that a spillage would cause serious pollution incident.

Table 3.1, obtained from the *Design Manual for Roads and Bridges,* tabulates the spillage rates for different roadways and for varying types of junctions. The rates are expressed in million heavy goods vehicles kilometers per year.

Table 3.1 Serious Spillages Rates

JUNCTION TYPE	MOTORWAY		ALL PURPOSE	
	URBAN	RURAL	URBAN	RURAL
No Junction	0.0022	0.0014	0.0039	0.0017
Slip Road*	0.0032	0.0023	0.0058	0.0035
Side Road*	N/A	N/A	0.0106	0.0042
Roundabout*	N/A	N/A	0.0296	0.0119
Cross Road*	N/A	N/A	0.0159	0.0044
Overall	0.0024	0.0019	0.0075	0.0025

Note: * Risk factor applies to all road lengths within 100 m of these junction types, that is for a side road joining an All Purpose Road the risk is 0.0106 for 100 m of the side road and for a 200 m length of the All Purpose Road centered on the junction itself.

3.1.1 Description of Terms

The following are descriptions of the terms used to determine the probability of a serious accidental spillage,

- The term "**no junction**" is referred when the segment of roadway under consideration is without any ramps or intersections.
- A "**slip road**" joins the carriageway at a very shallow angle; traffic on the slip road ideally matches its speed to that on the main carriageway and joins the traffic by merging into a gap. In other words, a slip road may also be described as an accelerating lane merging onto a freeway.

- A "**side road**" is where a lesser road joins an all purpose road more or Less at right angles at a T-junction and traffic has to give way to traffic on the main road. Traffic on the side road will come to a stop or reduce to a very low speed before turning into the main road during a gap in traffic and then accelerating.
- A "**cross road**" describes an intersection with four or more approaches.
- The term "**road length**" is used to describe length of the roadway segment under consideration.
- The "**serious spillage rates**" are obtained by dividing the total number of accidents involving spills by the total number of heavy good vehicle kilometers traveled per year.
- "**AADT**" is the Annual Average Daily Traffic for the segment of the roadway under consideration.
- "**%HGV**" is obtained by dividing the total number of heavy goods vehicles by the total number of vehicles in the segment.
- A "**Motorway**" is the same as a freeway except that the number of lanes may not be as much as some freeways have.
- "**All purpose**" roadways include all types of roadways excluding motorways.

3.1.2 Procedure

The following steps explain the procedure used in this study to determine the probability of a serious accidental spillage:

1. First, the total length of the roadway, for which the probability is to be calculated, is determined.

2. Based on the type of roadway and type of segment being analyzed, the appropriate serious spillage rates are obtained from Table 3.1.
3. The two-way AADT of the segment is determined.
4. From traffic counts data, the percentage of heavy goods vehicle is obtained.
5. The above data are then substituted in Equation 3.1 to determine the Probability of Serious Accidental Spillages.

3.2. Theses Methodology

As explained in the literature review, since the British rates could not be used to determine the probability of an accident in United States separate rates have to be calculated and substituted. To obtain the spillage rates, the first step is to determine the number of hazardous materials accidents from accident data. The state specific accident data would be more accurate and detailed, than any data obtained from any federal agency. Also, since statewide data includes all the accidents in the State, the New Jersey Department of Transportation's accident database is used. The database was generated based on police accident reports. Accident data between 1997 and 2000 were used to determine the number of hazardous accidents in the state. The accidents were summarized based on the functional classification of the roadway, obtained from the Straight Line Diagrams, at which each accident took place. They were categorized as Interstate and Highway accidents. The Highway accidents included both US route and State Highways in New Jersey. Then the accidents were classified based on the location, i.e., Urban or Rural. Table 3.2 summarizes the total number of accidents for each category.

Table 3.2 Number of Hazardous Material Truck Accidents

Number of Accidents	**Urban**	**Rural**
Interstates	64	16
Highways	146	25
Total	**210**	**41**

The Annual Average Daily Traffic (AADT) for each type of routes obtained from the NJDOT's Straight Line Diagrams. The AADT is to calculate the probability of an HAZMAT accident. Since only trucks carry hazardous materials, truck percentages are considered the same as percentage of heavy vehicles, which is used in the British equation. Table 3.3 lists the percentage of trucks by roadway functional classification, obtained from the NJDOT on each type of roadway. Since there is a negligible number of hazardous material truck accidents on local and collector streets, and also since the roadway mileage they contribute to the US and State routes were very small, these roadway types were not included while calculating the percentage of trucks for the highway category.

Table 3.4 shows the truck million miles traveled for different functional classifications of roadways in New Jersey. The truck million miles traveled on rural principal and minor arterials are added together to obtain the total truck million miles traveled in the rural highway category. Similarly the truck million miles traveled on the urban freeways, principal and minor arterials are added to obtain the total truck million miles traveled in urban Highway category. The percentages of trucks for the highway category are calculated as follows:

$$\text{Truck Percentage} = \frac{\text{Truck Million Vehicle Miles Traveled x } 100 \text{ x } 10^6}{\text{Daily Vehicle Miles Traveled}} \quad (3.2)$$

Table 3.3 Percentage of Trucks

Functional Classification	**Percentage Trucks**
Rural Interstate	15.67
Rural Other Principal Arterial	9.19
Rural Minor Arterial	3.85
Rural Minor Collector	5.42
Rural Major Collector	5.43
Rural Local	2.34
Urban Interstate	11.39
Urban Freeway & Expressway	10.06
Urban Other Principal Arterial	8.57
Urban Minor Arterial	4.83
Urban Collector	3.37
Urban Local	8.34

Table 3.4 Truck Million Miles Traveled

Functional Classification	**Truck Million Miles Traveled**
Rural Interstate	1.07
Rural Other Principal Arterial	1.13
Rural Minor Arterial	0.17
Rural Minor Collector	0.32
Rural Major Collector	0.09
Rural Local	0.15
Urban Interstate	3.14
Urban Freeway & Expressway	2.53
Urban Other Principal Arterial	3.23
Urban Minor Arterial	1.21
Urban Collector	0.35
Urban Local	1.74

Table 3.5 obtained from NJDOT, lists the daily Vehicle Miles Traveled in each type of roadway in New Jersey.

Table 3.5 Daily Vehicle Miles Traveled

Functional Classification	Daily Vehicle Miles Traveled
Rural Interstate	6,817,037
Rural Other Principal Arterial	12,278,727
Rural Minor Arterial	4,444,010
Rural Minor Collector	5,821,946
Rural Major Collector	1,713,428
Rural Local	6,328,577
Urban Interstate	27,598,015
Urban Freeway & Expressway	25,157,919
Urban Other Principal Arterial	37,675,982
Urban Minor Arterial	25,050,986
Urban Collector	10,230,042
Urban Local	20,916,589

Table 3.6 lists the percentage of trucks in each category of highway.

Table 3.6 General Percentage of Trucks

Percentage of Trucks	Urban	Rural
Interstates	11.39	15.67
Highways	7.93	7.77

Based on the number of accidents and the heavy goods vehicles million miles, the spillage rates are calculated as:

$$\text{Spillage Rate} = \frac{\text{No. of Accidents per year}}{\text{Truck Million Vehicle Miles} \times 365} \quad (3.3)$$

Table 3.7 lists the spillage rates calculated using the above equation.

Table 3.7 Spillage Rates

Percentage of Trucks	**Urban**	**Rural**
Interstates	0.014	0.010
Highways	0.014	0.013

The rates obtained when compared to the rates used by the British Highways Agency are significantly high. One of the main reasons is because of the units used. The Highways Agency have used kilometer to represent the length of the roadway or to describe the distance traveled by trucks. However, the methodology in this paper uses miles to represent the same. If the distances were measured in kilometers instead of miles then the rates would decrease by 1.609 times, since 1 mile equals 1.609 kilometers. This would reduce the rates considerably, but still the rates would be few times greater. Since various parameters like the AADT, percentage of trucks, and number of accidents control the value of the spillage rates, so further research need to be done to explain the difference in spillage rates.

The above variables, like the spillage rate, truck percentage and the AADT, are substituted in Equation 3.1 to obtain the probability of a hazardous material accident in a given section of a roadway. The following chapters explain how these variables are used to determine the probabilities for each category of highways.

3.3. Summary

The chapter describes the methodology used by the British Highways Agency to obtain the probability of a serious accidental spillage over a given section of a roadway. It later describes the methodology used in the thesis and how the various parameters, such as percentage of trucks, and AADT used in the predictive equation were obtained. Finally, it explains how the spillage rates, used in the equation, are derived.

CHAPTER 4

ANALYSIS

The chapter analyzes the probability of accidents on rural and urban Interstates and highways by substituting respective parameters used in the *Roadways Design Manual*, of the British Highways Agency, by appropriate values, obtained from the State of New Jersey's accident and traffic data. It also provides examples obtained from the *Roadways Design Manual* of the British Highways Agency. The chapter is divided into three sections: the first section analyzes the probability of an accident on each type of roadway for each of the functional classes; the second section shows examples from the Roadway Design Manual; and the third section analyzes entire length of three Interstates and three Highways in New Jersey showing how the probability changes for different sections of the same roadway.

The basic purpose of the analysis is to identify segments with higher chances or probability of accidents involving hazardous materials. Hence, by identifying the danger prone segments, based on the probability, the best suited engineering solution could be applied to those segments and arrest the spills due to such accidents or divert them to appropriate places.

4.1 General Examples

The following examples show how the probability of an accident in Interstates and Highways are calculated. In general, these examples consider certain segments of the Interstates/ Highways and determine the probability of an accident in that particular segment.

4.1.1 Interstates

Consider the segment of Interstate 80 between exits 38 and 39, i.e., between mileposts 38.81 and 39.57. The straight line diagram, obtained from the NJDOT website, shows an AADT of 130,700 vehicles in the year 2000. Since the truck percentages are not available in the straight line diagrams (SLD), they are obtained from Table 3.6. This section of the highway is functionally classified as an urban Interstate. Thus, referring to Table 3.6 the percentage of heavy goods vehicle is 11.39%. The section being analyzed is 0.76 miles long. The spillage rate for an Urban Interstate, obtained from Table 3.7, is 0.014. Therefore, substituting the above data in Equation 3.1 the probability of an accidental spillage in the given section of the highway is determined to be

$$P_{acc} = RL \times SS \times \ (AADT \times 365 \times 10^{-6}) \times (\%HGV \div 100) \tag{3.1}$$

$\text{Pacc} = 0.76 \text{ x } 0.014 \text{ x } (130700\text{x}365\text{x}10^{-6}) \text{ x } (11.39/100)$

$\therefore \text{Pacc} = 0.0578.$

Therefore, it could be explained that the probability of a serious accidental spillage in this segment is 0.0578 per year. Since the inverse of probability is the recurrence interval, it could also be concluded that the chance for a hazardous material accident to occur is 1 in 17 years for this 0.76 mile stretch. A recurrence interval of once in 17 years is mostly acceptable, but however the particular segment should be field inspected to decide whether hazardous material accident 1 in 17 years is acceptable, based on environment, at this location. The decision to accept or not to accept a recurrence interval depends on the location of the segment under consideration.

4.1.2 U.S. Highways

Similarly, consider US highway Route 1 between mileposts 41.0 and 42.0. There are four signalized intersections and two unsignalized intersections, however this theses only considers the functional class of highway. Since the highway is an urban principal arterial, the respective columns are referred in Tables 3.6 and 3.7 to obtain the %HGV and the spillage rates. They are found to be 7.93% and 0.014 respectively. The SLD's are referred for the assumed section and the AADT is obtained to be 82,014 in the year 1999. Substituting these values in Equation 3.1 the probability is obtained as shown below:

$\text{Pacc} = 1.0 \text{ x } 0.014 \text{ x } (82014\text{x}365\text{x}10^{-6}) \text{ x } (7.93/100)$

$\therefore \text{Pacc} = 0.0332.$

Thus, the probability of a serious accidental spillage in this segment is 0.0332 meaning that the chance of a serious accidental spillage to occur is 1 in 30 years. If this recurrence interval is acceptable, this segment need not be considered for any mitigation measures unless there are any serious environmental or social concerns.

4.2 Examples from Design Manual for Roads and Bridges

The following examples were obtained from the Roadways Design Manual of the British Highways Agency to demonstrate how an existing segment of a particular roadway and a proposed new roadway could be analyzed to determine the probability of a hazardous material truck accident in the segments under consideration. The examples shown are representative of British standards, however these examples could be used for further study in determining the probability of a hazardous material truck accident for a proposed roadway in New Jersey. Also these examples explain how an intersection or a junction needs to be analyzed, which are not analyzed in this study.

4.2.1 Existing No Junction Segment

A rural motorway of 3 km length having a two way AADT of 120,000 per year is to be analyzed. The motorway has a heavy goods vehicle percentage of ten percent. It is assumed that there are no junctions or intersections within the proximity of the roadway. With these data and referring to Table 3.1 for a rural motorway, the spillage rates are determined to be 0.0014. Substituting these values in Equation 3.1, the probability of serious accidental spillage is obtained as,

$P_{acc} = 3 \times 0.0014 \times (120000 \times 365 \times 10^{-6}) \times (10/100)$

$\therefore Pacc = 0.01839.$

4.2.2 New Roadway Segment with Junctions

A new 3 km long two-lane urban motorway with a two-way AADT flow of 18,000 and eight percent HGV is to be constructed. There are two ramps, one entering and another exiting the motorway, are located near the new scheme and measure 100 meters in length. Assume the AADT in the exit and entry ramps to be 2000 and 2500, respectively. The probability of serious accidental spillage is calculated as shown below:

For the new motorway more than 100 m away from ramp junctions, the probability is

$P_{acc} = (3 - 2 \text{ x} .01) \text{ x } 0.0022 \text{ x } (18000 \text{ x } 365 \text{ x } 10^{-6}) \text{ x } (8/100)$

$\therefore$ Pacc = 0.00324.

For the new motorway less than 100 m away from the ramp junctions, the probability is calculated as

$P_{acc} = (2 \text{ x} .01) \text{ x } 0.0032 \text{ x } (18000 \text{ x } 365 \text{ x } 10^{-6}) \text{ x } (8/100)$

$\therefore$ Pacc = 0.00034.

For the exit slip road

$P_{acc} = 0.01 \text{ x } 0.0032 \text{ x } (2000 \text{ x } 365 \text{ x } 10^{-6}) \text{ x } (8/100)$

$\therefore P_{acc} = 0.00002.$

For the entry slip road

$P_{acc} = 0.01 \text{ x } 0.0032 \text{ x } (2500 \text{ x } 365 \text{ x } 10^{-6}) \text{ x } (8/100)$

$\therefore P_{acc} = 0.00002.$

Therefore, the total risk of spillage for all new motorway and ramps combined is calculated as

$P_{acc} = (3.238 + 0.3364 \text{x} 0.01869 + 0.02336) \text{ x } 10^{-3}$

$\therefore P_{acc} = 0.00362.$

4.3 Across a Single Roadway

As described in the previous section, this section shows how the probability of an accident could vary across a roadway. Three Interstates and three highways, including one US highway and two State Highways, are considered to explain how the probability changes across the roadways. This section is subdivided into three sections: the first section shows how the probability is calculated for NJ Routes 34 and 46; the second section shows calculating the probability of US Route 1; the third section shows calculating the probability for Interstates 78, 80, and 287. For the Interstates, the segments are considered between exits, but for the Highways, the segments are considered based on the AADT. Since the AADT is not always available for shorter segments, it is assumed that the AADT remains the same throughout the entire segment and the segments are considered based on the position of important trip feeding intersections. Best judgments are made to make sure that these intersections do not affect the value of the probability to a greater extent. Due to lack of data, both the 1999 and 2000 year AADT's are used assuming that there would not be many discrepancies between the two year's data's. However, it is seen to the best that the year 2000's data is mostly used than 1999's data when both the data are available for the same station.

4.3.1 NJ Routes 34 and 46

NJ 34, which is an important connector between the Monmouth and the Middlesex counties, is referred as an example. The highway is 26.79 miles long and starts as an urban roadway and becomes a rural roadway for certain segments. The entire stretch of the highway changes its functional classifications eight times before it ends as an urban highway. Table 4.1 describes the probability of different segments considered and shows how the probability and the recurrence interval changes between different adjacent segments.

Table 4.1 Probability Table of NJ 34

#	Mile Post		Segment Length	AADT	Classifi -cation	Truck Percent age	Spillage Rates	Proba- bility	Probability per Mile
	Begin	End							
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1	0	0.33	0.33	35,600	Urban	7.93	0.014	0.005	0.014
2	0.33	0.71	0.38	35,600	Rural	7.771	0.013	0.005	0.013
3	0.71	0.95	0.24	35,600	Urban	7.93	0.014	0.003	0.014
4	0.95	1.97	1.02	35,291	Rural	7.771	0.013	0.013	0.013
5	1.97	2.63	0.66	35,291	Urban	7.93	0.014	0.009	0.014
6	2.63	4.77	2.14	35,291	Rural	7.771	0.013	0.028	0.013
7	4.77	8.76	3.99	23,788	Rural	7.771	0.013	0.035	0.009
8	8.76	18.75	9.99	20041	Rural	7.771	0.013	0.074	0.007
9	18.75	19.98	1.23	20041	Urban	7.93	0.014	0.010	0.008
10	19.98	20.44	0.46	20041	Rural	7.771	0.013	0.003	0.007
11	20.44	26.79	6.35	20041	Urban	7.93	0.014	0.052	0.008

Columns (1) through (9) have already been explained in the previous sections. Thus, even though the segments remain adjacent to one another the probability of spillage changes abruptly. Also, the example shows that the longer the segments being analyzed the higher are their probabilities. Column (10) is obtained by dividing the probability by the length of the segment considered, i.e., by dividing Column (9) by Column (4). Thus, Column describes the probability of a hazardous material accident per mile of that segment. This gives a better uniformity of results while comparing different segments than while comparing the probability of a hazardous material accident for a segment.

The highway has a recurrence interval ranging from once in 71 years to once in 142 years. It could be concluded that this highways does not need any mitigative measure.

Table 4.2 shows the probability of a hazardous material accident on Route 46 which is an important state highway connecting Warren and Bergen counties. The route changes its classification three times between rural and urban in the entire stretch.

Table 4.2 Probability Table of NJ 46

#	Mile Post		Segment Length	AADT	Classification	Truck Percentage	Spillage Rates	Probability	Probability per Mile
	Begin	End							
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1	0	9.82	9.82	10485	RURAL	7.771	0.013	0.04	0.00
2	9.82	15.19	5.37	4216	RURAL	7.771	0.013	0.01	0.00
3	15.19	20.63	5.44	9417	RURAL	7.771	0.013	0.02	0.00
4	20.63	21.83	1.2	16669	URBAN	7.93	0.014	0.01	0.01
5	21.83	25.51	3.68	16669	RURAL	7.771	0.013	0.02	0.01
6	25.51	27.78	2.27	16669	URBAN	7.93	0.014	0.02	0.01
7	27.78	30.57	2.79	13047	URBAN	7.93	0.014	0.02	0.01
8	30.57	40.3	9.73	47170	URBAN	7.93	0.014	0.19	0.02
9	40.3	47.76	7.46	30100	URBAN	7.93	0.014	0.09	0.01
10	47.76	54.48	6.72	44910	URBAN	7.93	0.014	0.12	0.02
11	54.48	60.45	5.97	134594	URBAN	7.93	0.014	0.33	0.05
12	60.45	72.09	11.64	43576	URBAN	7.93	0.014	0.21	0.02

The recurrence interval for this highway is between 1 in 20 years to over 1 in 100 years. Except for segment 11, which has the highest probability, whereas other segments have very less probability, hence other segments need not be considered to provide any mitigating measures. Based on the environment nearby, segment 11 could be analyzed and verified if it would be worth to provide any mitigative measures to this segment.

4.3.2 US Route 1

Route 1 is an important highway in New Jersey as it runs across the state from West to East. The entire stretch of highway is classified as an urban roadway. However, this is a very good example to understand how the probability could vary even if the classification remains the same. Table 4.3 describes the probability of a hazardous material accident in various segments along US route 1.

Table 4.3 Probability Table of US 1

#	Mile Post		Segment Length	AADT	Classification	Truck %	Spillage Rates	Proba bility	Probability per Mile
	Begin	End							
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1	0	0.9	0.9	49,300	URBAN	7.93	0.014	0.02	0.02
2	0.9	10.86	9.96	59,800	URBAN	7.93	0.014	0.24	0.02
3	10.86	16.96	6.1	51,995	URBAN	7.93	0.014	0.13	0.02
4	16.96	19.52	2.56	52,860	URBAN	7.93	0.014	0.05	0.02
5	19.52	21.38	1.86	50,338	URBAN	7.93	0.014	0.04	0.02
6	21.38	24.15	2.77	57,698	URBAN	7.93	0.014	0.06	0.02
7	24.15	26.39	2.24	92,600	URBAN	7.93	0.014	0.08	0.04
8	26.39	29.88	3.49	79,994	URBAN	7.93	0.014	0.11	0.03
9	29.88	34.06	4.18	66,116	URBAN	7.93	0.014	0.11	0.07
10	34.06	35.89	1.83	49,788	URBAN	7.93	0.014	0.04	0.02
11	35.89	41.06	5.17	58,420	URBAN	7.93	0.014	0.12	0.02
12	41.06	45.44	4.38	82,014	URBAN	7.93	0.014	0.15	0.03
13	45.44	49.55	4.11	126,448	URBAN	7.93	0.014	0.21	0.05
14	49.55	54.67	5.12	100,352	URBAN	7.93	0.014	0.21	0.04
15	54.67	56.24	1.57	51,700	URBAN	7.93	0.014	0.03	0.02
16	56.24	59.03	2.79	29,579	URBAN	7.93	0.014	0.03	0.01
17	59.03	62.71	3.68	36,588	URBAN	7.93	0.014	0.05	0.02
18	62.71	64.88	2.17	60,093	URBAN	7.93	0.014	0.05	0.02

As long as the AADT are approximately the same, the probability per mile does not change. However, when the AADT per mile increases abruptly the probability per mile changes accordingly as it could be seen in segments 6 through 10. Hence, it could be determined that AADT controls most part of the probability equation. The greater the AADT per given mile of roadway, higher the probability of a serious hazardous material accident. The recurrence interval for this highway is between 1 in 14 years to over 1 in 100 years. Except segments 9 and 13, other segments need not be considered to provide any mitigating measures. Based on the environment nearby, segments 9 and 13 could be analyzed before providing any mitigating measures.

4.3.3 Interstates 78, 80, 287

Interstate 80 is one of the more important routes connecting many routes and locations in the state. It runs between Warren and Bergen counties. The accident data collection revealed that there were three hazardous material truck accidents in the last four years near the exits 38 and 39. Thus, this interstate was chosen to analyze and determine the probability of a hazardous material accident. The Table 4.4 shows the calculated probability for Interstate 80 in New Jersey.

Exits 38 and 39, where the serious spill occurred in the year 2000, are at Mileposts 38.81 and 39.57 respectively. When referred to Table 4.4, the probability of a hazardous material accident is about 0.08, meaning that the chance of an accident is once in every 12 ½ years. This is the maximum recurrence interval for the entire length of the interstate. There are six segments of the roadway with the same recurrence interval. The same type of mitigative measures need be taken for all the segments. For segments with high environmental or geographical concerns, better mitigative measures like Streamsaver, an automatic detection system, could be installed which would automatically detect the presence of oil or hazardous material and shut off the valve in the storm drains so that the spilled material would be contained in a specific location and thereby preventing damage to the neighborhood. However, for moderately important localities where a spillage would affect the environment a storm drain filter could be installed near the storm water inlet points in the roadway so that the spilled material would be filtered to a certain extent before entering the drainage pipes. If it were found out that there would not be any significant impact due to a hazardous material spill, then no preventive measures be taken since the cost to benefit ratio in these cases would usually be high.

Table 4.4 Probability Table of I - 80

#	Mile Post		Segment Length	AADT	Classification	Truck Percentage	Spillage Rates	Probability	Probability per Mile
	Begin	End							
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1	0.00	2.05	2.05	49,700	Rural	15.67	0.010	0.06	0.03
2	2.05	4.7	2.65	45,304	Rural	15.67	0.010	0.07	0.03
3	4.70	12.03	7.33	43,500	Rural	15.67	0.010	0.18	0.02
4	12.03	19.88	7.85	42,402	Rural	15.67	0.010	0.19	0.02
5	19.88	25.05	5.17	42,402	Rural	15.67	0.010	0.13	0.02
6	25.05	25.25	0.20	56,349	Urban	11.39	0.014	0.01	0.03
7	25.25	26.25	1.00	64,706	Urban	11.39	0.014	0.04	0.04
8	26.25	28.82	2.57	78,511	Urban	11.39	0.014	0.12	0.05
9	28.82	30.61	1.79	42,915	Urban	11.39	0.014	0.04	0.02
10	30.61	30.8	0.19	42,915	Urban	11.39	0.014	0.00	0.02
11	30.80	31.98	1.18	42,915	Rural	15.67	0.010	0.03	0.02
12	31.98	34.18	2.20	107,200	Urban	11.39	0.014	0.14	0.06
13	34.18	35.33	1.15	133,200	Urban	11.39	0.014	0.09	0.08
14	35.33	38.81	3.48	135,100	Urban	11.39	0.014	0.27	0.08
15	38.81	39.57	0.76	130,700	Urban	11.39	0.014	0.06	0.08
16	39.57	47.83	8.26	134,900	Urban	11.39	0.014	0.65	0.08
17	47.83	52.48	4.65	102,600	Urban	11.39	0.014	0.28	0.06
18	52.48	53.62	1.14	107,261	Urban	11.39	0.014	0.07	0.06
19	53.62	59.06	5.44	122,600	Urban	11.39	0.014	0.39	0.07
20	59.06	62.34	3.28	132,935	Urban	11.39	0.014	0.25	0.08
21	62.34	65.8	3.46	121,768	Urban	11.39	0.014	0.25	0.07
22	65.80	68.54	2.74	144,500	Urban	11.39	0.014	0.23	0.08
21	62.34	65.8	3.46	121,768	Urban	11.39	0.014	0.25	0.07
22	65.80	68.54	2.74	144,500	Urban	11.39	0.014	0.23	0.08

Interstate 78 connects Warren County with New Jersey Turnpike in Hudson County. The classification of the interstate changes from urban to rural or vice versa at four locations. Table 4.5 describes the probability of an accident for various segments of the Interstate.

Table 4.5 Probability Table of I - 78

#	Mile Post		Segment Length	AADT	Classification	Truck Percentage	Spillage Rates	Probability	Probability per Mile
	Begin	End							
1	0	4.15	4.15	42,200	URBAN	11.39	0.014	0.10	0.03
2	4.15	7.03	2.88	66,700	RURAL	15.67	0.010	0.11	0.04
3	7.03	15.04	8.01	73,500	RURAL	15.67	0.010	0.34	0.04
4	15.04	18.83	3.79	77,016	RURAL	15.67	0.010	0.17	0.04
5	18.83	20.78	1.95	79,305	RURAL	15.67	0.010	0.09	0.05
6	20.78	25.03	4.25	84,715	RURAL	15.67	0.010	0.21	0.05
7	25.03	30.81	5.78	43,581	URBAN	11.39	0.014	0.15	0.03
8	30.81	32.47	1.66	27,915	RURAL	15.67	0.010	0.03	0.02
9	32.47	34.58	2.11	40,602	URBAN	11.39	0.014	0.05	0.02
10	34.58	37.39	2.81	37,413	URBAN	11.39	0.014	0.06	0.02
11	37.39	40.98	3.59	78,010	URBAN	11.39	0.014	0.16	0.05
12	40.98	44.01	3.03	75,480	URBAN	11.39	0.014	0.13	0.04
13	44.01	46.72	2.71	84,788	URBAN	11.39	0.014	0.13	0.05
14	46.72	49.28	2.56	84,037	URBAN	11.39	0.014	0.13	0.05
15	49.28	51.43	2.15	163,833	URBAN	11.39	0.014	0.21	0.10
16	51.43	51.76	0.33	180,000	URBAN	11.39	0.014	0.04	0.11
17	51.76	53.42	1.66	123,998	URBAN	11.39	0.014	0.12	0.07
18	53.42	56.45	3.03	179,070	URBAN	11.39	0.014	0.32	0.10
19	56.45	57.44	0.99	199,272	URBAN	11.39	0.014	0.12	0.12
20	57.44	58.03	0.59	172,930	URBAN	11.39	0.014	0.06	0.10
21	58.03	62.01	3.98	66,400	URBAN	11.39	0.014	0.15	0.04
22	62.01	64.2	2.19	51,700	URBAN	11.39	0.014	0.07	0.03
23	64.2	67.83	3.63	97,300	URBAN	11.39	0.014	0.21	0.06

The recurrence interval for this interstate varies between once in 8 years to once in every 50 years. Serious considerations should be made to segment 19. Depending on the environment nearby suitable mitigating measures be taken to reduce the impact of any hazardous material accident that might take place within the next eight years.

Interstate 287 connects Middlesex County with Bergen County. Table 4.6 describes the probability of an accident for various segments of the Interstate. The classification of the interstate changes at three locations.

Table 4.6 Probability Table of I - 287

#	Mile Post		Segment Length	AADT	Classification	Truck %	Spillage Rates	Probability	Probability per Mile
	Begin	End							
1	0	3.09	3.09	106,510	URBAN	11.39	0.014	0.19	0.06
2	3.09	4.62	1.53	80,782	URBAN	11.39	0.014	0.07	0.05
3	4.62	5.88	1.26	71,212	URBAN	11.39	0.014	0.05	0.04
4	5.88	6.41	0.53	71,520	URBAN	11.39	0.014	0.02	0.04
5	6.41	8.47	2.06	54,445	URBAN	11.39	0.014	0.07	0.03
6	8.47	12.3	3.83	40,594	URBAN	11.39	0.014	0.09	0.02
7	12.3	14.3	2	57,328	URBAN	11.39	0.014	0.07	0.03
8	14.3	17.73	3.43	42,612	URBAN	11.39	0.014	0.09	0.03
9	17.73	23.28	5.55	56,352	URBAN	11.39	0.014	0.18	0.03
10	23.28	24.96	1.68	41,882	RURAL	15.67	0.01	0.04	0.02
11	24.96	30.17	5.21	43,319	URBAN	11.39	0.014	0.13	0.03
12	30.17	31.85	1.68	47,456	RURAL	15.67	0.01	0.05	0.03
13	31.85	34.02	2.17	78,500	URBAN	11.39	0.014	0.10	0.05
14	34.02	34.67	0.65	96,360	URBAN	11.39	0.014	0.04	0.06
15	34.67	35.83	1.16	96,891	URBAN	11.39	0.014	0.07	0.06
16	35.83	36.61	0.78	111,383	URBAN	11.39	0.014	0.05	0.07
17	36.61	37.96	1.35	122,210	URBAN	11.39	0.014	0.10	0.07
18	37.96	39.55	1.59	165,060	URBAN	11.39	0.014	0.15	0.10
19	39.55	42.02	2.47	153,940	URBAN	11.39	0.014	0.22	0.09
20	42.02	53.83	11.81	83,206	URBAN	11.39	0.014	0.57	0.05
21	53.83	59.94	6.11	81,031	URBAN	11.39	0.014	0.29	0.05
22	59.94	67.54	7.6	108,814	URBAN	11.39	0.014	0.48	0.06

The recurrence interval for this interstate varies between once in 10 years to once in every 50 years. Serious considerations should be made to segments having a high probability of a hazardous material accident.

4.4 Summary

The chapter analyzes the probability of an accident in certain segments of interstates and highways in New Jersey, then explains examples from the *Roadway Design Manual* and finally analyzes entire lengths of three Interstates and three Highways in New Jersey showing how the probability changes for different sections of the same roadway. It also explains based on the recurrence intervals, should any preventive measures be taken in the segment under analysis. It provides reasons as to when a preventive measure shall be taken and when it is not necessary to take one.

CHAPTER 5

SUMMARY AND RECOMMENDATIONS

The chapter is of three sections, the first one explaining the findings of this study, the second section describing the conclusions and the third section explaining how this study could be expanded for better and more accurate results.

5.1 Findings

The AADT, percentage heavy goods vehicles, and spillage rates were derived based on the traffic and accident data obtained from the NJDOT. These parameter derived based on New Jersey standards were substituted in the British predictive equation, obtained from the *Roadway Design Manual*, to determine the probability of a serious accidental spillage shall be used. The spillage rates derived from the state traffic and accident data was acceptable. The calculated spillage rates are only few times higher when compared to the spillage rates provided by the Highways Agency. Further investigation could be carried to determine the difference in the spillage rates, which is in fact related to the AADT, percentage of trucks and number of accidents. The analyzes showed that even if two segments of the same roadway have the same AADT, but have different functional classifications, the probability of a serious accidental spillage would differ significantly mainly because of the spillage rates and the percentage of trucks on the roadways.

5.2 Conclusions

As the probabilities obtained during analysis of any section of highway are believed to be reasonable, the probability of a serious accidental spillage in a given segment can be used to indicate the most appropriate engineering solution to mitigate the impact of a hazardous material spills due to truck accidents. The probability of a spill in a given segment of a highway is directly related to the Annual Average Daily Traffic in the segment under analysis. The greater the number of vehicles using a particular segment, the higher the probability of a serious accidental spillage on it. Thus it could be concluded that the probability is directly proportional to the AADT used. When the length of the segment under analysis is increased, the probability also increases.

Even though this is a valid fact, it is also reasonable to calculate the probability of a serious accidental spillage per mile. Only this probability should be compared with other segments, or should be used to determine if an engineering solution is required for the given segment. It can be concluded that all the parameters used in the probability equation, AADT, percentage of trucks, segment length and spillage rates, are directly proportional to the probability of a serious accidental spillage. If more accurate information on AADT and percentage of trucks were available, like the traffic counts, including the percentage of trucks, for the segment or roadway under analysis were performed and substituted instead of the data sources as described in this theses, the probability calculated would be more accurate. If all the accident locations could be identified exactly, then the respective spillage rates for each functional classification of roadways could be determined.

5.3 Further Research

The probability of a serious accidental spillage per mile calculated for a given roadway segment indicate that the chances of an accident in a given roadway segment is constant throughout the entire segment. However further research could be carried on to determine the probability for a particular location or for smaller stretches of a segment even though their AADT may not change. Study could also be performed to reduce the spillage rates, which are high compared to the spillage rates used in the *Roadways Design Manual.* This study did not determine the probability of accidents at or near intersections, entrance and exit ramps. Further study could be carried out to determine the spillage rate for different intersections, merge areas, weaving areas, other types of access points. Since most bridges in New Jersey freeze before the roadway surface, further research could be done to determine the impact of bridges in a particular segment and how they could modify the value of the probability calculated.

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