TRANSPORTATION RISK ASSESSMENT FOR ETHANOL TRANSPORT

A Thesis

by

ANECIA SHELTON-DAVIS

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

MASTER OF SCIENCE

December 2007

Major Subject: Chemical Engineering

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Approved by:

Chair of Committee,	M. Sam Mannan
Committee Members,	Christine Ehlig-Economides
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ABSTRACT

Transportation Risk Assessment for Ethanol Transport. (December 2007)

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Chair of Advisory Committee: Dr. M. Sam Mannan

This research is aimed at assessing the quantitative risks involved with an ethanol pipeline. Pipelines that run from the Midwest, where the vast majority of ethanol is produced, to the target areas where reformulated gasoline is required (California, Texas Gulf Coast, New England Atlantic Coast) will be of particular interest. The goal is to conduct a quantitative risk assessment on the pipeline, truck, and rail transportation modes to these areas. As a result of the quantitative risk assessment, we are able to compare the risk associated with the different modes of transportation for ethanol. In order to perform and compare the quantitative risk assessment, the following challenges are addressed:

- Identify target areas requiring reformulated gasoline
- Map detailed route for each transportation mode to all three target areas
- Perform a quantitative risk assessment for each transportation mode
- Compare quantitative risk assessment results for each route and transportation mode

The focus is on California, Texas Gulf Coast, and New England Atlantic Coast because of the large volume. It is beneficial to look at these areas as opposed to the

smaller areas because pipeline transportation requires very large volumes. In order to find a meaningful comparison between all three transportation modes, only the areas with the three large volumes were evaluated. Since the risk assessment is completed using historical data, each route is segmented in a way that is consistent with the data that is available.

All of the curves support the hypothesis that pipeline transportation poses the least societal risk when transporting ethanol from the Midwest to target areas. Rail transportation poses the largest amount of societal risk. While overall rail incidents are not as frequent as road incidents, the frequency of a fatality is much higher when an incident does occur.

DEDICATION

To God for blessing me beyond measure.

To Brad for his constant love, encouragement, support and being by my side through the good and bad times.

To my great-grandparents, grandparents and parents for the foundation to achieve great things.

To Dr. Mannan and the members of the Mary Kay O'Connor Process Safety Center for their support and guidance.

ACKNOWLEDGEMENTS

I would like to thank my committee chair, Dr. Mannan, and my committee members, Dr. El-Halwagi and Dr. Economides, for their guidance throughout my research. Special thanks go to Dr. Steven Zhang and Dr. Rogers for all of their assistance and always pointing me in the right direction with my research. I would also like to thank Towanna Hubacek for all of her assistance with registration and help with paperwork while at Texas A&M.

Thanks also go to my colleagues in the Artie McFerrin Department of Chemical Engineering for making my graduate school years fun and interesting.

Finally, thanks to my husband for his patience and love and to my family for their encouragement and support.

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CHAPTER I

INTRODUCTION

Ethanol (EtOH, C_2H_6O) is a clear, colorless, flammable liquid, typically made from corn. Ethanol is used in alcoholic beverages; however according to the Renewable Fuels Association, the largest use of ethanol is as a motor fuel and fuel additive. Typically pure ethanol is not used as a motor fuel, but a percentage of ethanol is combined with unleaded gasoline.

Any amount of ethanol can be combined with gasoline, but the most common blend is E10 (10% ethanol, 90% unleaded gasoline). E10 has been approved for use in any make of model of vehicle sold in the United States. In fact gas stations in major metropolitan areas such as Houston and Los Angeles are already blending unleaded gasoline to produce E10.

There are many benefits to blending ethanol with gasoline, which includes a decrease in both reliance on foreign oil and harmful emissions.

One effect of blending ethanol with gasoline is increasing the nation's energy security by reducing reliance on foreign oil. According to the Energy Information Administration, in 2005 United States gasoline consumption was about 385 million gallons per day, of which about 60% of this demand is met with foreign oil. By displacing a portion of the gasoline that we put into our cars, fuel ethanol will reduce the amount of oil needed to be imported into the country.

This thesis follows the style of the Chemical Engineering Journal.

The use of fuels blended with oxygenates reduces tailpipe emissions. Both MTBE and ethanol have been widely used as oxygenates in gasoline. However, the expanded use of MTBE has caused contamination of water supplies, impacting 30% of urban wells in the United States. In reaction to this, twenty states have enacted MTBE bans or limits. Ethanol is not expected to pose the same problems as MTBE because it is a biodegradable, renewable oxygenate that does not harm drinking water resources [1].

According to the Environmental Protection Agency (EPA), a steady decrease in on-road vehicle emissions since the 1970s can be attributed to a combination of regulatory and voluntary control programs. In a continued effort to decrease tailpipe emissions and clean up the air, government agencies, such as the EPA, Department of Energy (DOE) and Department of Transportation (DOT) are working together to pass legislation that would increase the use of biofuels. There is research being done to create new biofuels, however, ethanol is the biofuel of choice.

While the production and use for ethanol is increasing, ethanol does pose one major drawback: it is not easily transported through the country's pipeline system. Pipelines are generally the fastest and most economical mode of transporting liquid fuels. The reasons for ethanol being unable to travel through pipelines is it's affinity for water and the likelihood of ethanol dissolving and carrying impurities that are present inside multi-product pipelines, making it harmful to automobile engines when blended with gas, logistical limitations of existing pipelines, and insufficient volumes of ethanol to be transported [2].

Although transportation of ethanol by pipeline can be difficult due to the aforementioned challenges, it is not impossible. Williams Bio-Energy successfully shipped ethanol via pipeline from Des Moines, Iowa to Kansas City, Kansas in the early 1980s [3].

With the increase in demand for ethanol and the need to deliver it to target markets safely and efficiently, ethanol transportation via pipeline may be further developed in the future. This study will focus on finding the safest mode of ethanol transportation by comparing the risk involve with delivering ethanol by truck, rail and pipeline.

CHAPTER II

PROBLEM STATEMENT

This research is aimed at assessing the quantitative risks involved with an ethanol pipeline. Pipelines that run from the Midwest, where the vast majority of ethanol is produced, to the target areas where reformulated gasoline is required (California, Texas Gulf Coast, New England Atlantic Coast) will be of particular interest. The goal is to conduct a quantitative risk assessment on the pipeline, truck, and rail transportation modes to these areas. As a result of the quantitative risk assessment, we will be able to compare the risk associated with the different modes of transportation for ethanol. In order to perform and compare the quantitative risk assessment, the following challenges will be addressed:

1. Identify target areas requiring reformulated gasoline
2. Map detailed route for each transportation mode to all three target areas
3. Perform a quantitative risk assessment for each transportation mode
4. Compare quantitative risk assessment results for each route and transportation mode

CHAPTER III

PROPOSED METHODOLOGY

The research focus is on assessing the quantitative risks of an ethanol pipeline compared to the current methods of transportation: truck and rail. The hypothesis is that a thorough quantitative risk assessment will reveal pipeline transportation of ethanol is the best option, from a safety standpoint. The first step is to identify which areas are required by the Clean Air Act to use reformulated gasoline. Next, the route for each transportation mode will be mapped in detail to each target area. After the routes are determined, a quantitative risk assessment will be performed for each transportation mode: rail, truck and pipeline. A comparison of the quantitative risk assessment results will be done after all of the data is collected. Once again the methodology to be used in this thesis is as follows [Adapted from 4]:

- Identify target areas requiring reformulated gasoline
- Map detailed route for each transportation mode to all three target areas
- Perform a quantitative risk assessment for each transportation mode
- Compare quantitative risk assessment results for each route and transportation mode

1. <u>Identify Target Areas</u>

The Clean Air Act Amendments of 1990 focuses on vehicular fuel emissions as a source of air pollution and mandates the use of cleaner burning fuels in cities that do not meet ozone standards set by the Environmental Protection Agency. For this particular study I chose to only include the areas with the mandates for cleaner burning fuel because of the large volume required for shipment via pipeline. The map in Figure 1 highlights the areas that are required to use reformulated gasoline:

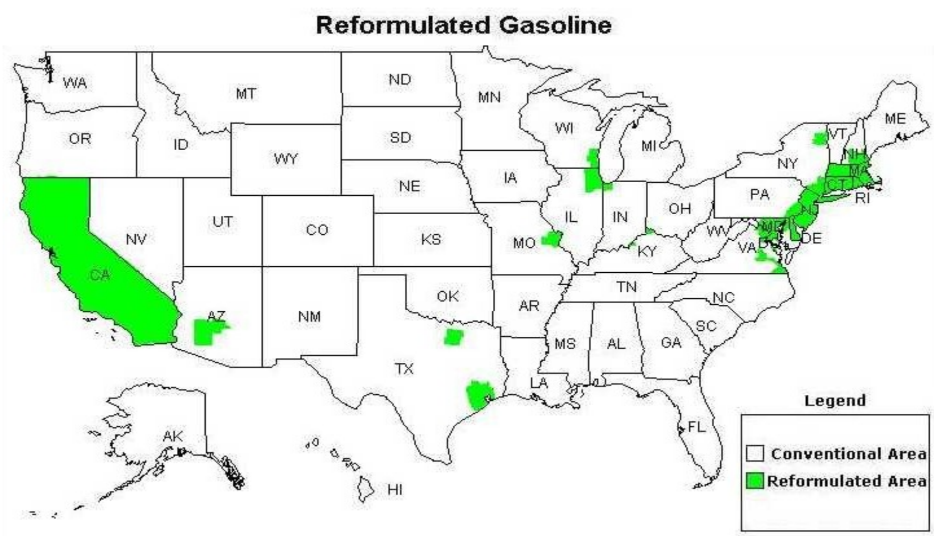

Figure 1 Reformulated gasoline areas [5]

The focus will be on California, Texas Gulf Coast, and New England Atlantic Coast because of the large volume. It is beneficial to look at these areas as opposed to the smaller areas because pipeline transportation requires very large volumes. In order to find a meaningful comparison between all three transportation modes, only the areas with the three large volumes will be evaluated.

2. Map Detailed Route for Each Transportation Mode

In order to quantify risk associated with each transportation mode, we must decide the route that will be studied. For this work I am only looking at the most likely route that ethanol will take from the Midwest to the target areas.

Rail

Because there has been a rise in ethanol production and a need to transport it to target areas efficiently, some rail companies already have routes and rail cars dedicated to ethanol transportation. When applicable the dedicated ethanol route will be used in the evaluation.

Road

In order to compare routes with the same origin and destination points, the road risk assessed will begin and end at the same points as the rail analysis. The United States Department of Transportation Federal Highway Administration publishes an estimated average annual daily truck traffic map. The analysis is done based on the assumption that the tucks transporting ethanol will use the same routes as the majority of other freight trucks to make their deliveries.

Pipeline

Since there is currently no ethanol transportation via pipeline in the United States, the risk analysis will be performed on existing refined products pipelines originating in Mason City, Iowa. The major assumption is ethanol will be shipped in modified existing pipelines or along the same right of way as the existing pipelines.

3. Segmentation and Data Collection

Since the risk assessment will be completed using historical data, each route must be segmented in a way that is consistent with the data that is available. The segmentation of the routes will vary with transportation mode.

Rail

Each route for rail transportation will be segmented by county, as this is the smallest segment for which data is available. The data is also company specific within each county to narrow the risk assessment even further.

The data source to be used for the risk assessment is the Ten Year Accident/Incident Database maintained by the Federal Railroad Administration's Office of Safety Analysis. The relevant data that will be obtained for each segment is as follows:

- Total number of incidents
- Total fatalities

Road

The road portion of the quantitative risk analysis will be divided by county. The vehicular collisions will be obtained from the National Large Truck Crash Facts Database. This database is compiled with collision data from Fatality Analysis Reporting System (FARS) and the Motor Carrier Management Information System (MCMIS). The data includes:

- Non-fatal crashes
- Fatal crashes
- Injury crashes

Pipeline

The pipeline portion of the risk assessment will be segmented by state. The risk assessment data will be obtained from the Office of Pipeline Safety within the United States Department of Transportation Pipeline and Hazardous Materials Safety Administration Incident Report Database. The following information will be obtained from the database:

- Transmission mileage (by county)
- Number of incidents
- Number of injuries
- Number of fatalities

4. Perform a quantitative risk assessment for each transportation mode

After performing the route segmentation and collecting all of the data, a quantitative risk assessment will be performed to determine the risks associated with each route. The risk will be assessed using event trees.

Road

Figure 2 displays the event tree that will be used to determine the probability of various outcomes for a truck involved in a collision.

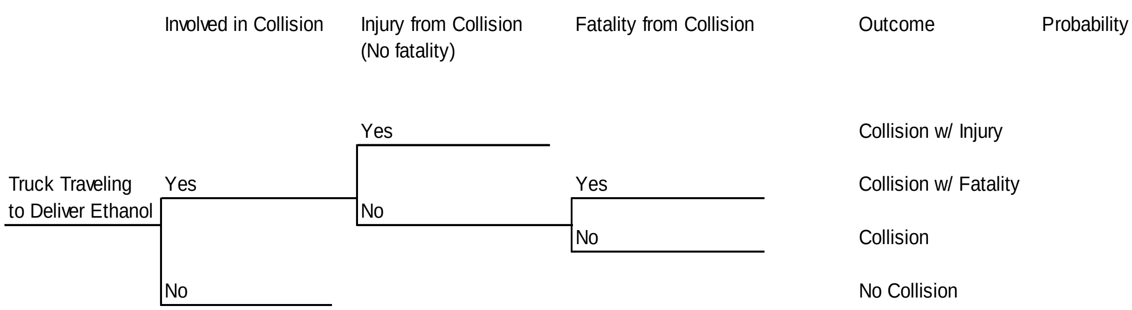

Figure 2 Road Collision Event Tree

Rail

The event tree for a railroad incident involved in a collision is the similar to that for road transportation and is shown in Figure 3.

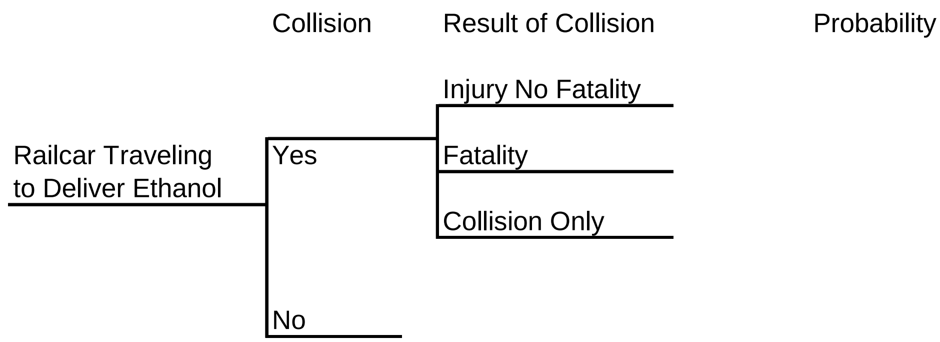

Figure 3 Rail Incident Event Tree

Pipeline

The event tree in Figure 4 shows a fatality or injury resulting from pipeline shipment of ethanol.

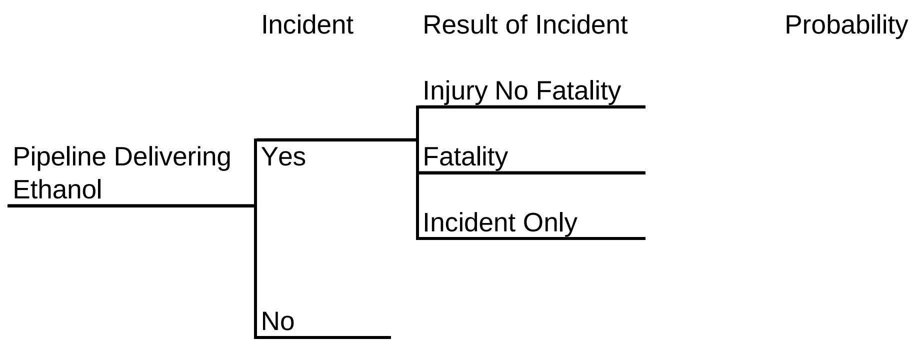

Figure 4 Pipeline Incident Event Tree

5. Compare assessment results for each route and transportation mode

The risk assessment results will be presented in an F-N curve. The F-N curve is the main form used to present societal risk [6]. The plot in Figure 5 is an example of the F-N graph to be populated with the risk data.

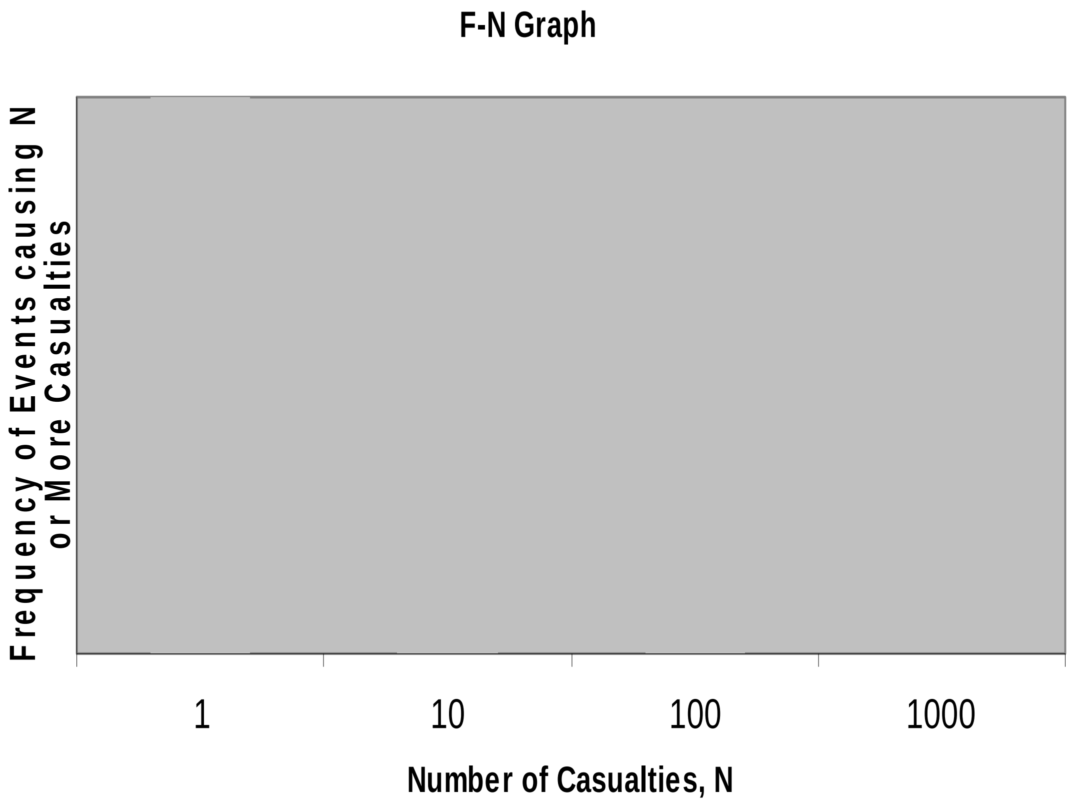

Figure 5 F-N Curve [Adapted from 6]

6. <u>Summary</u>

Figure 6 is a swim lane diagram illustrating the data input and display for the study.

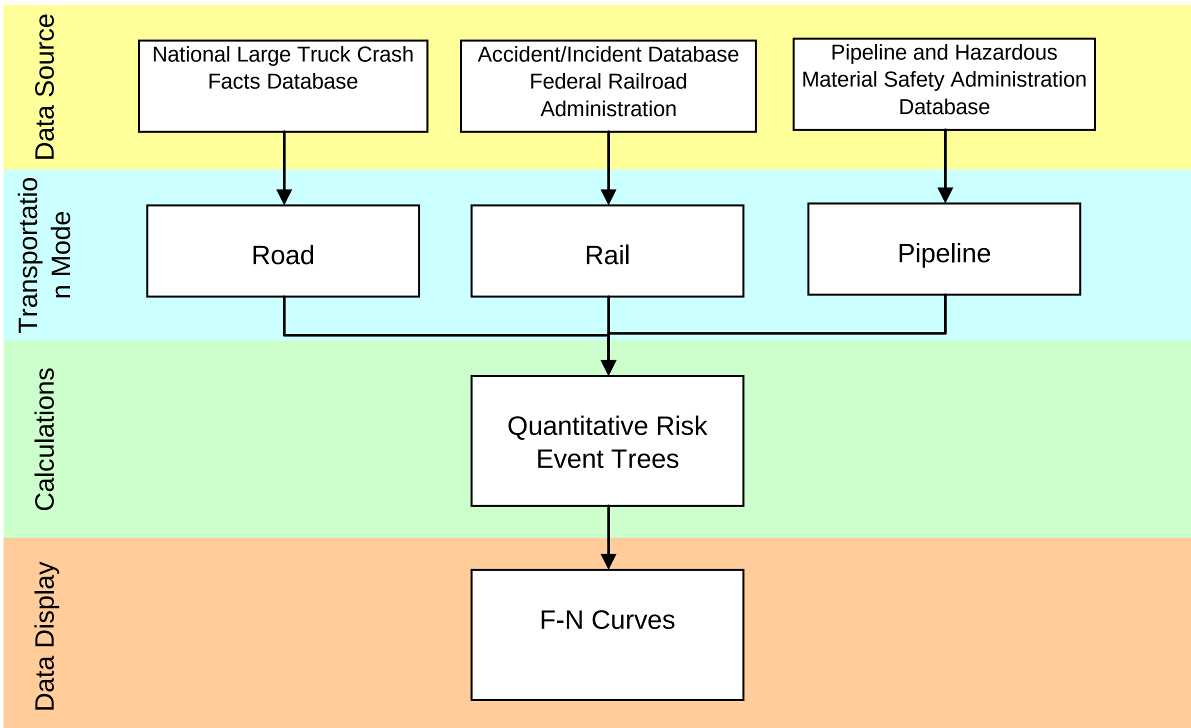

Figure 6 Swim Lane Diagram

CHAPTER IV

IDENTIFYING TARGET AREAS

The vast majority of ethanol in the United States is created from corn, which makes ethanol production heavily concentrated in the Midwest region of the country. Figure 7 shows a map of existing ethanol plants in the U.S.

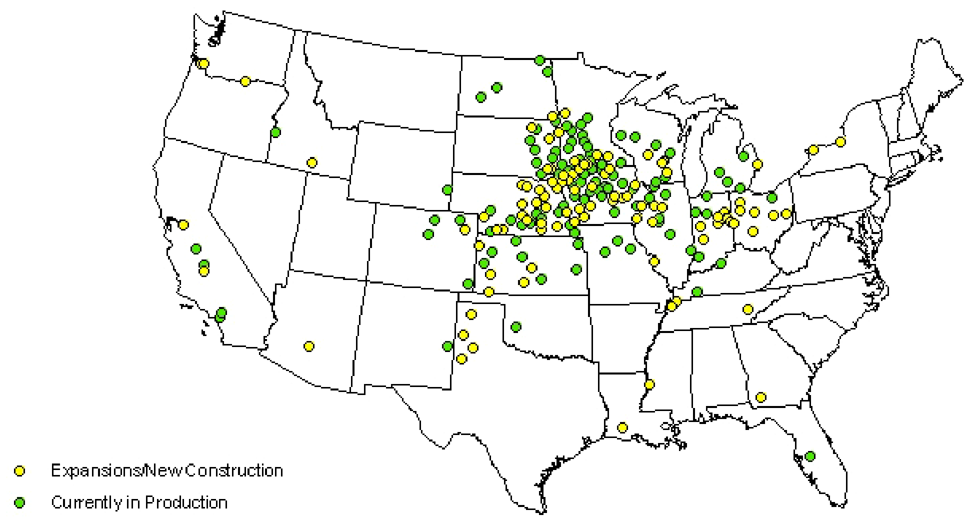

Figure 7 United States Ethanol Plants [1]

There is ongoing research to create other biodiesels from materials other than corn such as animal fat or vegetable oil. This would change the landscape of ethanol plants being concentrated in the Midwest. However, the quantitative risk assessment only takes into account the current ethanol production originating in the Midwest and traveling to the three target areas.

The target areas for the study were based on the areas where the EPA has made a mandate for cleaner burning fuel. Because pipeline transportation of ethanol requires large volumes, the study focuses on the areas where pipeline transportation would be feasible based solely on volume.

The three target areas of interest are California, New England Coast, and Texas Gulf Coast. Because values are required for the actual demand of ethanol in target areas to calculate the number of trips needed, 2003 data will be used. The 2003 ethanol demand from the Energy Information Administration is the most recent and detailed data available for ethanol usage in gasohol by state. Table 1 shows the yearly demand of ethanol in the target area.

Table 1 Ethanol Demand 2003 [5]

Target Area	**Ethanol Use in Gasohol (thousand Gallons)**
California	588,743
Texas Gulf Coast	22,924
New England Coast	129,316
• New York	22,440
• Connecticut	20,478
• Pennsylvania	6,673
• Virginia	79,725

The demand used in the study was the same for each mode of transportation. The risk was assessed based on the assumption that 100% of the ethanol demand is met through a single transportation source. For example, when assessing the risk posed by shipping ethanol via rail to California, the assessment is based on the total demand being met by shipping ethanol via rail without considering pipeline or truck as a transportation mode. While multiple modes of transportation are used to ship ethanol in practice, this assumption allows a meaningful comparison to be made regarding the relative risk of the different transportation modes.

CHAPTER V

MAP DETAILED ROUTE FOR EACH TRANSPORTATION MODE

1. Rail

Due to the increase in ethanol production and the need to transport it quickly from the Midwest, some rail companies already have dedicated routes from the Midwest to target areas for ethanol shipments. These routes were used in the study to perform the quantitative risk assessment and are described in detail below:

Atlantic Coast

CSX Corporation has developed Ethanol Express Delivery, also known as EthX, to quickly move ethanol from the Midwest to the Atlantic Coast. The route begins in Mason City, Iowa and ends at the ethanol terminal in Albany, NY [7]. The route is shown in Figure 8.

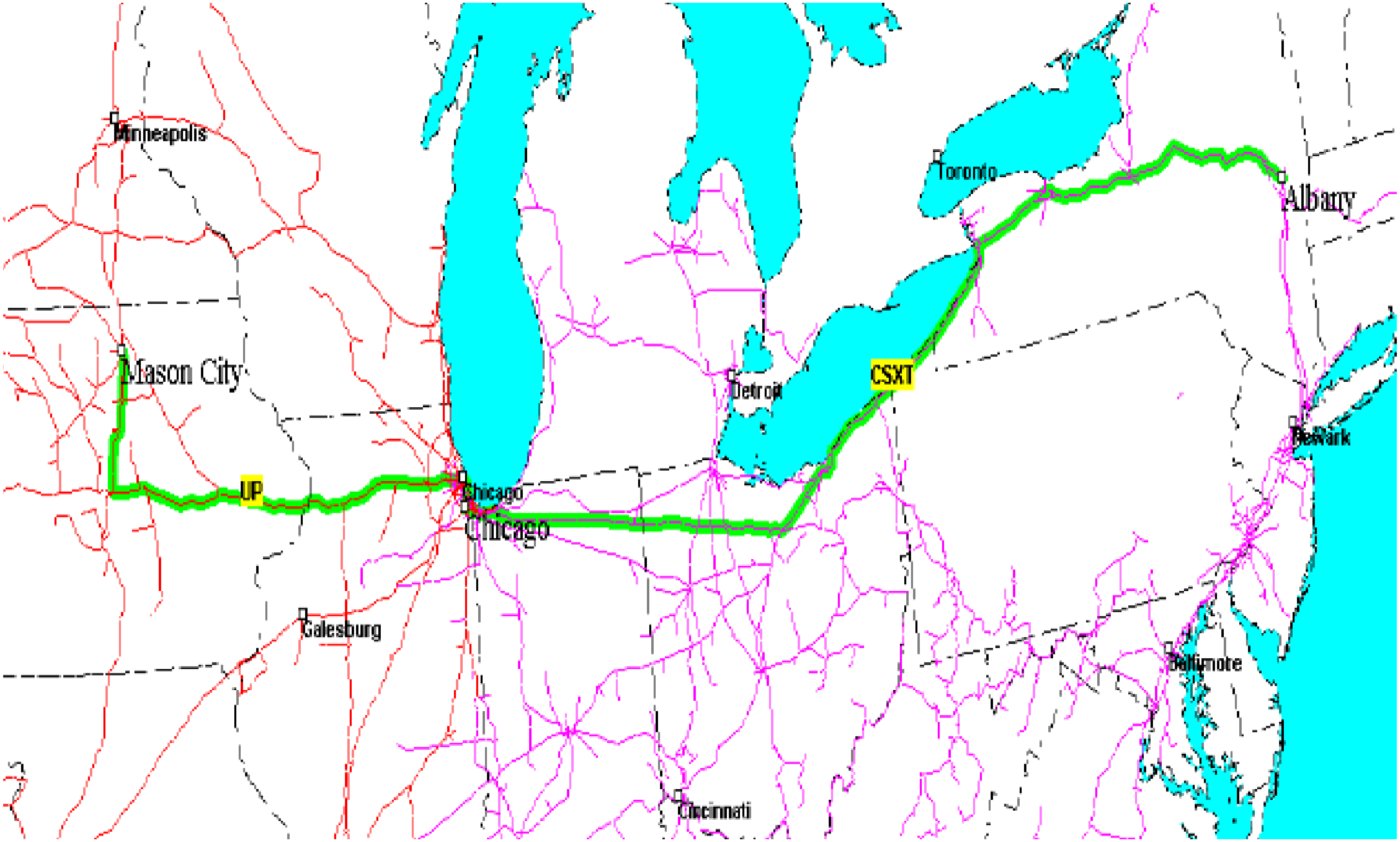

Figure 8 Route for rail transport to Albany, NY [Adapted from 7]

West Coast

Like CSX on the Atlantic Coast, Burlington Northern Santa Fe (BNSF) has a dedicated ethanol route, Ethanol Express, from various ethanol plants in the Midwest to an ethanol terminal in Watson, California [8]. For the quantitative risk assessment, the point of origin is Omaha, Nebraska because it is in the center of the ethanol plants, also for comparison with the other transportation modes, it is better to begin with a single point of origin rather than multiple plants in order to compare the risk accurately. The map in Figure 9 shows the route for the quantitative risk assessment highlighted in green.

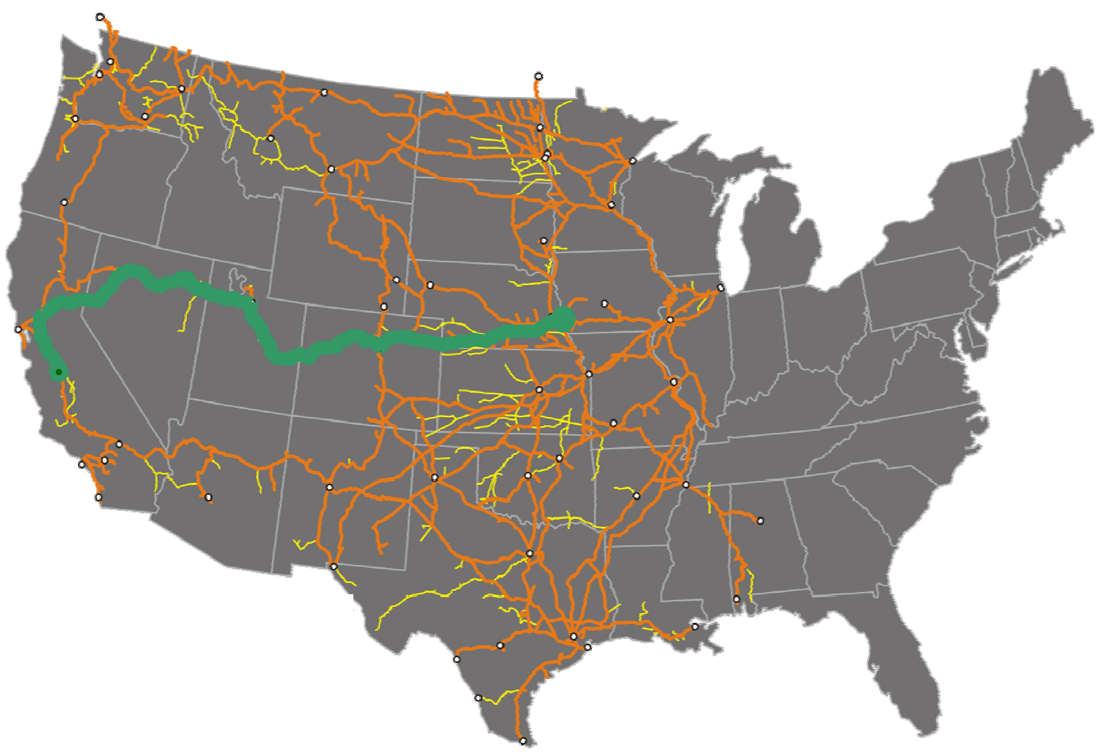

Figure 9 Route for rail transportation to California [Adapted from 8]

Gulf Coast

There is not a specific ethanol route to the Gulf Coast. For the quantitative risk assessment, BNSF's route from Omaha, Nebraska to Texas City, Texas is used. The map in Figure 10 shows the route for the quantitative risk assessment highlighted in green.

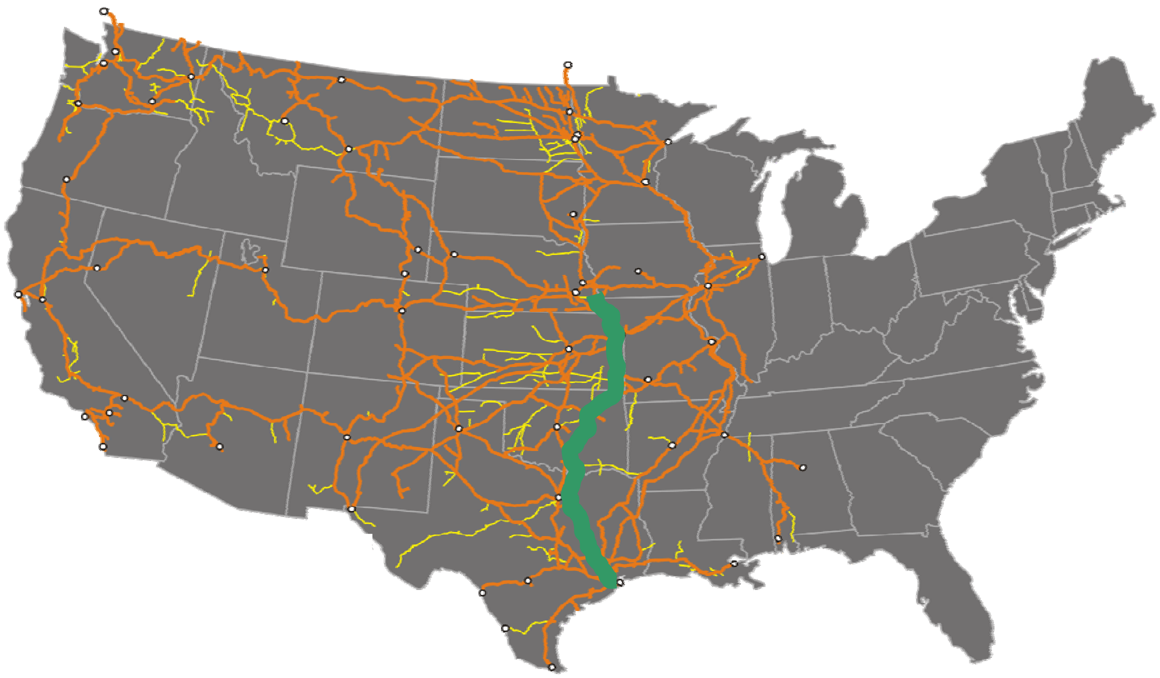

Figure 10 Route for rail transportation to the Gulf Coast [Adapted from 8]

2. Road

To maintain consistency in the comparison of the quantitative risks in each transportation mode, the routes for trucks were assumed to have the same origins and endpoints as the rail transportation. The United States Department of Transportation Federal Highway Administration has published an estimated average annual daily truck traffic map. The routes are based on the assumption that the trucks carrying ethanol will travel along the same routes as the majority of the other freight trucks. The maps in Figures 11-13 show the estimated average annual daily traffic in 2020 and the routes that will be used in the risk assessment from the origins to the endpoints of interest.

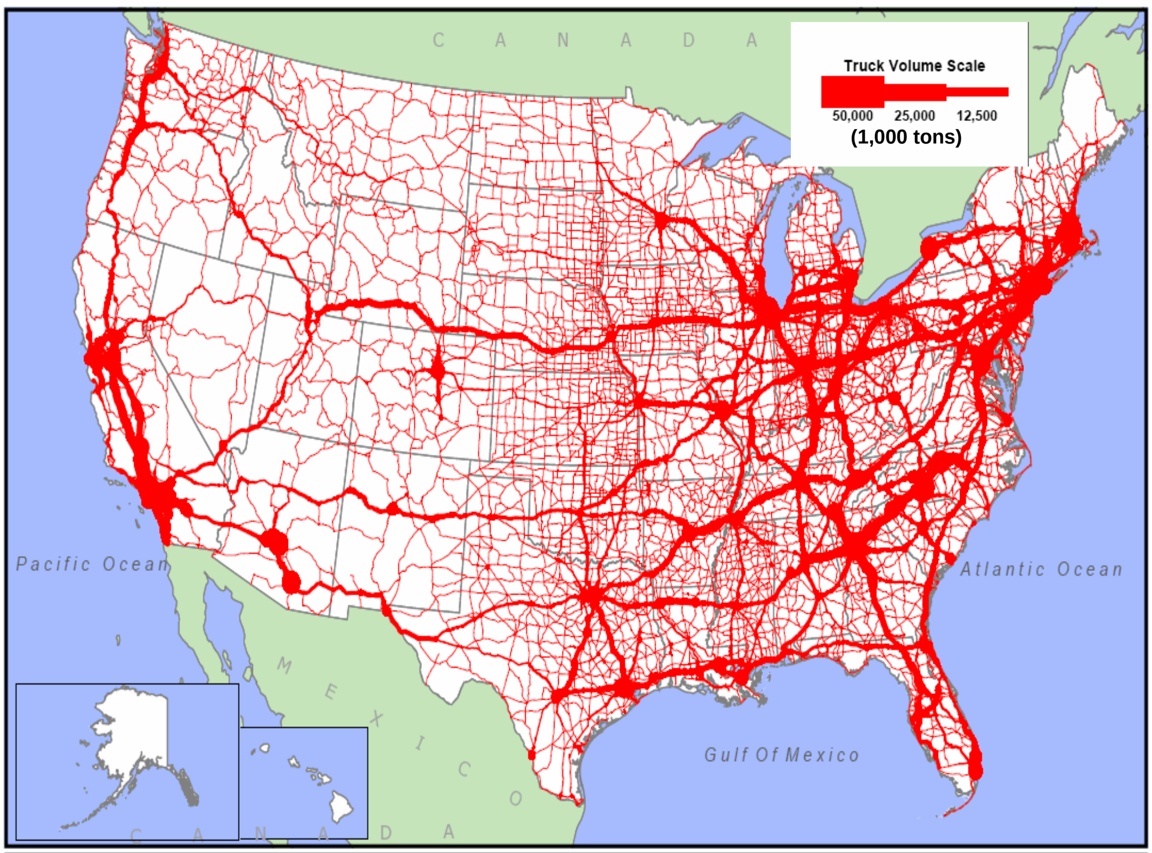

Figure 11 Estimated average annual daily truck traffic 1998 [9]

Figure 12 Route for road transportation (West Coast and Gulf Coast) (Courtesy of www.mapquest.com)

Figure 13 Route for road transportation (New England) (Courtesy of www.mapquest.com)

3. <u>Pipeline</u>

Since there is currently no ethanol transportation by pipeline, the detailed route used is along existing refined products pipelines. The route is assuming that ethanol will be shipped along the same right of way as existing pipelines or existing pipelines can be modified in a way such that ethanol will be transported from Mason City, Iowa to Watson, California and Texas City, Texas. The ethanol will then be shipped to Albany, New York from Texas City, Texas via pipeline. The routes were developed using pipeline maps from Kinder Morgan Energy Partners, Magellan Midstream Partners, and Texas Eastern Products Pipeline Company. The map in Figure 14 shows the detailed pipeline routes to each target area highlighted in red.

Figure 14 Route for pipeline transportation (Adapted from www.mapsearch.com)

CHAPTER VI

SEGMENTATION AND DATA COLLECTION

1. Rail

The routes for rail transportation were segmented by county and narrowed to the specific railroad company that is designated for the particular route. The Federal Railroad Administration Office of Safety Analysis was used to collect the statistics of the railroad company by county. Although the historical data is not one hundred percent correlated to ethanol transportation the risk can still be evaluated. If a railcar has an incident, the incident will be independent of what is being shipped in the railcar, but will depend solely on events external to the material being transferred. Looking at the data by county and railroad company allows us to account for counties that may be problematic to rail transportation, such as those in heavily populated areas, and also to account for railroad companies that may perform better or worse than other railroad companies within the same county. The county segments and data collected are found in Appendix A.

2. Road

Like the segments for the rail portion of the study, the road portion is segmented by county. The data is not specific to any particular carrier as the opportunity for incidents are mainly due to external factors such as weather and road conditions. The vehicular collisions are obtained from the National Large Truck Crash Facts Database. This database is compiled with collision data from Fatality Analysis Reporting System (FARS) and the Motor Carrier Management Information System (MCMIS). The data includes:

- Non-fatal crashes
- Fatal crashes
- Injury crashes

The data for road portion and counties can be found in Appendix B.

3. Pipeline

The pipeline portion of the risk assessment will be segmented by state and county to obtain the pipeline mileage along the route. In this study only the external factors that contribute to pipeline incidents are observed. Incidents relating to corrosion and internal pipe concerns are not in the scope of this research. External events are independent of the material inside of the pipe and since we are using the same right of way of existing pipelines as the ethanol pipelines the external events are very relevant to quantifying the risks. The risk assessment data will be obtained from the Office of Pipeline Safety within the United States Department of Transportation Pipeline and Hazardous Materials Safety Administration Incident Report Database. The following information is obtained from the database:

- Transmission mileage (by county)
- Number of incidents
- Number of injuries
- Number of fatalities

The data for the pipeline portion can be found in Appendix C.

CHAPTER VII

PERFORM QUANTITATIVE RISK ASSESSMENT

Event Trees

As mentioned earlier, event trees were used to perform the quantitative risk assessment. Since the data will be summarized using F-N curves the frequency of fatalities is the outcome of interest. Equation 1 is used to determine the frequency of fatality for each route and transportation mode.

Rail/Road/Pipeline

$$Frequency = \frac{Fatality \times \Pr obability\ of\ Fatality}{Gallon - Miles} \qquad \text{(Equation 1)}$$

Constant Values:

Tanker volume (road)	5,000 gallons
Tanker volume (rail)	3,000 gallons

Segments

Because each route is composed by several segments (counties) the frequency of fatality is found in each county. The frequency will not be cumulative of the entire trip, but by each individual county. This assumption is based on the fact that the same fatality cannot occur in a subsequent county. See Appendices A, B, C for rail, road, and pipeline calculations, respectively.

CHAPTER VIII

COMPARE QRA RESULTS

Figures 15, 16, and 17 illustrate the results of the quantitative risk analysis.

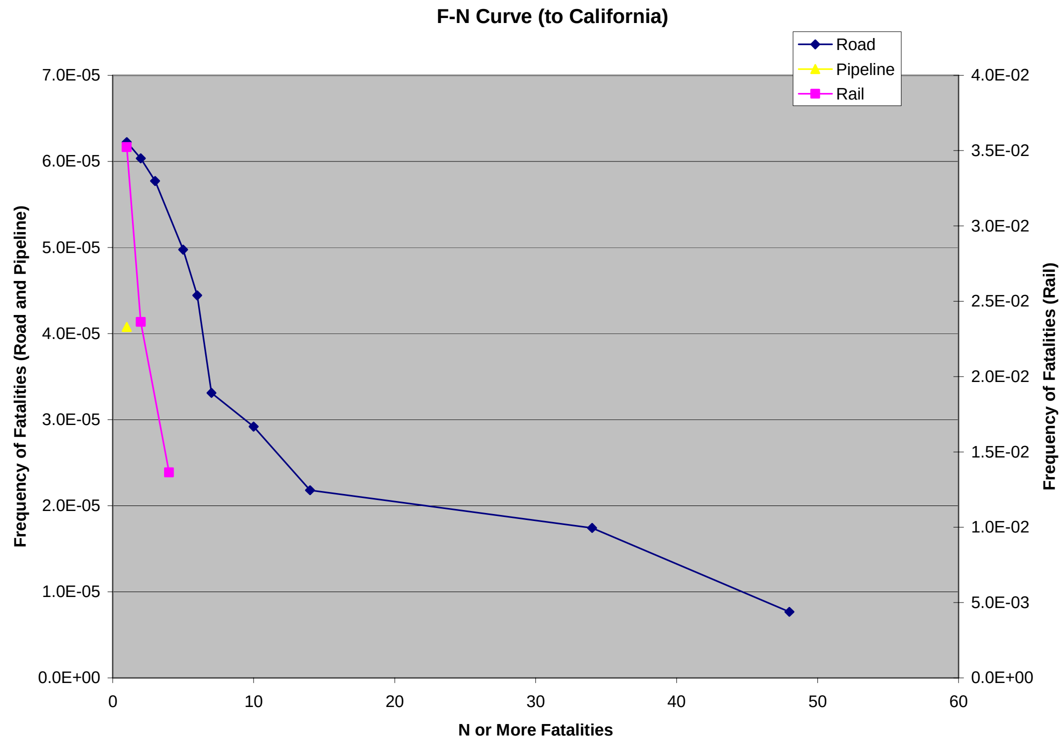

Figure 15 F-N Curve (to California)

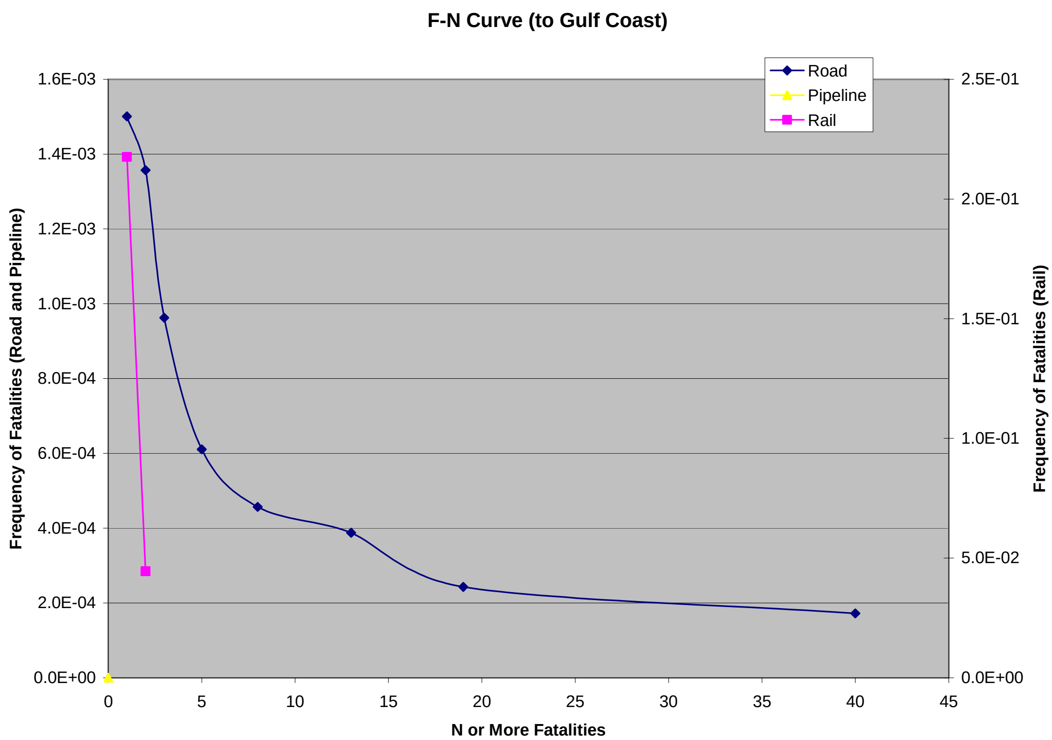

Figure 16 F-N Curve (to Gulf Coast)

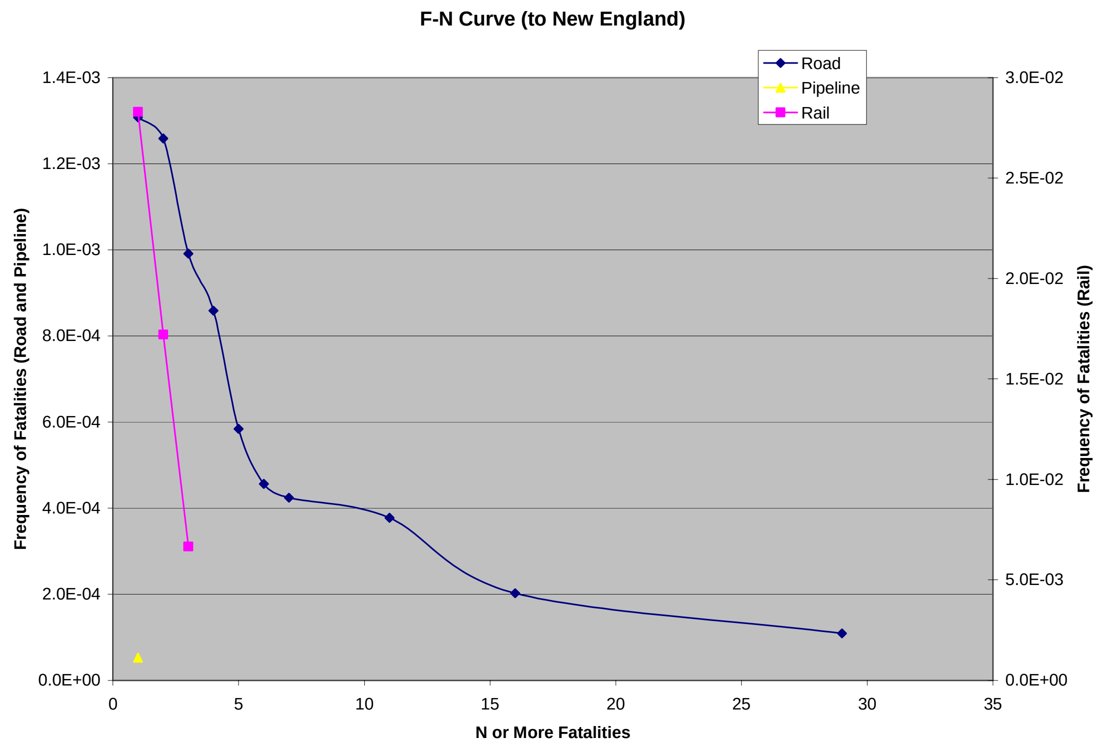

Figure 17 F-N Curve (to New England)

All of the curves support the hypothesis that pipeline transportation poses the least societal risk when transporting ethanol from the Midwest to target areas. Rail transportation poses the largest amount of societal risk. While overall rail incidents are not as frequent as road incidents, the frequency of a fatality is much higher when an incident does occur.

CHAPTER IX

SUMMARY

The method of determining the safest mode of ethanol transportation is a quantitative risk assessment with results illustrated on an F-N curve. The purpose of the curves is to determine the method of transportation that would cause the least number of fatalities. The curves show that existing pipelines cause far fewer fatalities than the other available methods for transporting ethanol, truck and rail. Pipelines are followed by road transportation, with rail having the highest frequency of fatalities.

CHAPTER X

FUTURE WORK

Because of the unavailability of actual ethanol pipelines and limitations on available data, this study made several assumptions to conduct the quantitative risk analysis. To further improve the analysis a more detailed study of the ethanol pipeline would be beneficial. The exact right of way and material of construction will change the miles traveled, thus changing the frequency of fatality. Another improvement is performing detailed fire and explosion studies for ethanol spills and leaks to give a more robust assessment of the risk involved with ethanol transportation. Work can also be done to find ways to mitigate the risk. Both road and rail transportation have higher incidents and fatalities in densely populated areas. If alternate rights of way can be developed, the risk should reduce significantly.

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APPENDIX A

RAIL DATA AND CALCULATIONS

1. Rail Data- West Coast

County	Total Incidents	Total Fatalities	County	Total Incidents	Total Fatalities
Nebraska			**Utah**		
Sarpy	3	0	Grand	1	0
Cass	0	0	Emery	0	0
Lancaster	36	1	Carbon	0	0
Saline	2	0	Utah	5	1
Fillmore	1	0	Salt Lake	0	0
Clay	2	2	Tooele	0	0
Adams	1	0	**Nevada**		
Kearney	0	0	Elko	0	0
Phelps	0	0	Eureka	0	0
Harlan	1	0	Lander	0	0
Furnas	0	0	Humboldt	0	0
Red Willow	2	0	Pershing	0	0
Hitchcock	1	0	Churchill	0	0
Dundy	1	0	Storey	0	0
Colorado			Washoe	0	0
Yuma	0	0	**California**		
Washington	0	0	Placer	1	1
Morgan	4	0	Sacremento	3	1
Weld	1	0	San Joaquin	16	1
Adams	1	0	Stanislaus	10	0
Denver	33	0	Merced	4	1
Jefferson	1	0	Madera	1	0
Gilpin	0	0	Fresno	24	4
Grand	1	0	Kings	2	0
Eagle	0	0	Tulare	1	0
Garfield	2	0	Kern	29	4
Mesa	2	0	San Bernadino	64	2

2. Rail Data - Gulf Coast

County	Total Incidents	Total Fatalities	County	Total Incidents	Total Fatalities
Nebraska			**Oklahoma**		
Sarpy	3	0	Craig	2	0
Cass	0	0	Rogers	3	0
Iowa			Tulsa	16	1
Mills	0	0	Creek	7	2
Fremont	0	0	Okmulgee	2	1
Kansas			Okfuskee	1	1
Atchison	0	0	Hughes	1	0
Missouri			Pontotoc	3	0
Holt	1	0	Johnston	0	0
Andrew	0	0	Marshall	2	0
Buchanan	6	0	Bryan	0	0
Platte	2	0	**Texas**		
Clay	21	0	Grayson	4	0
Johnson	0	0	Collin	0	0
Kansas			Dallas	4	1
Miami	3	1	Ellis	2	0
Linn	1	0	Navarro	0	0
Bourbon	2	0	Freestone	4	0
Crawford	0	0	Leon	1	0
Cherokee	4	0	Madison	0	0
Ottawa	1	0	Grimes	3	0
			Montgomery	2	1
			Harris	37	2
			Brazoria	4	0
			Galveston	4	0

3. Rail Data – New England Coast

County	Total Incidents	Total Fatalities
Iowa		
Cerro Gordo	0	0
Floyd	0	0
Butler	0	0
Blackhawk	0	0
Benton	0	0
Linn	0	0
Johnson	0	0
Muscatine	0	0
Scott	0	0
Illinois		
Rock Island	4	0
Henry	1	0
Bureau	0	0
La Salle	9	0
Grundy	5	0
Will	39	1
Du Page	5	0
Cook	10	0
Indiana		
Lake	9	3
Porter	5	2
LaPorte	3	0
St. Joseph	0	0
Marshall	0	0
Elkhart	1	0
Kosciusko	1	0
Noble	1	0
Dekalb	4	0

County	Total Incidents	Total Fatalities
Ohio		
Van Wert	0	0
Allen	6	2
Hardin	1	0
Wyandot	0	0
Crawford	2	0
Richland	0	0
Huron	21	0
Lorain	4	1
Cuyahoga	13	0
Lake	2	1
Ashtabula	4	0
Pennsylvania		
Erie	3	1
New York		
Chautauqua	5	0
Erie	28	2
Genesee	0	0
Monroe	9	3
Wayne	6	0
Cayuga	1	0
Onodaga	8	2
Oneida	2	0
Herkimer	0	0
Montgomery	1	1
Schenectady	2	0
Albany	40	0

4. Rail Calculations - West Coast

County	Total Incidents	Total Fatalities	Probability of Fatality	Frequency of Fatality
Nebraska				
Sarpy	3	0	0	0
Cass	0	0	0	0
Lancaster	36	1	0.028	0.0001
Saline	2	0	0	0
Fillmore	1	0	0	0
Clay	2	2	1	0.0097
Adams	1	0	0	0
Kearney	0	0	0	0
Phelps	0	0	0	0
Harlan	1	0	0	0
Furnas	0	0	0	0
Red Willow	2	0	0	0
Hitchcock	1	0	0	0
Dundy	1	0	0	0
Colorado				
Yuma	0	0	0	0
Washington	0	0	0	0
Morgan	4	0	0	0
Weld	1	0	0	0
Adams	1	0	0	0
Denver	33	0	0	0
Jefferson	1	0	0	0
Gilpin	0	0	0	0
Grand	1	0	0	0
Eagle	0	0	0	0
Garfield	2	0	0	0
Mesa	2	0	0	0
Utah				
Grand	1	0	0	0
Emery	0	0	0	0
Carbon	0	0	0	0
Utah	5	1	0.200	0.001
Salt Lake	0	0	0	0
Tooele	0	0	0	0
Nevada				
Elko	0	0	0	0
Eureka	0	0	0	0
Lander	0	0	0	0
Humboldt	0	0	0	0
Pershing	0	0	0	0
Churchill	0	0	0	0
Storey	0	0	0	0
Washoe	0	0	0	0

Rail Calculations - West Coast (cont.)

County	Total Incidents	Total Fatalities	Probability of Fatality	Frequency of Fatality
California				
Placer	1	1	1	0.00484082
Sacramento	3	1	0.333	0.002
San Joaquin	16	1	0.063	0.000
Stanislaus	10	0	0	0
Merced	4	1	0.250	0.001
Madera	1	0	0	0
Fresno	24	4	0.167	0.003
Kings	2	0	0	0
Tulare	1	0	0	0
Kern	29	4	0.138	0.0027
San Bernardino	64	2	0.031	0.0003
Riverside	10	4	0.4	0.0077
Orange	2	1	0.5	0.0024
Los Angeles	43	1	0.023	0.0001

5. Rail Calculations - Gulf Coast

County	Total Incidents	Total Fatalities	Probability of Fatality	Frequency of Fatality
Nebraska				
Sarpy	3	0	0	0
Cass	0	0	0	0
Iowa				
Mills	0	0	0	0
Fremont	0	0	0	0
Kansas				
Atchison	0	0	0	0
Missouri				
Holt	1	0	0	0
Andrew	0	0	0	0
Buchanan	6	0	0	0
Platte	2	0	0	0
Clay	21	0	0	0
Johnson	0	0	0	0
Kansas				
Miami	3	1	0.333	2.18E-02
Linn	1	0	0	0
Bourbon	2	0	0	0
Crawford	0	0	0	0
Cherokee	4	0	0	0
Ottawa	1	0	0	0
Oklahoma				
Craig	2	0	0	0
Rogers	3	0	0	0
Tulsa	16	1	0.063	4.09E-03
Creek	7	2	0.286	3.74E-02
Okmulgee	2	1	0.500	3.27E-02
Okfuskee	1	1	1	6.54E-02
Hughes	1	0	0	0
Pontotoc	3	0	0	0
Johnston	0	0	0	0
Marshall	2	0	0	0
Bryan	0	0	0	0

Rail Calculations - Gulf Coast (cont.)

Texas	[redacted]	[redacted]	[redacted]	[redacted]
Grayson	4	0	0	0
Collin	0	0	0	0
Dallas	4	1	0.250	1.64E-02
Ellis	2	0	0	0
Navarro	0	0	0	0
Freestone	4	0	0	0
Leon	1	0	0	0
Madison	0	0	0	0
Grimes	3	0	0	0
Montgomery	2	1	0.500	3.27E-02
Harris	37	2	0.054	7.07E-03
Brazoria	4	0	0	0
Galveston	4	0	0	0

6. Rail Calculations – New England Coast

County	Total Incidents	Total Fatalities	Probability of Fatality	Frequency of Fatality
Iowa				
Cerro Gordo	0	0	0	0
Floyd	0	0	0	0
Butler	0	0	0	0
Blackhawk	0	0	0	0
Benton	0	0	0	0
Linn	0	0	0	0
Johnson	0	0	0	0
Muscatine	0	0	0	0
Scott	0	0	0	0
Illinois				
Rock Island	4	0	0	0
Henry	1	0	0	0
Bureau	0	0	0	0
La Salle	9	0	0	0
Grundy	5	0	0	0
Will	39	1	0.026	0.026
Du Page	5	0	0	0
Cook	10	0	0	0
Indiana				
Lake	9	3	0.333	0.333
Porter	5	2	0.4	0.4
LaPorte	3	0	0	0
St. Joseph	0	0	0	0
Marshall	0	0	0	0
Elkhart	1	0	0	0
Kosciusko	1	0	0	0
Noble	1	0	0	0
Dekalb	4	0	0	0
Ohio				
Van Wert	0	0	0	0
Allen	6	2	0.333	0.333
Hardin	1	0	0	0
Wyandot	0	0	0	0
Crawford	2	0	0	0
Richland	0	0	0	0
Huron	21	0	0	0
Lorain	4	1	0.25	0.25
Cuyahoga	13	0	0	0
Lake	2	1	0.5	0.5
Ashtabula	4	0	0	0
Pennsylvania				
Erie	3	1	0.333	0.333

Rail Calculations – New England Coast (cont.)

New York	[redacted]	[redacted]	[redacted]	[redacted]
Chautauqua	5	0	0	0
Erie	28	2	0.071	0.071
Genesee	0	0	0	0
Monroe	9	3	0.333	0.333
Wayne	6	0	0	0
Cayuga	1	0	0	0
Onodaga	8	2	0.250	0.250
Oneida	2	0	0	0
Herkimer	0	0	0	0
Montgomery	1	1	1	1
Schenectady	2	0	0	0
Albany	40	0	0	0

APPENDIX B

ROAD DATA AND CALCULATIONS

1. Road Data - West Coast

County Nebraska Counties on Route	Number of Incidents	Injury from Collision No Fatality	Fatality from Collision
Douglas	209	83	2
Sarpy	61	24	1
Cass	29	15	1
Lancaster	120	51	2
Seward	40	18	5
York	30	13	0
Hamilton	13	3	0
Hall	42	15	2
Buffalo	27	11	6
Dawson	41	12	0
Lincoln	46	21	0
Keith	24	14	0
Deuel	21	8	1
Colorado Counties			
Sedgwick	7	2	0
Logan	14	5	0
Washington	9	2	0
Morgan	15	4	0
Weld	115	37	10
Adams	133	31	3
Jefferson	75	15	2
Clear Creek	24	3	3
Summit	36	13	2
Eagle	34	9	3
Garfield	33	9	1
Mesa	24	14	1
Utah Counties			
Grand	22	12	0
Emery	20	9	1
Sevier	24	9	0
Beaver	8	4	0
Iron	39	25	3
Washington	36	21	0
Arizona Counties			
Mohave	106	53	7
Nevada Counties			
Clark	379	172	14
California Counties			
San Bernadino	1008	491	34
Los Angeles	2552	1157	48

2. Road Data – Gulf Coast

County Nebraska Counties	Number of Incidents	Injury from Collision No Fatality	Fatality from Collision
Douglas	209	83	2
Otoe	13	5	1
Nehama	4	3	0
Richardson	2	0	0
Iowa Counties			
Pottawattamie	95	56	2
Mills	6	4	0
Fremont	26	18	1
Kansas Counties			
Brown	7	3	0
Jackson	4	3	1
Shawnee	74	16	3
Osage	5	0	2
Lyon	23	6	3
Chase	19	4	3
Butler	36	10	1
Sedgwick	171	46	5
Sumner	27	13	0
Oklahoma Counties			
Kay	23	17	0
Noble	18	13	0
Payne	11	9	0
Logan	10	8	1
Oklahoma	201	160	8
Cleveland	36	25	3
McClain	24	16	3
Garvin	21	17	1
Murray	9	6	2
Carter	35	17	2
Love	8	4	0
Texas Counties			
Cooke	24	7	1
Denton	255	111	13
Dallas	1110	549	19
Ellis	93	37	5
Navarro	86	27	5
Freestone	39	12	2
Leon	27	9	2
Madison	13	5	1
Walker	50	12	2
Harris	2028	892	40
Galveston	68	34	2

3. Road Data- New England Coast

County Iowa Counties	Number of Incidents	Injury from Collision No Fatality	Fatality from Collision
Cerro Gordo	34	23	0
Chickasaw	4	3	0
Bremer	7	5	2
Black Hawk	41	25	2
Buchanan	6	4	0
Benton	3	1	0
Linn	39	27	1
Johnson	74	38	1
Cedar	46	22	2
Scott	104	67	0
Illinois Counties			
Rock Island	43	9	0
Henry	24	9	0
Bureau	17	8	1
La Salle	52	21	4
Grundy	32	8	1
Will	223	90	6
Cook	1539	575	29
Indiana Counties			
Lake	551	178	16
Porter	123	65	1
LaPorte	138	53	11
St. Joseph	116	45	2
Elkhart	169	67	3
LaGrange	48	15	4
Steuben	50	15	3
Ohio Counties			
Williams	31	14	1
Fulton	55	24	2
Lucas	176	114	4
Wood	117	69	4
Sandusky	72	40	5
Erie	59	36	2
Lorain	86	56	5
Cuyahoga	267	206	3
Lake	48	36	2
Ashtabula	42	12	2
Pennsylvania Counties			
Erie	126	61	3
New York Counties			
Chautauqua	54	25	3
Erie	210	107	7
Gensee	47	23	3
Monroe	121	60	4
Ontario	54	28	2
Seneca	29	11	1
Cayuga	36	14	0
Onondaga	136	65	1
Madison	35	20	0
Oneida	73	36	4
Herkimer	29	8	0
Montgomery	29	15	1
Schenectady	26	7	2
Albany	105	43	4

4. Road Calculations- West Coast

County	Number of Incidents	Injury from Collision No Fatality	Fatality from Collision	Probability of Fatality from Collision	Frequency of Fatality
Nebraska					
Douglas	209	83	2	0.010	1.625E-07
Sarpy	61	24	1	0.016	1.392E-07
Cass	29	15	1	0.034	2.929E-07
Lancaster	120	51	2	0.017	2.831E-07
Seward	40	18	5	0.125	5.308E-06
York	30	13	0	0.000	0.000E+00
Hamilton	13	3	0	0.000	0.000E+00
Hall	42	15	2	0.048	8.088E-07
Buffalo	27	11	6	0.222	1.132E-05
Dawson	41	12	0	0.000	0.000E+00
Lincoln	46	21	0	0.000	0.000E+00
Keith	24	14	0	0.000	0.000E+00
Deuel	21	8	1	0.048	4.044E-07
Colorado					
Sedgwick	7	2	0	0.000	0.000E+00
Logan	14	5	0	0.000	0.000E+00
Washington	9	2	0	0.000	0.000E+00
Morgan	15	4	0	0.000	0.000E+00
Weld	115	37	10	0.087	7.385E-06
Adams	133	31	3	0.023	5.747E-07
Jefferson	75	15	2	0.027	4.529E-07
Clear Creek	24	3	3	0.125	3.185E-06
Summit	36	13	2	0.056	9.436E-07
Eagle	34	9	3	0.088	2.248E-06
Garfield	33	9	1	0.030	2.574E-07
Mesa	24	14	1	0.042	3.539E-07
Utah					
Grand	22	12	0	0.000	0.000E+00
Emery	20	9	1	0.050	4.246E-07
Sevier	24	9	0	0.000	0.000E+00
Beaver	8	4	0	0.000	0.000E+00
Iron	39	25	3	0.077	1.960E-06
Washington	36	21	0	0.000	0.000E+00
Arizona					
Mohave	106	53	7	0.066	3.926E-06
Nevada					
Clark	379	172	14	0.037	4.392E-06
California					
San Bernardino	1008	491	34	0.034	9.740E-06
Los Angeles	2552	1157	48	0.019	7.667E-06

5. Road Calculations - Gulf Coast

County	Number of Incidents	Injury from Collision No Fatality	Fatality from Collision	Probability of Fatality from Collision	Frequency of Fatality
Nebraska					
Douglas	209	83	2	0.010	4.17439E-06
Otoe	13	5	1	0.077	1.67778E-05
Nehama	4	3	0	0.000	0
Richardson	2	0	0	0.000	0
Iowa					0
Pottawattamie	95	56	2	0.021	9.18366E-06
Mills	6	4	0	0.000	0
Fremont	26	18	1	0.038	8.38892E-06
Kansas					0
Brown	7	3	0	0.000	0
Jackson	4	3	1	0.250	5.4528E-05
Shawnee	74	16	3	0.041	2.65271E-05
Osage	5	0	2	0.400	0.00017449
Lyon	23	6	3	0.130	8.53482E-05
Chase	19	4	3	0.158	0.000103316
Butler	36	10	1	0.028	6.05867E-06
Sedgwick	171	46	5	0.029	3.18877E-05
Sumner	27	13	0	0.000	0
Oklahoma					0
Kay	23	17	0	0.000	0
Noble	18	13	0	0.000	0
Payne	11	9	0	0.000	0
Logan	10	8	1	0.100	2.18112E-05
Oklahoma	201	160	8	0.040	6.94486E-05
Cleveland	36	25	3	0.083	5.4528E-05
McClain	24	16	3	0.125	8.1792E-05
Garvin	21	17	1	0.048	1.03863E-05
Murray	9	6	2	0.222	9.69387E-05
Carter	35	17	2	0.057	2.49271E-05
Love	8	4	0	0.000	0
Texas					0
Cooke	24	7	1	0.042	9.088E-06
Denton	255	111	13	0.051	0.000144553
Dallas	1110	549	19	0.017	7.09355E-05
Ellis	93	37	5	0.054	5.86323E-05
Navarro	86	27	5	0.058	6.34047E-05
Freestone	39	12	2	0.051	2.23705E-05
Leon	27	9	2	0.074	3.23129E-05
Madison	13	5	1	0.077	1.67778E-05
Walker	50	12	2	0.040	1.7449E-05
Harris	2028	892	40	0.020	0.00017208

6. Road Calculations – New England Coast

County	Number of Incidents	Injury from Collision No Fatality	Fatality from Collision	Probability of Fatality from Collision	Frequency of Fatality
Iowa					
Cerro Gordo	34	23	0	0.000	0
Chickasaw	4	3	0	0.000	0
Bremer	7	5	2	0.286	0.0001143
Black Hawk	41	25	2	0.049	1.951E-05
Buchanan	6	4	0	0.000	0
Benton	3	1	0	0.000	0
Linn	39	27	1	0.026	5.128E-06
Johnson	74	38	1	0.014	2.703E-06
Cedar	46	22	2	0.043	1.739E-05
Scott	104	67	0	0.000	0
Illinois					
Rock Island	43	9	0	0.000	0
Henry	24	9	0	0.000	0
Bureau	17	8	1	0.059	1.176E-05
La Salle	52	21	4	0.077	6.154E-05
Grundy	32	8	1	0.031	6.25E-06
Will	223	90	6	0.027	3.229E-05
Cook	1539	575	29	0.019	0.0001093
Indiana					
Lake	551	178	16	0.029	9.292E-05
Porter	123	65	1	0.008	1.626E-06
LaPorte	138	53	11	0.080	0.0001754
St. Joseph	116	45	2	0.017	6.897E-06
Elkhart	169	67	3	0.018	1.065E-05
LaGrange	48	15	4	0.083	6.667E-05
Steuben	50	15	3	0.060	0.000036
Ohio					
Williams	31	14	1	0.032	6.452E-06
Fulton	55	24	2	0.036	1.455E-05
Lucas	176	114	4	0.023	1.818E-05
Wood	117	69	4	0.034	2.735E-05
Sandusky	72	40	5	0.069	6.944E-05
Erie	59	36	2	0.034	1.356E-05
Lorain	86	56	5	0.058	5.814E-05
Cuyahoga	267	206	3	0.011	6.742E-06
Lake	48	36	2	0.042	1.667E-05
Ashtabula	42	12	2	0.048	1.905E-05
Pennsylvania					
Erie	126	61	3	0.024	1.429E-05

Road Calculations – New England Coast (cont.)

County	Number of Incidents	Injury from Collision No Fatality	Fatality from Collision	Probability of Fatality from Collision	Frequency of Fatality
New York					
Chautauqua	54	25	3	0.056	3.333E-05
Erie	210	107	7	0.033	4.667E-05
Gensee	47	23	3	0.064	3.83E-05
Monroe	121	60	4	0.033	2.645E-05
Ontario	54	28	2	0.037	1.481E-05
Seneca	29	11	1	0.034	6.897E-06
Cayuga	36	14	0	0.000	0
Onondaga	136	65	1	0.007	1.471E-06
Madison	35	20	0	0.000	0
Oneida	73	36	4	0.055	4.384E-05
Herkimer	29	8	0	0.000	0
Montgomery	29	15	1	0.034	6.897E-06
Schenectady	26	7	2	0.077	3.077E-05
Albany	105	43	4	0.038	3.048E-05

APPENDIX C

PIPELINE DATA AND CALCULATIONS

1. Pipeline Data

California

State	Total Liquid Mileage	Number of Incidents	Number of Fatalities	Number of Injuries
Iowa	4395	3	0	0
Missouri	5373	1	0	0
Kansas	9832	12	0	1
Oklahoma	10691	11	0	0
Texas	52463	37	0	2
New Mexico	5859	6	1	1
Arizona	695	3	0	0
California	7380	11	1	1

Texas Gulf Coast

State	Total Liquid Mileage	Number of Incidents	Number of Fatalities	Number of Injuries
Iowa	4395	3	0	0
Missouri	5373	1	0	0
Kansas	9832	12	0	1
Oklahoma	10691	11	0	0
Texas	52463	37	0	2

New England Coast

State	Total Liquid Mileage	Number of Incidents	Number of Fatalities	Number of Injuries
Iowa	4395	3	0	0
Missouri	5373	1	0	0
Kansas	9832	12	0	1
Oklahoma	10691	11	0	0
Texas	52463	37	0	2
Louisiana	15780	8	0	0
Arkansas	1722	1	0	0
Missouri	7836	13	0	3
Illinois	7836	6	0	1
Indiana	3790	5	1	2
Ohio	4088	2	0	0
Pennsylvania	3028	2	0	0
New York	1084	1	0	0

2. Pipeline Calculations

West Coast

State	Total Liquid Mileage	Number of Incidents	Number of Fatalities	Probability of Fatality	Frequency of Fatality
Iowa	4395	3	0	0	0
Missouri	5373	1	0	0	0
Kansas	9832	12	0	0	0
Oklahoma	10691	11	0	0	0
Texas	52463	37	0	0	0
New Mexico	5859	6	1	0.167	2.845E-05
Arizona	695	3	0	0	0
California	7380	11	1	0.091	1.232E-05

Gulf Coast

State	Total Liquid Mileage	Number of Incidents	Number of Fatalities	Probability of Fatality	Frequency of Fatality
Iowa	4395	3	0	0	0
Missouri	5373	1	0	0	0
Kansas	9832	12	0	0	0
Oklahoma	10691	11	0	0	0
Texas	52463	37	0	0	0

New England

State	Total Liquid Mileage	Number of Incidents	Number of Fatalities	Probability of Fatality	Frequency of Fatality
Iowa	4395	3	0	0	0
Missouri	5373	1	0	0	0
Kansas	9832	12	0	0	0
Oklahoma	10691	11	0	0	0
Texas	52463	37	0	0	0
Louisiana	15780	8	0	0	0
Arkansas	1722	1	0	0	0
Missouri	7836	13	0	0	0
Illinois	7836	6	0	0	0
Indiana	3790	5	1	0.2	5.277E-05
Ohio	4088	2	0	0	0
Pennsylvania	3028	2	0	0	0
New York	1084	1	0	0	0

VITA

Anecia Shelton-Davis received her Bachelor of Science degree in chemical engineering from the University of Oklahoma in 2003. She spent two years as a process development engineer at Cargill Corn Wet-Milling facility in Memphis, Tennessee. She entered the chemical engineering program at Texas A&M University in August 2005 and received her Master of Science degree in December 2007. Anecia is now a Facilities Engineer at BP working with Gulf of Mexico Deepwater Production.

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