MODEL FOR THE ROUTING OF HAZARDOUS MATERIAL TRANSPORTS THROUGH THE CENTRAL BUSINESS DISTRICT OF DALLAS

Rene Anderson
Joseph Davila
Michael Rowland

CSE 4395 - Senior Design
May 8, 1992
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Abstract

The objective of this study was to define a method of calculating freeway and arterial route segment risk levels, and to create a logical model that will allow for the assessment of the safest route for a transport to take between any two points (or nodes) within the Central Business District of Dallas. The significant raw data available for the segments included in the study was converted into an additive, aggregate risk level using a series of mathematical operations. The resulting risk levels served as inputs for a least-cost (least-risk) network model. A Fortran code of Floyd's algorithm accepted the risk level inputs and provided the optimal paths between each of the nodes in the network, along with a cumulative risk level for each path. Both the factor level calculation process and the network model are flexible enough to be applied for similar analysis in other cities.
# Model for the Routing of Hazardous Material Transports through the Central Business District of Dallas

## Table of Contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Background Information</td>
<td>1</td>
</tr>
<tr>
<td>II</td>
<td>Goals of Study</td>
<td>5</td>
</tr>
<tr>
<td>III</td>
<td>Data Inventory</td>
<td>5</td>
</tr>
<tr>
<td>IV</td>
<td>Risk Level Calculation</td>
<td>6</td>
</tr>
<tr>
<td>V</td>
<td>Routing Model Network Definition</td>
<td>8</td>
</tr>
<tr>
<td>VI</td>
<td>Analysis of the Network</td>
<td>14</td>
</tr>
<tr>
<td>VII</td>
<td>Analysis of Program Output</td>
<td>16</td>
</tr>
<tr>
<td>VIII</td>
<td>Related Issues</td>
<td>17</td>
</tr>
<tr>
<td>IX</td>
<td>Conclusions</td>
<td>18</td>
</tr>
<tr>
<td>Appendices</td>
<td></td>
<td>19</td>
</tr>
<tr>
<td>- A:</td>
<td>Risk Level Calculation for Segments</td>
<td>20</td>
</tr>
<tr>
<td>- B:</td>
<td>Program Using Floyd's Algorithm</td>
<td>24</td>
</tr>
<tr>
<td>- C:</td>
<td>Input to Floyd's Algorithm</td>
<td>28</td>
</tr>
<tr>
<td>- D:</td>
<td>Output from Floyd's Algorithm</td>
<td>30</td>
</tr>
<tr>
<td>- E:</td>
<td>Sample Route Paths</td>
<td>35</td>
</tr>
</tbody>
</table>
Model for the Routing of Hazardous Material Transports through the Central Business District of Dallas

SECTION I: BACKGROUND INFORMATION

Many developments involving advanced technology have surfaced in the past twenty years. These high technology developments have brought upon many negative side-effects, such as the production of hazardous waste and the handling of these materials. Presently there exist several problems with the transportation of hazardous materials in Texas. These problems include the shortage of available information, the lack of safety concerns for trucks and automobiles, the obscure restrictions and largely unenforced regulations regarding the transportation of hazardous materials.

The most significant problem with the routing of hazardous materials is the unavailability of information regarding accidents that occur on Texas highways. For example, there are no state policies requiring the reporting of information regarding accidents in which hazardous materials are involved. Presently, the Texas Department of Transportation does not account for all accidents in detail. Important details that are not acknowledged at the site of an accident include the location of the accident, what materials, if any, the vehicles were transporting, the amount of these materials, and whether or not any citations were issued to involved vehicles.

The available statistics emphasize the importance of monitoring hazardous material transport activities in Texas.
According to the most recent survey, Texas has the second largest number of trucks transporting hazardous materials. These 45,000 trucks travel over 1.6 billion miles each year. With this many trucks transversing the state, the occurrence of accidents is expected. However, the Texas Department of Highways reports that sixty-five percent of recorded accidents involving hazardous materials are caused by inattention to safety precautions and insufficient planning. In addition, over ninety percent of commercial vehicle accidents are the result of driver error.

Unfortunately, there is only one vague restriction for routing hazardous materials in Texas regulated by the Department of Transportation. Article 49 CFR 379.9 states:

Unless there is no practicable alternative, a motor vehicle which contains hazardous materials must be operated over routes which do not go through or near heavily populated areas, places at which crowds are assembled, tunnels, narrow streets, or alleys.

Because of the lack of more precise state restrictions, studies have been completed concerning the routing of hazardous materials on Texas roadways. Dan Kessler, the Senior Transportation Planner at the Transportation and Energy Department of the North Central Texas Council of Governments, conducted three such studies concerning the routing of hazardous material transports through the Dallas Central Business District. Kessler conducted these studies in an effort to assess and compare the risks involved with freeway and arterial route transporting. Current statistics show that 29% of all freeway accidents, resulting in injury, involve trucks, as opposed to only 17% of
arterial route accidents.

The first study Kessler completed was "Phase II" in 1985. This study simulated seventeen risk assessments using several variables including impact distance and risk measures. The impact distance is the area in the proximity of an accident, and the risk measure is the risk involved in transporting hazardous materials. Kessler used the Federal Administration's Risk Assessment Guidelines to determine the risk levels. Once he determined these risk levels, he used a ratio to compare the freeway risk level with the arterial risk level. If, in dividing the freeway risk level by the arterial risk level, the resulting ratio is greater than one, the arterial route is safer. If the ratio is less than one, then the freeway is safer.

Kessler's study concluded that freeways are generally safer than arterial routes. However, after viewing the study, the Dallas Fire Department suggested that the severity of accidents, the frequency of truck accidents, and the below-grade portions of the freeways should be addressed in the next study.

Kessler's second study, "Hazardous Materials Routing Study Analysis of Frequency and Severity on Freeways and Arterials," was completed in 1986. He used the same methods as in "Phase II," however, he altered the variables. This study was conducted for several reasons. The first and most important reason was to address potential accident exposure to special event populations. The aim was to determine the relative potential severity of freeway accidents compared to arterial route accidents. Kessler also added some additional routing options. He wanted to reconsider the
proximity of routes to local businesses. Kessler discovered that some of the routes presented maneuvering difficulties for large trucks. In addition, he wished to address the issue of evacuation procedures and emergency vehicle access in the case of a hazardous material accident.

By using ratios to compare freeways against arterial routes, Kessler discovered that truck accident severity is two-thirds higher for freeways than arterial routes. The Dallas Fire Department, however, was still concerned about emergency response capabilities.

This concern prompted Kessler's third study, "Analysis of Arterial Routing Options for Hazardous Materials Truck Shipment in the Dallas Central Business District Area" in 1987. This study addressed the same issues as the 1986 study. Kessler used the same variables, however additional routes were included in his new analysis.

The study suggested some safer alternative routes, however the travel time tended to increase as safety increased. This conclusion also presented the dilemma of having hazardous material transports travel a greater distance, possibly exposing more people to danger in an accident situation. Kessler's final conclusion emphasized that several problems and variables associated with hazardous material routing are in need of further investigation. A selection of these problems and variables are the focus of the study that will be described in the following pages.
SECTION II: GOALS OF STUDY

The initial decision in the routing study was to declare the most significant and influential factors or variables when considering a routing problem. These factors would be the subject of a statistical analysis in order to determine their effects and influences on the overall risk assessment for a route or segment. After defining a method of calculating segment risk, a logical model will be created that will allow for the assessment of the safest route (theoretical) for a given transport to take between any two points, or nodes, in the Central Business District of Dallas. Ideally, the model will be flexible enough to accommodate studies in other cities with similar or very different routing patterns.

SECTION III: DATA INVENTORY

The North Central Texas Council of Governments provided an abundance of statistical data and general information concerning the routes of the Central Business District. Much of the data had been generated by the Texas Department of Highways. Specific data judged to be a significant contribution to the overall risk level of roadways was filtered from the data mass. The significant data included applicable segment names and lengths, average annual accidents for each segment, and average daily traffic for each segment. Summary statistics of tractor-trailer accidents, and the severity of these accidents, were also used. Finally, population figures were drawn from the data. The total population figure was broken down into three categories, the residents in proximity of
the segment, the individuals employed in proximity of the segment, and the average vehicle occupants at a given moment of time during the day. The vehicle occupants figure is weighted to reflect a daytime average that is two times that of the night average. The above data must be converted from its raw state into an aggregate risk level that will accurately reflect the effects of all pertinent factors incorporated into its calculation. For the purpose of producing additive input values for the routing model, a level, as opposed to a factor, will be more appropriate.

SECTION IV: RISK LEVEL CALCULATION

The risk level calculation is a multi-step process that incorporates the raw data at various stages. (A simplified representation of the calculations can be found in Appendix A.) The first step entails the multiplication of the average daily traffic by the number of days in a calendar year (365). This number was selected for the purpose of simplicity; however, a weighted figure (weighted for weekdays or working days) could be substituted if more applicable to the specific study being conducted. The product of this calculation is an average annual traffic value. This value is then multiplied by the segment length giving the annual vehicle miles travelled (VMT) value. Dividing the VMT, first by one million and, second, by the average number of semi-truck accidents per year yields the truck accident probability per million VMT, which will be used in a later calculation. From the accident statistic data, the number of injury or fatality semi-truck accidents is divided by the total number of semi-truck
accidents. The resulting semi-truck accident severity adjustment factor is based on the assumption that an injury or fatality accident is generally capable of resulting in the release of hazardous materials. By multiplying the adjustment factor by the previously determined truck accident probability per million VMT, an adjusted truck accident probability per million VMT is produced. At this point, the population values for the segment are combined to provide a total exposure or accident consequence value. The value is multiplied by the segment length to provide a total exposure miles product, $^A\text{value with people X miles as a unit.}$ The final step of the risk level calculation involves the multiplication of the total exposure miles by the adjusted truck accident probability per million VMT. The product of this operation is the exposure risk level, which will be used in the routing model. The spreadsheet used for the above series of calculations can be found at the end of Appendix A.

The exposure risk level was judged satisfactory by its ability to accurately reflect the population associated with the segment, the segment length, and the accident characteristics and probabilities for the segment. Because the level will be additive for vehicles travelling over more than one segment, it is a suitable input for many types of least-cost or shortest-distance routing models.
SECTION V: ROUTING MODEL NETWORK DEFINITION

The Central business District area of Dallas has numerous freeways feeding in and out of it, frequently used by hazardous materials transports. This characteristic made the area an ideal candidate for a network analysis. The freeway routes used in the analysis are: I-35, I-30, I-45, U.S. 75 Central Expressway, and Spur 386 or Woodall Rogers. Figure 1 shows the freeway routes used in our analysis. The arterial routes used in the analysis are: Continent/Industrial, Industrial, Industrial/Corinth/Lamar, Corinth/Central Expressway/Pearl Expressway, Good Latimer/U.S. 75, and Canton/1st Avenue/2nd Avenue/Parry/Peak. Figure 2 shows the arterial routes used in our analysis. A schematic of all of the routes, both arterial and freeway, is presented in Figure 3. Several pairs of nodes, Node 1 and Node 2, Node 2 to Node 3, Node 6 to Node 5, and Node 6 to Node 7, have more than one possible route between them. By referring to the previously calculated exposure risk levels, the route in each pair with the highest risk level was eliminated from the network. The route which was retained is highlighted in bold in Figure 4. Routes A3, A4, F3 and F4 all have unique links and were, therefore, required to remain in the network. No alternate route exists for Woodall Rodgers (F7), designating the freeway a vital link in the network. The elimination of routes F1, F2, A5 and A6 resulted in our revised network, Figure 5, with one risk level between any two pair of nodes.
FREEWAY ROUTES THROUGH
DALLAS CENTRAL BUSINESS DISTRICT

I.H 35

SPUR 386

U.S. 75

I-30

I-45

FIGURE 1
ALL POSSIBLE ROUTES THROUGH THE DALLAS CENTRAL BUSINESS DISTRICT
RISK LEVELS ON CBD ROUTES

<table>
<thead>
<tr>
<th>Route Code</th>
<th>Description</th>
<th>Risk Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>Continent/Industrial</td>
<td>1,001</td>
</tr>
<tr>
<td>F1</td>
<td>I-35 Stemmons</td>
<td>3,969</td>
</tr>
<tr>
<td>A2</td>
<td>Industrial</td>
<td>486</td>
</tr>
<tr>
<td>F2</td>
<td>I-30, I-35 Common</td>
<td>1,790</td>
</tr>
<tr>
<td>A3</td>
<td>Industrial/Corinth/Lamar</td>
<td>3,279</td>
</tr>
<tr>
<td>F3</td>
<td>I-30</td>
<td>14,474</td>
</tr>
<tr>
<td>A4</td>
<td>Corinth/Central Expwy/Pear Expwy</td>
<td>9,466</td>
</tr>
<tr>
<td>F4</td>
<td>I-45</td>
<td>5,191</td>
</tr>
<tr>
<td>A5</td>
<td>Good Latimer/U.S. 75</td>
<td>12,123</td>
</tr>
<tr>
<td>F6</td>
<td>U.S. 75</td>
<td>6,561</td>
</tr>
<tr>
<td>A6</td>
<td>Canton/1st Ave./2nd Ave./Parry/Peak</td>
<td>6,759</td>
</tr>
<tr>
<td>F5</td>
<td>I-30 E. R.L. Thorton</td>
<td>4,928</td>
</tr>
<tr>
<td>F7</td>
<td>Spur 386/Woodall Rogers</td>
<td>10,057</td>
</tr>
</tbody>
</table>
LEAST RISK ROUTES THROUGH THE DALLAS CENTRAL BUSINESS DISTRICT
SECTION VI: ANALYSIS OF THE NETWORK

To determine the minimum risk for travel between all pairs of nodes in the network, an algorithm called Floyd's algorithm (Figure 6) was implemented. $L_{ij}$ is defined as the risk level between node $i$ and node $j$. If nodes $i$ and $j$ are not directly adjacent, $L_{ij}$ receives a value of infinity ($\infty$), a number that will prevent the route from being considered a possibility. The risk level between any node and itself is defined as zero (0). The algorithm uses a series of imbedded "do loops" which run from $k,i,$ and $j$ to $N$ where $N$ is the number of nodes in the network. The primary operation of the algorithm is similar to matrix multiplication, however, addition replaces multiplication operations and minimization replaces addition operations.

Floyd's algorithm was coded into Fortran by Dr. Dick Helgason. A listing of the actual code can be found in Appendix B. The program requires the following inputs: the number of nodes in the network (eight in the current study), a list of information about the network including all adjacent node pairs, the risk level assigned to the arc between these node pairs, and an indicator telling if the arc is uni- or bi-directional, using a "1" or "2" respectively. In the Central Business District network, all the risk levels are the same between nodes $i$ and $j$ in either direction. Therefore, the input was minimized by listing the arcs only once and by declaring them bi-directional. Input for this study is listed in Appendix C.

The program output contains the path of minimum risk between every two nodes in the network. Nodes which are next to one
FLOYD'S ALGORITHM

\[ L_{ij} = \begin{cases} 
\text{length of arc between node } i \text{ and } j \\
+\infty \text{ if no link between node } i \text{ and } j 
\end{cases} \]

\[ L_{ii} = 0 \]

\[ \begin{align*}
    &k = 1 \text{ to } N \\
    &i = 1 \text{ to } N \\
    &j = 1 \text{ to } N
\end{align*} \]

where \( N \) is the number of Nodes in the Network

\[ L_{ij}^{(k)} = \min(L_{ij}^{(k-1)}, L_{ik}^{(k-1)} + L_{kj}^{(k-1)}) \]
another are indicated by the words, "is a link". The risk level on the arc is then provided. When the path from one node to another involves the use of intermediary nodes, the intermediary nodes are listed in the order that they would be encountered, along with the risk level incurred travelling to each. The risk levels incurred along the path are added together, the sum being the total risk level for the path between the start and end nodes. The output file for the study network data is displayed in Appendix D.

SECTION VII: ANALYSIS OF PROGRAM OUTPUT

The path with the maximum risk is the path between Node 1 and Node 5 with a risk level of 14,885. This path uses the links A1 (west on Continent and south on Industrial), A2 (south on Industrial), A3 (south on Industrial to Corinth, and south on Lamar to I-45), F4 (I-45 north), and F5 (I-30 east bound). The same links are used between any intermediary node and the start or end node. For instance, the path between Node 2 and Node 5 uses the same intermediary arcs as the path between Node 1 and Node 5. This property is consistent throughout the network. Also, because of the bi-directional nature of the arcs, the path between Node 1 and Node 5 is the same as the path between Node 5 and Node 1; this holds true for any pair of nodes in the network. The arcs F3 (risk level 14,474) and A4 (risk level 9,466) are never selected as paths because of their high risk levels. Examples of several route paths are given in Appendix E.
SECTION VIII: RELATED ISSUES

The effects of altering the input factors can be approximated through an informal sensitivity analysis. Using the risk level calculation spreadsheet, input data can be easily altered. The ripple effects of the changes appear as risk level variation. By performing this type of analysis, it was determined that segment length has the least effect on the risk level outcome. An increase in the segment length increases the annual VMT. If the number of accidents remains constant for the segment, the accident probability per million VMT will decrease. The result is a risk level that is nearly unchanged. Because the population figures are a direct multiple in the risk level calculation, altering their values has a direct relationship to the final risk level value. Increasing or decreasing the number of annual accidents per segment has the greatest effect on the resulting risk level (a direct relationship). Because the number of accidents is used early in the risk level calculation procedure, (during the accident probability determination), slight increases or decreases have a significant effect on the risk level.

The results of the network portion of this study can also be altered by modifying the node structure. When considering paths which require the transition from a freeway to an arterial route (or the opposite), a cost or risk level can be assigned to the intermediary node. This is achieved by splitting the intermediary node into two "dummy" nodes. An appropriate risk level will then be assigned to the new arc between the "dummy" nodes.
SECTION IX: CONCLUSIONS

The hazardous material transport routing study has illustrated a method of determining the safest routes between locations in the Central Business District of Dallas. Raw data has been converted into an aggregate risk level that serves as an input to a network analysis model. The risk level calculation process and the network routing program are flexible enough to be applied to the routing scenarios that exist in different locations. The procedure can be modified by incorporating additional factors and characteristics unique to specific locations.
APPENDICES
Appendix A

Risk Level Calculation for Segments
RISK LEVEL CALCULATION

THE PROCESS BEGINS ...

- For each segment included in the study:

<table>
<thead>
<tr>
<th>STEP 1:</th>
<th>'Average Daily Traffic ( \times 365 ) = Average Annual Traffic</th>
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<tbody>
<tr>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>STEP 2:</th>
<th>Average Annual Traffic ( \times ) Segment Length = Vehicle Miles Travelled (VMT)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| STEP 3: | 'Annual Vehicle Miles Travelled (VMT) \( \div \) 'Average Semi-truck Accidents = Truck Accident Probability Per Million VMT |
|---------|----------------------------------------------------------------|---------------------------------------------------------------|
|         |                                                                 |

| STEP 4: | 'Number of Injury or Fatality Semi-truck Accidents \( \div \) 'Total Semi-truck Accidents = Semi-truck Severity Adjustment Factor |
|---------|----------------------------------------------------------------|---------------------------------------------------------------|
|         |                                                                 |

| STEP 5: | Truck Accident Probability Per Million VMT \( \times \) Adjusted Truck Accident Probability Per Million VMT |
|---------|----------------------------------------------------------------|---------------------------------------------------------------|
|         |                                                                 |

* Data provided
RISK LEVEL CALCULATION

THE PROCESS CONTINUES...

**STEP 6:**

\[\text{Total Employment in Segment Proximity} \times \text{Population Residing in Segment Proximity} \times \text{Average Vehicle Occupants per Segment Proximity} = \text{Exposure or Accident Segment Consequence (67% day, 33% night)}\]

**STEP 7:**

\[\text{Total Exposure or Accident Consequence (Step 6)} \times \text{Segment Length} = \text{Total Exposure Miles (People* miles)}\]

**STEP 8:**

\[\text{Total Exposure Miles (Step 7)} \times \text{Adjusted Truck Accident Probability Per Million VMT (Step 5)} = \text{Exposure Risk Level (Used in model)}\]

* Data provided
<table>
<thead>
<tr>
<th>ROUTE</th>
<th>ROUTE DESCRIPTION</th>
<th>Length (Miles)</th>
<th>Annual Traffic Estimate (Av. daily traffic # 365 days)</th>
<th>Average Vehicle Miles Traveled (Seg. length # Ann. traffic)</th>
<th>Original Accident Prob. per Million VNT</th>
<th>Semi-truck Accident Prob. per Million VNT</th>
<th>Accident Severity Adjustment Factor Adj. factor</th>
<th>Total Employment in segment</th>
<th>Population Residing In segment</th>
<th>Average Vehicle Occupants Per segment</th>
<th>67% day 33% night Exposure Miles</th>
<th>Accident Consequence (sum of 3 columns to left)</th>
<th>Risk Level (Total Exp. miles * Accident Prob.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>Continent</td>
<td>1.31</td>
<td>8,030,000</td>
<td>10,519,300</td>
<td>0.1901</td>
<td>0.1765</td>
<td>0.034</td>
<td>22,024</td>
<td>630</td>
<td>103</td>
<td>22,767</td>
<td>29825</td>
<td>1001</td>
</tr>
<tr>
<td>A2</td>
<td>Industrial</td>
<td>0.70</td>
<td>8,760,000</td>
<td>6,132,000</td>
<td>0.5219</td>
<td>0.1765</td>
<td>0.092</td>
<td>7,319</td>
<td>40</td>
<td>182</td>
<td>7,541</td>
<td>5279</td>
<td>486</td>
</tr>
<tr>
<td>A3</td>
<td>Ind./Corinth/Lamar</td>
<td>3.41</td>
<td>6,570,000</td>
<td>22,403,700</td>
<td>0.1875</td>
<td>0.1765</td>
<td>0.033</td>
<td>19,956</td>
<td>9,016</td>
<td>90</td>
<td>29,062</td>
<td>99101</td>
<td>3279</td>
</tr>
<tr>
<td>A4</td>
<td>Corinth/Cent./Pearl</td>
<td>1.70</td>
<td>4,745,000</td>
<td>8,066,500</td>
<td>0.2727</td>
<td>0.1765</td>
<td>0.048</td>
<td>109,951</td>
<td>5,539</td>
<td>180</td>
<td>115,670</td>
<td>196639</td>
<td>9466</td>
</tr>
<tr>
<td>A5</td>
<td>Good Lat./US 75</td>
<td>1.52</td>
<td>3,285,000</td>
<td>9,993,200</td>
<td>0.6008</td>
<td>0.1765</td>
<td>0.106</td>
<td>70,858</td>
<td>4,236</td>
<td>119</td>
<td>75,213</td>
<td>114324</td>
<td>12123</td>
</tr>
<tr>
<td>A6</td>
<td>Canton/1st/2nd/Ferry/Peak</td>
<td>2.36</td>
<td>2,920,000</td>
<td>6,891,200</td>
<td>0.2322</td>
<td>0.1765</td>
<td>0.041</td>
<td>51,966</td>
<td>17,765</td>
<td>127</td>
<td>69,888</td>
<td>164936</td>
<td>6759</td>
</tr>
</tbody>
</table>

| F1    | IH 35 Stearns          | 1.59           | 67,525,000                                              | 107,364,750                                               | 0.2291                                   | 0.3138                                   | 0.072                                         | 33,464                               | 634                               | 622                                 | 34,720                              | 55205                           | 3969                                          |
| F2    | IH 30 IH 35 Common     | 1.17           | 67,160,000                                              | 78,577,200                                               | 0.4581                                   | 0.3138                                   | 0.144                                         | 10,111                               | 105                               | 428                                 | 10,644                              | 12453                           | 1790                                          |
| F3    | IH 30                  | 2.31           | 50,735,000                                              | 117,197,050                                               | 0.4079                                   | 0.3138                                   | 0.128                                         | 43,751                               | 4,577                             | 629                                 | 48,957                              | 113090                          | 14474                                         |
| F4    | IH 45                  | 3.50           | 29,200,000                                              | 102,200,000                                              | 0.1037                                   | 0.3138                                   | 0.033                                         | 30,324                               | 14,783                            | 462                                 | 45,569                              | 159491                          | 5191                                          |
| F5    | IH 30 E. R.L.T.        | 1.49           | 46,720,000                                              | 69,379,200                                               | 0.3027                                   | 0.3138                                   | 0.095                                         | 20,910                               | 13,603                            | 424                                 | 34,937                              | 51882                           | 4928                                          |
| F6    | IH 345/US 75           | 2.40           | 39,055,000                                              | 93,556,725                                               | 0.0877                                   | 0.3138                                   | 0.028                                         | 88,858                               | 10,258                            | 467                                 | 99,583                              | 238502                          | 6561                                          |
| F7    | SH 366/SH 366          | 2.23           | 22,630,000                                              | 50,351,750                                               | 0.1390                                   | 0.3138                                   | 0.044                                         | 97,146                               | 6,219                             | 244                                 | 103,609                             | 230530                          | 10057                                         |
Appendix B

Program Using Floyd's Algorithm
PROGRAM MAIN

Program to compute shortest paths using Floyd's algorithm.
Written by R. Helgason
3/15/92
Modified by R. Helgason
4/21/92
Will now detail the link composition of the shortest paths.

IMPLICIT NONE
INT INTEGER ORIGD(20,20)
INTEGER PATHD(20,20)
INTEGER USING(20,20)
INTEGER HOW(2,20)
INTEGER MAXNOD, NODES
INTEGER I, J, K, L, M, Q, D, W; BIG
REAL SUM

MAXNOD = 20

WRITE(*,*) 'Input Number of Nodes:
READ(*,*) NODES
WRITE(*,*) NODES, ' Nodes'
IF(NODES . GT . MAXNOD) STOP 'Too Many'

DO 20 I=1, NODES
DO 10 J=1, NODES
  ORIGD(I,J) = -1
10 CONTINUE
ORIGD(I,I) = 0
20 CONTINUE

WRITE(*,*) 'Input From Node, To Node, Distance, 1 or 2 (way) Quadruples *(0 0 0 0 Ends Input):

SUM = 0

30 CONTINUE
READ(*,*) I, J, D, W
WRITE(*,*) I, J, D, W
IF(D.LT.0) STOP 'Neg. Distance'
IF(W.NE.0) THEN
  ORIGD(I,J) = D
  IF(W.EQ.2) ORIGD(J,I) = D
  SUM = SUM+D
ENDIF

BIG = 10**(1+IFIX(ALOG10(SUM)))

DO 50 I=1, NODES
DO 40 J=1, NODES
  IF(ORIGD(I,J).EQ.-1) THEN
    PATHD(I,J) = BIG
    USING(I,J) = -1
  ELSE
    PATHD(I,J) = ORIGD(I,J)
  ENDIF

END
USING(I,J) = 0
ENDIF

40 CONTINUE

50 CONTINUE

WRITE(*,200) (I,I=1,NODES)
WRITE(*,300) ('-----',I=1,NODES)
DO 55 I=1,NODES
   WRITE(*,400) I,(PATHD(I,J),J=1,NODES)
55 CONTINUE

WRITE(*,300) ('-----',I=1,NODES)

DO 80 K=1,NODES
    WRITE(*,100) K
    Compute Best Path Distance
    Using Nodes 1,...,K as
    Intermediate Nodes
    DO 70 I=1,NODES
        DO 70 J=1,NODES
            D = PATHD(I,K)+PATHD(K,J)
            WRITE(*,*) I,K,J,
            ' : ',PATHD(I,K),' + ',PATHD(K,J),
            ' = ',D,' ?<? ',PATHD(I,J)
            IF(D.LT.PATHD(I,J)) THEN
                WRITE(*,*) 'YES: UPDATE'
                PATHD(I,J) = D
                USING(I,J) = K
            ENDIF
    70 CONTINUE

WRITE(*,200) (I,I=1,NODES)
WRITE(*,300) ('-----',I=1,NODES)
DO 75 I=1,NODES
    WRITE(*,400) I,(PATHD(I,J),J=1,NODES)
75 CONTINUE

WRITE(*,300) ('-----',I=1,NODES)
WRITE(*,500)

80 CONTINUE

WRITE(*,300) ('-----',I=1,NODES)

85 CONTINUE

WRITE(*,300) ('-----',I=1,NODES)

80 CONTINUE

100 FORMAT(5X,'( K =',15,1)1)
200 FORMAT(5X,20I5)
300 FORMAT(5X,20A5)
400 FORMAT(I4,'::',20I5)
500 FORMAT(5X,' USING')
600 FORMAT(5X,'THE PATH FROM ',I5,' TO ',I5,' @ ',I5,' USES:')
610 FORMAT(5X,'THE PATH FROM ',I5,' TO ',I5,' @ ',I5,' IS A LINK')
620 FORMAT(5X,' NO PATH FROM ',I5,' TO ',I5,' !!!')
700 FORMAT(5X,' LINK FROM ',I5,' TO ',I5,' @ ',I5)
710 FORMAT(5X,46(' - '))

DO 99 I=1,NODES
    DO 98 J=1,NODES
IF(I.EQ.J) GO TO 98
WRITE(*,710)
L = USING(I,J)
IF(L.EQ.-1) THEN
   WRITE(*,620) I,J
   GO TO 98
ELSEIF(L.EQ.0) THEN
   WRITE(*,610) I,J,PATHD(I,J)
   GO TO 98
ELSE
   WRITE(*,600) I,J,PATHD(I,J)
   Q = 0
   K = I
   M = J
91 CONTINUE
C Separate
   Q = Q+1
   HOW(1,Q) = L
   HOW(2,Q) = M
   Q = Q+1
   HOW(1,Q) = K
   HOW(2,Q) = L
92 CONTINUE
IF(Q.EQ.0) GO TO 98
   K = HOW(1,Q)
   M = HOW(2,Q)
   Q = Q-1
   L = USING(K,M)
IF(L.EQ.0) THEN
   WRITE(*,700) K,M,ORIGD(K,M)
   GO TO 92
ELSE
   GO TO 91
ENDIF
ENDIF
98 CONTINUE
99 CONTINUE
   WRITE(*,710)
STOP 'ok'
END
Appendix C

Input to Floyd's Algorithm Program
<table>
<thead>
<tr>
<th></th>
<th>1</th>
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<th>10057</th>
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<tr>
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Appendix D

Output from Floyd's Algorithm Program
<table>
<thead>
<tr>
<th>THE PATH FROM</th>
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<th>2 @ 1001 IS A LINK</th>
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<tr>
<td>THE PATH FROM</td>
<td>1 TO</td>
<td>3 @ 1487 USES:</td>
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<td>LINK FROM</td>
<td>1 TO</td>
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</tr>
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<td>2 TO</td>
<td>3 @ 486</td>
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<td>1 TO</td>
<td>4 @ 4766 USES:</td>
</tr>
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<td>1 TO</td>
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<td>2 TO</td>
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</tr>
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<td>3 TO</td>
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<td>THE PATH FROM</td>
<td>1 TO</td>
<td>5 @ 14885 USES:</td>
</tr>
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<td>1 TO</td>
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</tr>
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<td>LINK FROM</td>
<td>3 TO</td>
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</tr>
<tr>
<td>LINK FROM</td>
<td>8 TO</td>
<td>4 @ 1639</td>
</tr>
<tr>
<td>LINK FROM</td>
<td>4 TO</td>
<td>6 @ 5191</td>
</tr>
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<td>6 TO</td>
<td>5 @ 4928</td>
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<tr>
<td>THE PATH FROM</td>
<td>1 TO</td>
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<td>1 TO</td>
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<td>LINK FROM</td>
<td>2 TO</td>
<td>3 @ 486</td>
</tr>
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<td>THE PATH FROM</td>
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<td>1 TO</td>
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<td>2 TO</td>
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</tr>
<tr>
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<td>4 TO</td>
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<td>THE PATH FROM</td>
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<td>LINK FROM</td>
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</tr>
<tr>
<td>LINK FROM</td>
<td>4 TO</td>
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</tr>
<tr>
<td>THE PATH FROM</td>
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<td>7 @ 11058 USES:</td>
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</tr>
</tbody>
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THE PATH FROM 2 TO 8 @ 2126 USES:
LINK FROM 2 TO 3 @ 486
LINK FROM 3 TO 8 @ 1640

THE PATH FROM 3 TO 1 @ 1487 USES:
LINK FROM 3 TO 2 @ 486
LINK FROM 2 TO 1 @ 1001

THE PATH FROM 3 TO 2 @ 486 IS A LINK

THE PATH FROM 3 TO 4 @ 3279 USES:
LINK FROM 3 TO 8 @ 1640
LINK FROM 8 TO 4 @ 1639

THE PATH FROM 3 TO 5 @ 13398 USES:
LINK FROM 3 TO 8 @ 1640
LINK FROM 8 TO 4 @ 1639
LINK FROM 4 TO 6 @ 5191
LINK FROM 6 TO 5 @ 4928

THE PATH FROM 3 TO 6 @ 8470 USES:
LINK FROM 3 TO 8 @ 1640
LINK FROM 8 TO 4 @ 1639
LINK FROM 4 TO 6 @ 5191

THE PATH FROM 3 TO 7 @ 11544 USES:
LINK FROM 3 TO 2 @ 486
LINK FROM 2 TO 1 @ 1001
LINK FROM 1 TO 7 @ 10057

THE PATH FROM 3 TO 8 @ 1640 IS A LINK

THE PATH FROM 4 TO 1 @ 4766 USES:
LINK FROM 4 TO 8 @ 1639
LINK FROM 8 TO 3 @ 1640
LINK FROM 3 TO 2 @ 486
LINK FROM 2 TO 1 @ 1001

THE PATH FROM 4 TO 2 @ 3765 USES:
LINK FROM 4 TO 8 @ 1639
LINK FROM 8 TO 3 @ 1640
LINK FROM 3 TO 2 @ 486

THE PATH FROM 4 TO 3 @ 3279 USES:
LINK FROM 4 TO 8 @ 1639
LINK FROM 8 TO 3 @ 1640

THE PATH FROM 4 TO 5 @ 10119 USES:
LINK FROM 4 TO 6 @ 5191
LINK FROM 6 TO 5 @ 4928

THE PATH FROM 4 TO 6 @ 5191 IS A LINK

THE PATH FROM 4 TO 7 @ 11752 USES:
LINK FROM 4 TO 6 @ 5191
LINK FROM 6 TO 7 @ 6561

THE PATH FROM 4 TO 8 @ 1639 IS A LINK
THE PATH FROM 5 TO 1: 14885
- LINK FROM 5 TO 6: 4928
- LINK FROM 6 TO 4: 5191
- LINK FROM 4 TO 8: 1639
- LINK FROM 8 TO 3: 1640
- LINK FROM 3 TO 2: 486
- LINK FROM 2 TO 1: 1001

THE PATH FROM 5 TO 2: 13884
- LINK FROM 5 TO 6: 4928
- LINK FROM 6 TO 4: 5191
- LINK FROM 4 TO 8: 1639
- LINK FROM 8 TO 3: 1640
- LINK FROM 3 TO 2: 486

THE PATH FROM 5 TO 3: 13398
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- LINK FROM 6 TO 4: 5191
- LINK FROM 4 TO 8: 1639
- LINK FROM 8 TO 3: 1640

THE PATH FROM 5 TO 4: 10119
- LINK FROM 5 TO 6: 4928
- LINK FROM 6 TO 4: 5191

THE PATH FROM 5 TO 6: 4928
- LINK FROM 5 TO 6: 4928

THE PATH FROM 5 TO 7: 11489
- LINK FROM 5 TO 6: 4928
- LINK FROM 6 TO 7: 6561

THE PATH FROM 5 TO 8: 11758
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- LINK FROM 6 TO 4: 5191
- LINK FROM 4 TO 8: 1639

THE PATH FROM 6 TO 1: 9957
- LINK FROM 6 TO 4: 5191
- LINK FROM 4 TO 8: 1639
- LINK FROM 8 TO 3: 1640
- LINK FROM 3 TO 2: 486
- LINK FROM 2 TO 1: 1001

THE PATH FROM 6 TO 2: 8956
- LINK FROM 6 TO 4: 5191
- LINK FROM 4 TO 8: 1639
- LINK FROM 8 TO 3: 1640
- LINK FROM 3 TO 2: 486

THE PATH FROM 6 TO 3: 8470
- LINK FROM 6 TO 4: 5191
- LINK FROM 4 TO 8: 1639
- LINK FROM 8 TO 3: 1640

THE PATH FROM 6 TO 4: 5191
- LINK FROM 6 TO 4: 5191

THE PATH FROM 6 TO 5: 4928
- LINK FROM 6 TO 4: 5191

THE PATH FROM 6 TO 7: 6561
- LINK FROM 6 TO 4: 5191

THE PATH FROM 6 TO 8: 11758
- LINK FROM 6 TO 4: 5191
- LINK FROM 4 TO 8: 1639

THE PATH FROM 6 TO 9: 9957
- LINK FROM 6 TO 4: 5191
- LINK FROM 4 TO 8: 1639
- LINK FROM 8 TO 3: 1640
- LINK FROM 3 TO 2: 486

THE PATH FROM 6 TO 10: 8956
- LINK FROM 6 TO 4: 5191
- LINK FROM 4 TO 8: 1639
- LINK FROM 8 TO 3: 1640
- LINK FROM 3 TO 2: 486

THE PATH FROM 6 TO 11: 8470
- LINK FROM 6 TO 4: 5191
- LINK FROM 4 TO 8: 1639
- LINK FROM 8 TO 3: 1640

THE PATH FROM 6 TO 12: 5191
- LINK FROM 6 TO 4: 5191

THE PATH FROM 6 TO 13: 4928
- LINK FROM 6 TO 4: 5191

THE PATH FROM 6 TO 14: 6561
- LINK FROM 6 TO 4: 5191

THE PATH FROM 6 TO 15: 6561
- LINK FROM 6 TO 4: 5191
Appendix E

Sample Route Paths
LEAST RISK ROUTE FROM NODE 1 TO NODE 5
(S. BOUND I-35 TO E. BOUND I-30)
LEAST RISK ROUTE FROM NODE 2 TO NODE 5
(E. BOUND 1-30 TO E.BOUND 1-30)
LEAST RISK ROUTE FROM NODE 3 TO NODE 5
(N. BOUND 1-35 TO E. BOUND 1-30)
LEAST RISK ROUTE FROM NODE 8 TO NODE 5
LEAST RISK ROUTE FROM NODE 4 TO NODE 5
(N. BOUND 1-45 TO E. BOUND 1-30)
LEAST RISK ROUTE FROM NODE 6 TO NODE 5
(E. BOUND 1-30 CONTINUING E. BOUND 1-30)
LEAST RISK ROUTE FROM NODE 5 TO NODE 7
(W. BOUND I-30 TO N. BOUND U.S 75)
LEAST RISK ROUTE FROM NODE 4 TO NODE 7  
(N. BOUND I-45 CONTINUING TO N. BOUND U.S 75)
LEAST RISK ROUTE FROM NODE 8 TO NODE 7
LEAST RISK ROUTE FROM NODE 7 TO NODE 3
(N. BOUND I-35 TO N. BOUND U.S. 75)
MODEL FOR THE ROUTING OF HAZARDOUS MATERIAL TRANSPORTS THROUGH THE CENTRAL BUSINESS DISTRICT OF DALLAS

Rene Anderson
Joseph Davila
Michael Rowland

CSE 4395 - Senior Design
May 8, 1992
Abstract

The objective of this study was to define a method of calculating freeway and arterial route segment risk levels, and to create a logical model that will allow for the assessment of the safest route for a transport to take between any two points (or nodes) within the Central Business District of Dallas. The significant raw data available for the segments included in the study was converted into an additive, aggregate risk level using a series of mathematical operations. The resulting risk levels served as inputs for a least-cost (least-risk) network model. A Fortran code of Floyd's algorithm accepted the risk level inputs and provided the optimal paths between each of the nodes in the network, along with a cumulative risk level for each path. Both the factor level calculation process and the network model are flexible enough to be applied for similar analysis in other cities.
# Model for the Routing of Hazardous Material Transports through the Central Business District of Dallas

## Table of Contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Background Information</td>
<td>1</td>
</tr>
<tr>
<td>II</td>
<td>Goals of Study</td>
<td>5</td>
</tr>
<tr>
<td>III</td>
<td>Data Inventory</td>
<td>5</td>
</tr>
<tr>
<td>IV</td>
<td>Risk Level Calculation</td>
<td>6</td>
</tr>
<tr>
<td>V</td>
<td>Routing Model Network Definition</td>
<td>8</td>
</tr>
<tr>
<td>VI</td>
<td>Analysis of the Network</td>
<td>14</td>
</tr>
<tr>
<td>VII</td>
<td>Analysis of Program Output</td>
<td>16</td>
</tr>
<tr>
<td>VIII</td>
<td>Related Issues</td>
<td>17</td>
</tr>
<tr>
<td>IX</td>
<td>Conclusions</td>
<td>18</td>
</tr>
<tr>
<td>Appendices</td>
<td></td>
<td>19</td>
</tr>
<tr>
<td>- A:</td>
<td>Risk Level Calculation</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>for Segments</td>
<td></td>
</tr>
<tr>
<td>- B:</td>
<td>Program Using Floyd's Algorithm</td>
<td>24</td>
</tr>
<tr>
<td>- C:</td>
<td>Input to Floyd's Algorithm</td>
<td>28</td>
</tr>
<tr>
<td>- D:</td>
<td>Output from Floyd's Algorithm</td>
<td>30</td>
</tr>
<tr>
<td>- E:</td>
<td>Sample Route Paths</td>
<td>35</td>
</tr>
</tbody>
</table>
MODEL FOR THE ROUTING OF HAZARDOUS MATERIAL TRANSPORTS THROUGH THE CENTRAL BUSINESS DISTRICT OF DALLAS

SECTION I: BACKGROUND INFORMATION

Many developments involving advanced technology have surfaced in the past twenty years. These high technology developments have brought upon many negative side-effects, such as the production of hazardous waste and the handling of these materials. Presently there exist several problems with the transportation of hazardous materials in Texas. These problems include the shortage of available information, the lack of safety concerns for trucks and automobiles, the obscure restrictions and largely unenforced regulations regarding the transportation of hazardous materials.

The most significant problem with the routing of hazardous materials is the unavailability of information regarding accidents that occur on Texas highways. For example, there are no state policies requiring the reporting of information regarding accidents in which hazardous materials are involved. Presently, the Texas Department of Transportation does not account for all accidents in detail. Important details that are not acknowledged at the site of an accident include the location of the accident, what materials, if any, the vehicles were transporting, the amount of these materials, and whether or not any citations were issued to involved vehicles.

The available statistics emphasize the importance of monitoring hazardous material transport activities in Texas.
According to the most recent survey, Texas has the second largest number of trucks transporting hazardous materials. These 45,000 trucks travel over 1.6 billion miles each year. With this many trucks transversing the state, the occurrence of accidents is expected. However, the Texas Department of Highways reports that sixty-five percent of recorded accidents involving hazardous materials are caused by inattention to safety precautions and insufficient planning. In addition, over ninety percent of commercial vehicle accidents are the result of driver error.

Unfortunately, there is only one vague restriction for routing hazardous materials in Texas regulated by the Department of Transportation. Article 49 CFR 379.9 states:

Unless there is no practicable alternative, a motor vehicle which contains hazardous materials must be operated over routes which do not go through or near heavily populated areas, places at which crowds are assembled, tunnels, narrow streets, or alleys.

Because of the lack of more precise state restrictions, studies have been completed concerning the routing of hazardous materials on Texas roadways. Dan Kessler, the Senior Transportation Planner at the Transportation and Energy Department of the North Central Texas Council of Governments, conducted three such studies concerning the routing of hazardous material transports through the Dallas Central Business District. Kessler conducted these studies in an effort to assess and compare the risks involved with freeway and arterial route transporting. Current statistics show that 29% of all freeway accidents, resulting in injury, involve trucks, as opposed to only 17% of
arterial route accidents.

The first study Kessler completed was "Phase II" in 1985. This study simulated seventeen risk assessments using several variables including impact distance and risk measures. The impact distance is the area in the proximity of an accident, and the risk measure is the risk involved in transporting hazardous materials. Kessler used the Federal Administration's Risk Assessment Guidelines to determine the risk levels. Once he determined these risk levels, he used a ratio to compare the freeway risk level with the arterial risk level. If, in dividing the freeway risk level by the arterial risk level, the resulting ratio is greater than one, the arterial route is safer. If the ratio is less than one, then the freeway is safer.

Kessler's study concluded that freeways are generally safer than arterial routes. However, after viewing the study, the Dallas Fire Department suggested that the severity of accidents, the frequency of truck accidents, and the below-grade portions of the freeways should be addressed in the next study.

Kessler's second study, "Hazardous Materials Routing Study Analysis of Frequency and Severity on Freeways and Arterials," was completed in 1986. He used the same methods as in "Phase II," however, he altered the variables. This study was conducted for several reasons. The first and most important reason was to address potential accident exposure to special event populations. The aim was to determine the relative potential severity of freeway accidents compared to arterial route accidents. Kessler also added some additional routing options. He wanted to reconsider the
proximity of routes to local businesses. Kessler discovered that some of the routes presented maneuvering difficulties for large trucks. In addition, he wished to address the issue of evacuation procedures and emergency vehicle access in the case of a hazardous material accident.

By using ratios to compare freeways against arterial routes, Kessler discovered that truck accident severity is two-thirds higher for freeways than arterial routes. The Dallas Fire Department, however, was still concerned about emergency response capabilities.

This concern prompted Kessler's third study, "Analysis of Arterial Routing Options for Hazardous Materials Truck Shipment in the Dallas Central Business District Area" in 1987. This study addressed the same issues as the 1986 study. Kessler used the same variables, however additional routes were included in his new analysis.

The study suggested some safer alternative routes, however the travel time tended to increase as safety increased. This conclusion also presented the dilemma of having hazardous material transports travel a greater distance, possibly exposing more people to danger in an accident situation. Kessler's final conclusion emphasized that several problems and variables associated with hazardous material routing are in need of further investigation. A selection of these problems and variables are the focus of the study that will be described in the following pages.
SECTION II: GOALS OF STUDY

The initial decision in the routing study was to declare the most significant and influential factors or variables when considering a routing problem. These factors would be the subject of a statistical analysis in order to determine their effects and influences on the overall risk assessment for a route or segment. After defining a method of calculating segment risk, a logical model will be created that will allow for the assessment of the safest route (theoretical) for a given transport to take between any two points, or nodes, in the Central Business District of Dallas. Ideally, the model will be flexible enough to accommodate studies in other cities with similar or very different routing patterns.

SECTION III: DATA INVENTORY

The North Central Texas Council of Governments provided an abundance of statistical data and general information concerning the routes of the Central Business District. Much of the data had been generated by the Texas Department of Highways. Specific data judged to be a significant contribution to the overall risk level of roadways was filtered from the data mass. The significant data included applicable segment names and lengths, average annual accidents for each segment, and average daily traffic for each segment. Summary statistics of tractor-trailer accidents, and the severity of these accidents, were also used. Finally, population figures were drawn from the data. The total population figure was broken down into three categories, the residents in proximity of
the segment, the individuals employed in proximity of the segment, and the average vehicle occupants at a given moment of time during the day. The vehicle occupants figure is weighted to reflect a daytime average that is two times that of the night average. The above data must be converted from its raw state into an aggregate risk level that will accurately reflect the effects of all pertinent factors incorporated into its calculation. For the purpose of producing additive input values for the routing model, a level, as opposed to a factor, will be more appropriate.

SECTION IV: RISK LEVEL CALCULATION

The risk level calculation is a multi-step process that incorporates the raw data at various stages. (A simplified representation of the calculations can be found in Appendix A.) The first step entails the multiplication of the average daily traffic by the number of days in a calendar year (365). This number was selected for the purpose of simplicity; however, a weighted figure (weighted for weekdays or working days) could be substituted if more applicable to the specific study being conducted. The product of this calculation is an average annual traffic value. This value is then multiplied by the segment length giving the annual vehicle miles travelled (VMT) value. Dividing the VMT, first by one million and, second, by the average number of semi-truck accidents per year yields the truck accident probability per million VMT, which will be used in a later calculation. From the accident statistic data, the number of injury or fatality semi-truck accidents is divided by the total number of semi-truck
accidents. The resulting semi-truck accident severity adjustment factor is based on the assumption that an injury or fatality accident is generally capable of resulting in the release of hazardous materials. By multiplying the adjustment factor by the previously determined truck accident probability per million VMT, an adjusted truck accident probability per million VMT is produced. At this point, the population values for the segment are combined to provide a total exposure or accident consequence value. The value is multiplied by the segment length to provide a total exposure miles product, value with people X miles as a unit. The final step of the risk level calculation involves the multiplication of the total exposure miles by the adjusted truck accident probability per million VMT. The product of this operation is the exposure risk level, which will be used in the routing model. The spreadsheet used for the above series of calculations can be found at the end of Appendix A.

The exposure risk level was judged satisfactory by its ability to accurately reflect the population associated with the segment, the segment length, and the accident characteristics and probabilities for the segment. Because the level will be additive for vehicles travelling over more than one segment, it is a suitable input for many types of least-cost or shortest-distance routing models.
SECTION V: ROUTING MODEL NETWORK DEFINITION

The Central business District area of Dallas has numerous freeways feeding in and out of it, frequently used by hazardous materials transports. This characteristic made the area an ideal candidate for a network analysis. The freeway routes used in the analysis are: I-35, I-30, I-45, U.S. 75 Central Expressway, and Spur 386 or Woodall Rogers. Figure 1 shows the freeway routes used in our analysis. The arterial routes used in the analysis are: Continent/Industrial, Industrial, Industrial/Corinth/Lamar, Corinth/Central Expressway/Pearl Expressway, Good Latimer/U.S. 75, and Canton/1st Avenue/2nd Avenue/Parry/Peak. Figure 2 shows the arterial routes used in our analysis. A schematic of all of the routes, both arterial and freeway, is presented in Figure 3. Several pairs of nodes, Node 1 and Node 2, Node 2 to Node 3, Node 6 to Node 5, and Node 6 to Node 7, have more than one possible route between them. By referring to the previously calculated exposure risk levels, the route in each pair with the highest risk level was eliminated from the network. The route which was retained is highlighted in bold in Figure 4. Routes A3, A4, F3 and F4 all have unique links and were, therefore, required to remain in the network. No alternate route exists for Woodall Rodgers (F7), designating the freeway a vital link in the network. The elimination of routes F1, F2, A5 and A6 resulted in our revised network, Figure 5, with one risk level between any two pair of nodes.
FREEWAY ROUTES THROUGH
DALLAS CENTRAL BUSINESS DISTRICT

I.H 35
SPUR 386
U.S. 75
1-30
1-45
1-30
ALL POSSIBLE ROUTES THROUGH THE
DALLAS CENTRAL BUSINESS DISTRICT

FIGURE 3
### FIGURE 4

#### RISK LEVELS ON CBD ROUTES

<table>
<thead>
<tr>
<th></th>
<th>Description</th>
<th>Risk Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>Continent/Industrial</td>
<td>1,001</td>
</tr>
<tr>
<td>F1</td>
<td>I-35 Stemmons</td>
<td>3,969</td>
</tr>
<tr>
<td>A2</td>
<td>Industrial</td>
<td>486</td>
</tr>
<tr>
<td>F2</td>
<td>I-30, I-35 Common</td>
<td>1,790</td>
</tr>
<tr>
<td>A3</td>
<td>Industrial/Corinth/Lamar</td>
<td>3,279</td>
</tr>
<tr>
<td>F3</td>
<td>I-30</td>
<td>14,474</td>
</tr>
<tr>
<td>A4</td>
<td>Corinth/Central Expwy/Pear Expwy</td>
<td>9,466</td>
</tr>
<tr>
<td>F4</td>
<td>I-45</td>
<td>5,191</td>
</tr>
<tr>
<td>A5</td>
<td>Good Latimer/U.S. 75</td>
<td>12,123</td>
</tr>
<tr>
<td>F6</td>
<td>U.S. 75</td>
<td>6,561</td>
</tr>
<tr>
<td>A6</td>
<td>Canton/1st Ave./2nd Ave./Parry/Peak</td>
<td>6,759</td>
</tr>
<tr>
<td>F5</td>
<td>I-30 E. R.L. Thorton</td>
<td>4,928</td>
</tr>
<tr>
<td>F7</td>
<td>Spur 386/Woodall Rogers</td>
<td>10,057</td>
</tr>
</tbody>
</table>
LEAST RISK ROUTES THROUGH THE
DALLAS CENTRAL BUSINESS DISTRICT
SECTION VI: ANALYSIS OF THE NETWORK

To determine the minimum risk for travel between all pairs of nodes in the network, an algorithm called Floyd's algorithm (Figure 6) was implemented. \( L_{ij} \) is defined as the risk level between node \( i \) and node \( j \). If nodes \( i \) and \( j \) are not directly adjacent, \( L_{ij} \) receives a value of infinity (\( \infty \)), a number that will prevent the route from being considered a possibility. The risk level between any node and itself is defined as zero (0). The algorithm uses a series of imbedded "do loops" which run from \( k, i, \) and \( j \) to \( N \) where \( N \) is the number of nodes in the network. The primary operation of the algorithm is similar to matrix multiplication, however, addition replaces multiplication operations and minimization replaces addition operations.

Floyd's algorithm was coded into Fortran by Dr. Dick Helgason. A listing of the actual code can be found in Appendix B. The program requires the following inputs: the number of nodes in the network (eight in the current study), a list of information about the network including all adjacent node pairs, the risk level assigned to the arc between these node pairs, and an indicator telling if the arc is uni- or bi-directional, using a "1" or "2" respectively. In the Central Business District network, all the risk levels are the same between nodes \( i \) and \( j \) in either direction. Therefore, the input was minimized by listing the arcs only once and by declaring them bi-directional. Input for this study is listed in Appendix C.

The program output contains the path of minimum risk between every two nodes in the network. Nodes which are next to one
FLOYD'S ALGORITHM

\[ L_{ij} = \begin{cases} \text{length of arc between node } i \text{ and } j \\ +\infty \text{ if no link between node } i \text{ and } j \end{cases} \]

\[ L_{ii} = 0 \]

\[ k = 1 \text{ to } N \]
\[ i = 1 \text{ to } N \]
\[ j = 1 \text{ to } N \]

where \( N \) is the number of Nodes in the Network.

\[ L_{ij}^{(k-1)} = \min(L_{ij}, L_{ik}^{(k-1)} + L_{kj}^{(k-1)}) \]
another are indicated by the words, "is a link". The risk level on the arc is then provided. When the path from one node to another involves the use of intermediary nodes, the intermediary nodes are listed in the order that they would be encountered, along with the risk level incurred travelling to each. The risk levels incurred along the path are added together, the sum being the total risk level for the path between the start and end nodes. The output file for the study network data is displayed in Appendix D.

SECTION VII: ANALYSIS OF PROGRAM OUTPUT

The path with the maximum risk is the path between Node 1 and Node 5 with a risk level of 14,885. This path uses the links A1 (west on Continent and south on Industrial), A2 (south on Industrial), A3 (south on Industrial to Corinth, and south on Lamar to I-45), F4 (I-45 north), and F5 (I-30 east bound). The same links are used between any intermediary node and the start or end node. For instance, the path between Node 2 and Node 5 uses the same intermediary arcs as the path between Node 1 and Node 5. This property is consistent throughout the network. Also, because of the bi-directional nature of the arcs, the path between Node 1 and Node 5 is the same as the path between Node 5 and Node 1; this holds true for any pair of nodes in the network. The arcs F3 (risk level 14,474) and A4 (risk level 9,466) are never selected as paths because of their high risk levels. Examples of several route paths are given in Appendix E.
SECTION VIII: RELATED ISSUES

The effects of altering the input factors can be approximated through an informal sensitivity analysis. Using the risk level calculation spreadsheet, input data can be easily altered. The ripple effects of the changes appear as risk level variation. By performing this type of analysis, it was determined that segment length has the least effect on the risk level outcome. An increase in the segment length increases the annual VMT. If the number of accidents remains constant for the segment, the accident probability per million VMT will decrease. The result is a risk level that is nearly unchanged. Because the population figures are a direct multiple in the risk level calculation, altering their values has a direct relationship to the final risk level value. Increasing or decreasing the number of annual accidents per segment has the greatest effect on the resulting risk level (a direct relationship). Because the number of accidents is used early in the risk level calculation procedure, (during the accident probability determination), slight increases or decreases have a significant effect on the risk level.

The results of the network portion of this study can also be altered by modifying the node structure. When considering paths which require the transition from a freeway to an arterial route (or the opposite), a cost or risk level can be assigned to the intermediary node. This is achieved by splitting the intermediary node into two "dummy" nodes. An appropriate risk level will then be assigned to the new arc between the "dummy" nodes.
SECTION IX: CONCLUSIONS

The hazardous material transport routing study has illustrated a method of determining the safest routes between locations in the Central Business District of Dallas. Raw data has been converted into an aggregate risk level that serves as an input to a network analysis model. The risk level calculation process and the network routing program are flexible enough to be applied to the routing scenarios that exist in different locations. The procedure can be modified by incorporating additional factors and characteristics unique to specific locations.
Appendix A

Risk Level Calculation for Segments
RISK LEVEL CALCULATION

THE PROCESS BEGINS ...

- For each segment included in the study:

**STEP 1:**

- Average Daily Traffic \( \times \frac{365}{\text{days/year}} \) \( = \) Average Annual Traffic

**STEP 2:**

- Average Annual Traffic \( \times \) Segment Length (miles) \( = \) Vehicle Miles Travelled (VMT)

**STEP 3:**

- Average Annual Semi-truck Accidents \( \div \) Annual Miles Travelled (VMT) \( = \) Truck Accident Probability Per Million VMT

**STEP 4:**

- Number of Semi-truck Accidents \( \div \) Total Semi-truck Accident Severity Adjustment Factor

**STEP 5:**

- Truck Accident Probability Per Million VMT \( \times \) Semi-truck Accident Severity Adjustment Factor \( \div \) Adjusted Truck Accident Probability Per Million VMT

* Data provided
RISK LEVEL CALCULATION

THE PROCESS CONTINUES ...

**STEP 6:**
- Total Employment in Segment Proximity
- Population Residing in Segment Proximity
- Average Vehicle Occupants per Accident Segment Consequence

**STEP 7:**
- Total Exposure or Accident Consequence (Step 6) X Segment Length

**STEP 8:**
- Total Exposure Miles (Step 7) X Adjusted Truck Accident Probability Per Million VMT (Step 5)
- Total Exposure Risk Level (Used in model)

* Data provided
<table>
<thead>
<tr>
<th>ROUTE</th>
<th>ROUTE DESCRIPTION</th>
<th>Segment Length (Miles)</th>
<th>Average Annual Traffic (Av. daily traffic x 365 days)</th>
<th>Annual Vehicle Miles Travelled (Seg. length + Ann. traffic)</th>
<th>Original Accident Prob. per Million VMT</th>
<th>Accident Severity Factor</th>
<th>Adj. factor</th>
<th>Risk Level Calculation Spreadsheet</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>Continent</td>
<td>1.31</td>
<td>8,030,000</td>
<td>10,519,300</td>
<td>0.1901</td>
<td>0.1765</td>
<td>0.034</td>
<td>22,034</td>
</tr>
<tr>
<td>A2</td>
<td>Industrial</td>
<td>0.70</td>
<td>8,760,000</td>
<td>6,833,000</td>
<td>0.5219</td>
<td>0.1765</td>
<td>0.092</td>
<td>7,319</td>
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<tr>
<td>A3</td>
<td>Ind./Corinth/Lamar</td>
<td>3.41</td>
<td>6,570,000</td>
<td>22,463,700</td>
<td>0.1875</td>
<td>0.1765</td>
<td>0.033</td>
<td>19,956</td>
</tr>
<tr>
<td>A4</td>
<td>Corinth/Cent./Pear</td>
<td>1.70</td>
<td>4,745,000</td>
<td>8,066,000</td>
<td>0.2727</td>
<td>0.1765</td>
<td>0.048</td>
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<tr>
<td>A5</td>
<td>Good Lat./US 75</td>
<td>1.52</td>
<td>3,285,000</td>
<td>4,993,200</td>
<td>0.6008</td>
<td>0.1765</td>
<td>0.106</td>
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<tr>
<td>A6</td>
<td>Canton/1st/2nd/</td>
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<td>6,891,200</td>
<td>0.2322</td>
<td>0.1765</td>
<td>0.041</td>
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<tr>
<td></td>
<td>Parry/Pea.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F1</td>
<td>IH 35 Steamons</td>
<td>1.59</td>
<td>67,525,000</td>
<td>107,364,750</td>
<td>0.2291</td>
<td>0.3138</td>
<td>0.072</td>
<td>33,464</td>
</tr>
<tr>
<td>F2</td>
<td>IH 30 IH 35 COLOR</td>
<td>1.17</td>
<td>67,160,000</td>
<td>78,577,200</td>
<td>0.4581</td>
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<td>2.31</td>
<td>50,735,000</td>
<td>117,197,850</td>
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<td>102,290,000</td>
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<td>0.3138</td>
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<tr>
<td>F5</td>
<td>IH 30 E.R.L.T.</td>
<td>1.49</td>
<td>46,720,000</td>
<td>99,379,200</td>
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<td>0.3138</td>
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<td>F6</td>
<td>IH 345/US 75</td>
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<td>0.3138</td>
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<tr>
<td>F7</td>
<td>SH 168/171 Rogers</td>
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<td>22,630,000</td>
<td>50,351,750</td>
<td>0.1390</td>
<td>0.3138</td>
<td>0.044</td>
<td>97,146</td>
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</tbody>
</table>

**People**

- **Miles**: 23
- **Accidents**: 8,030,000
- **Cars**: 0.1901
- **Car-Miles**: 0.1765
- **People**: 0.034
- **Accident Consequence**: 22,034
- **Exposure Miles**: 33,464
- **Risk Level**: 55205
- **Total Segment Length**: 29825
- **Exp. miles**: 3969
- **Accident Prob.**: 1001
Appendix B

Program Using Floyd's Algorithm
PROGRAM MAIN
Program to compute shortest paths using Floyd's algorithm.
Written by R. Helgason
3/15/92
Modified by R. Helgason
4/21/92
Will now detail the link composition of the shortest paths.
IMPLICIT NONE
INTEGER ORIGD(20,20)
INTEGER PATHD(20,20)
INTEGER USING(20,20)
INTEGER HOW(2,20)
INTEGER MAXNOD,NODES
INTEGER I,J,K,L,M,Q,D,W,BIG
REAL SUM

MAXNOD = 20

WRITE(*,*) 'Input Number of Nodes:
READ(*,*) NODES
WRITE(*,*) NODES,' Nodes'
IF(NODES.GT.MAXNOD) STOP 'Too Many'

DO 20 I=1,NODES
  DO 10 J=1,NODES
    ORIGD(I,J) = -1
  0 CONTINUE
  ORIGD(I,I) = 0
  0 CONTINUE

WRITE(*,*) 'Input From Node, *To Node, Distance, 1 or 2 (way) Quadruples *(0 0 0 0 Ends Input):'
SUM = 0

0 CONTINUE
READ(*,*) I,J,D,W
WRITE(*,*) I,J,D,W
IF(D.LT.0) STOP 'Neg. Distance'
IF(W.NE.0) THEN
  ORIGD(I,J) = D
  IF(W.EQ.2) ORIGD(J,I) = D
  SUM = SUM+D
  GO TO 30
ENDIF

BIG = 10**(1+IFIX(ALOG10(SUM)))

DO 50 I=1,NODES
  DO 40 J=1,NODES
    IF(ORIGD(I,J).EQ.-1) THEN
      PATHD(I,J) = BIG
      USING(I,J) = -1
    ELSE
      PATHD(I,J) = ORIGD(I,J)
    ENDIF
  40 CONTINUE
50 CONTINUE
Computing Best Path Distance

Using Nodes 1,...,K as Intermediate Nodes

DO 70 I=1,NODES
    DO 70 J=1,NODES
        D = PATHD(I,K)+PATHD(K,J)
        WRITE(*,*) I,K,J,
        ' : PATHD(I,K) + PATHD(K,J),
        ' = D, ?<? PATHD(I,J)
        IF(D.LT.PATHD(I,J)) THEN
            WRITE(*,*) ' YES: UPDATE'
            PATHD(I,J) = D
            USING(I,J) = K
        ENDIF
    CONTINUE

WRITE(*,200) (I,I=1,NODES)
WRITE(*,300) ('-----',I=1,NODES)
DO 75 I=1,NODES
    WRITE(*,400) I,(PATHD(I,J),J=1,NODES)
    5 CONTINUE
WRITE(*,300) ('-----',I=1,NODES)
WRITE(*,300) ('-----',I=1,NODES)
DO 80 K=1,NODES
    WRITE(*,100) K
    Compute Best Path Distance
    Using Nodes 1,...,K as Intermediate Nodes
    DO 70 I=1,NODES
        DO 70 J=1,NODES
            D = PATHD(I,K)+PATHD(K,J)
            WRITE(*,*) I,K,J,
            ' : PATHD(I,K) + PATHD(K,J),
            ' = D, ?<? PATHD(I,J)
            IF(D.LT.PATHD(I,J)) THEN
                WRITE(*,*) ' YES: UPDATE'
                PATHD(I,J) = D
                USING(I,J) = K
            ENDIF
        CONTINUE
    WRITE(*,200) (I,I=1,NODES)
    WRITE(*,300) ('-----',I=1,NODES)
    DO 75 I=1,NODES
        WRITE(*,400) I,(PATHD(I,J),J=1,NODES)
        5 CONTINUE
    WRITE(*,300) ('-----',I=1,NODES)
    WRITE(*,500)
    WRITE(*,200) (I,I=1,NODES)
    WRITE(*,300) ('-----',I=1,NODES)
    DO 85 I=1,NODES
        WRITE(*,400) I,(USING(I,J),J=1,NODES)
        85 CONTINUE
    WRITE(*,300) ('-----',I=1,NODES)
    DO 99 I=1,NODES
        DO 98 J=1,NODES
            98 CONTINUE
            99 CONTINUE

DO 99 I=1,NODES
    DO 98 J=1,NODES

26
IF(I.EQ.J) GO TO 98
WRITE(*,710)
L = USING(I,J)
IF(L.EQ.-1) THEN
   WRITE(*,620) I,J
   GO TO 98
ELSEIF(L.EQ.0) THEN
   WRITE(*,610) I,J,PATHD(I,J)
   GO TO 98
ELSE
   WRITE(*,600) I,J,PATHD(I,J)
   Q = 0
   K = I
   M = J
1   CONTINUE
Separate
   Q = Q+1
   HOW(1,Q) = L
   HOW(2,Q) = M
   Q = Q+1
   HOW(1,Q) = K
   HOW(2,Q) = L
2   CONTINUE
   IF(Q.EQ.0) GO TO 98
   K = HOW(1,Q)
   M = HOW(2,Q)
   Q = Q-1
   L = USING(K,M)
   IF(L.EQ.0) THEN
      WRITE(*,700) K,M,ORIGD(K,M)
      GO TO 92
   ELSE
      GO TO 91
   ENDIF
ENDIF
8 CONTINUE
9 CONTINUE
   WRITE(*,710)
STOP 'ok'
END
Appendix C

Input to Floyd's Algorithm Program
Appendix D

Output from Floyd's Algorithm Program
<table>
<thead>
<tr>
<th>The Path From</th>
<th>1 To</th>
<th>2 @</th>
<th>1001 is a link</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Path From</td>
<td>1 To</td>
<td>3 @</td>
<td>1487 Uses:</td>
</tr>
<tr>
<td>Link From</td>
<td>1 To</td>
<td>2 @</td>
<td>1001</td>
</tr>
<tr>
<td>Link From</td>
<td>2 To</td>
<td>3 @</td>
<td>486</td>
</tr>
<tr>
<td>The Path From</td>
<td>1 To</td>
<td>4 @</td>
<td>4766 Uses:</td>
</tr>
<tr>
<td>Link From</td>
<td>1 To</td>
<td>2 @</td>
<td>1001</td>
</tr>
<tr>
<td>Link From</td>
<td>2 To</td>
<td>3 @</td>
<td>486</td>
</tr>
<tr>
<td>Link From</td>
<td>3 To</td>
<td>8 @</td>
<td>1640</td>
</tr>
<tr>
<td>Link From</td>
<td>8 To</td>
<td>4 @</td>
<td>1639</td>
</tr>
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<td>1 To</td>
<td>2 @</td>
<td>1001</td>
</tr>
<tr>
<td>Link From</td>
<td>2 To</td>
<td>3 @</td>
<td>486</td>
</tr>
<tr>
<td>Link From</td>
<td>3 To</td>
<td>8 @</td>
<td>1640</td>
</tr>
<tr>
<td>Link From</td>
<td>8 To</td>
<td>4 @</td>
<td>1639</td>
</tr>
<tr>
<td>Link From</td>
<td>4 To</td>
<td>6 @</td>
<td>5191</td>
</tr>
<tr>
<td>Link From</td>
<td>6 To</td>
<td>5 @</td>
<td>4928</td>
</tr>
<tr>
<td>The Path From</td>
<td>1 To</td>
<td>6 @</td>
<td>9957 Uses:</td>
</tr>
<tr>
<td>Link From</td>
<td>1 To</td>
<td>2 @</td>
<td>1001</td>
</tr>
<tr>
<td>Link From</td>
<td>2 To</td>
<td>3 @</td>
<td>486</td>
</tr>
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- Link from 3 to 8 @ 1640

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- Link from 3 to 1 @ 1001

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- Link from 8 to 4 @ 1639

**The Path from 3 to 5 @ 13398 Uses:**
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- Link from 8 to 4 @ 1639
- Link from 4 to 6 @ 5191
- Link from 6 to 5 @ 4928

**The Path from 3 to 6 @ 8470 Uses:**
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- Link from 8 to 4 @ 1639
- Link from 4 to 6 @ 5191

**The Path from 3 to 7 @ 11544 Uses:**
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- Link from 1 to 7 @ 10057

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- Link from 2 to 1 @ 1001

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- Link from 8 to 3 @ 1640
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**The Path from 4 to 3 @ 3279 Uses:**
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LINK FROM  5 TO  6 @ 4928
LINK FROM  6 TO  7 @ 6561

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LEAST RISK ROUTE FROM NODE 3 TO NODE 5
(N. BOUND 1-35 TO E. BOUND 1-30)
LEAST RISK ROUTE FROM NODE 8 TO NODE 5
LEAST RISK ROUTE FROM NODE 4 TO NODE 5
(N. BOUND 1-45 TO E. BOUND 1-30)
LEAST RISK ROUTE FROM NODE 6 TO NODE 5
(E. BOUND 1-30 CONTINUING E. BOUND 1-30)
LEAST RISK ROUTE FROM NODE 5 TO NODE 7
(W. BOUND I-30 TO N. BOUND U.S 75)
LEAST RISK ROUTE FROM NODE 4 TO NODE 7
(N. BOUND I-45 CONTINUING TO N. BOUND U.S. 75)
LEAST RISK ROUTE FROM NODE 8 TO NODE 7
LEAST RISK ROUTE FROM NODE 7 TO NODE 3
(N. BOUND I-35 TO N. BOUND U.S. 75)
MODEL FOR THE ROUTING OF HAZARDOUS MATERIAL TRANSPORTS THROUGH THE CENTRAL BUSINESS DISTRICT OF DALLAS

Rene Anderson
Joseph Davila
Michael Rowland

CSE 4395 - Senior Design
May 8, 1992
Abstract

The objective of this study was to define a method of calculating freeway and arterial route segment risk levels, and to create a logical model that will allow for the assessment of the safest route for a transport to take between any two points (or nodes) within the Central Business District of Dallas. The significant raw data available for the segments included in the study was converted into an additive, aggregate risk level using a series of mathematical operations. The resulting risk levels served as inputs for a least-cost (least-risk) network model. A Fortran code of Floyd's algorithm accepted the risk level inputs and provided the optimal paths between each of the nodes in the network, along with a cumulative risk level for each path. Both the factor level calculation process and the network model are flexible enough to be applied for similar analysis in other cities.
# Table of Contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Background Information</td>
<td>1</td>
</tr>
<tr>
<td>II</td>
<td>Goals of Study</td>
<td>5</td>
</tr>
<tr>
<td>III</td>
<td>Data Inventory</td>
<td>5</td>
</tr>
<tr>
<td>IV</td>
<td>Risk Level Calculation</td>
<td>6</td>
</tr>
<tr>
<td>V</td>
<td>Routing Model Network Definition</td>
<td>8</td>
</tr>
<tr>
<td>VI</td>
<td>Analysis of the Network</td>
<td>14</td>
</tr>
<tr>
<td>VII</td>
<td>Analysis of Program Output</td>
<td>16</td>
</tr>
<tr>
<td>VIII</td>
<td>Related Issues</td>
<td>17</td>
</tr>
<tr>
<td>IX</td>
<td>Conclusions</td>
<td>18</td>
</tr>
<tr>
<td>Appendices</td>
<td></td>
<td>19</td>
</tr>
<tr>
<td>- A:</td>
<td>Risk Level Calculation for Segments</td>
<td>20</td>
</tr>
<tr>
<td>- B:</td>
<td>Program Using Floyd's Algorithm</td>
<td>24</td>
</tr>
<tr>
<td>- C:</td>
<td>Input to Floyd's Algorithm</td>
<td>28</td>
</tr>
<tr>
<td>- D:</td>
<td>Output from Floyd's Algorithm</td>
<td>30</td>
</tr>
<tr>
<td>- E:</td>
<td>Sample Route Paths</td>
<td>35</td>
</tr>
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</table>
Model for the Routing of Hazardous Material Transports through the Central Business District of Dallas

SECTION I: BACKGROUND INFORMATION

Many developments involving advanced technology have surfaced in the past twenty years. These high technology developments have brought upon many negative side-effects, such as the production of hazardous waste and the handling of these materials. Presently there exist several problems with the transportation of hazardous materials in Texas. These problems include the shortage of available information, the lack of safety concerns for trucks and automobiles, the obscure restrictions and largely unenforced regulations regarding the transportation of hazardous materials.

The most significant problem with the routing of hazardous materials is the unavailability of information regarding accidents that occur on Texas highways. For example, there are no state policies requiring the reporting of information regarding accidents in which hazardous materials are involved. Presently, the Texas Department of Transportation does not account for all accidents in detail. Important details that are not acknowledged at the site of an accident include the location of the accident, what materials, if any, the vehicles were transporting, the amount of these materials, and whether or not any citations were issued to involved vehicles.

The available statistics emphasize the importance of monitoring hazardous material transport activities in Texas.
According to the most recent survey, Texas has the second largest number of trucks transporting hazardous materials. These 45,000 trucks travel over 1.6 billion miles each year. With this many trucks transversing the state, the occurrence of accidents is expected. However, the Texas Department of Highways reports that sixty-five percent of recorded accidents involving hazardous materials are caused by inattention to safety precautions and insufficient planning. In addition, over ninety percent of commercial vehicle accidents are the result of driver error.

Unfortunately, there is only one vague restriction for routing hazardous materials in Texas regulated by the Department of Transportation. Article 49 CFR 379.9 states:

Unless there is no practicable alternative, a motor vehicle which contains hazardous materials must be operated over routes which do not go through or near heavily populated areas, places at which crowds are assembled, tunnels, narrow streets, or alleys.

Because of the lack of more precise state restrictions, studies have been completed concerning the routing of hazardous materials on Texas roadways. Dan Kessler, the Senior Transportation Planner at the Transportation and Energy Department of the North Central Texas Council of Governments, conducted three such studies concerning the routing of hazardous material transports through the Dallas Central Business District. Kessler conducted these studies in an effort to assess and compare the risks involved with freeway and arterial route transporting. Current statistics show that 29% of all freeway accidents, resulting in injury, involve trucks, as opposed to only 17% of
arterial route accidents.

The first study Kessler completed was "Phase II" in 1985. This study simulated seventeen risk assessments using several variables including impact distance and risk measures. The impact distance is the area in the proximity of an accident, and the risk measure is the risk involved in transporting hazardous materials. Kessler used the Federal Administration's Risk Assessment Guidelines to determine the risk levels. Once he determined these risk levels, he used a ratio to compare the freeway risk level with the arterial risk level. If, in dividing the freeway risk level by the arterial risk level, the resulting ratio is greater than one, the arterial route is safer. If the ratio is less than one, then the freeway is safer.

Kessler's study concluded that freeways are generally safer than arterial routes. However, after viewing the study, the Dallas Fire Department suggested that the severity of accidents, the frequency of truck accidents, and the below-grade portions of the freeways should be addressed in the next study.

Kessler's second study, "Hazardous Materials Routing Study Analysis of Frequency and Severity on Freeways and Arterials," was completed in 1986. He used the same methods as in "Phase II," however, he altered the variables. This study was conducted for several reasons. The first and most important reason was to address potential accident exposure to special event populations. The aim was to determine the relative potential severity of freeway accidents compared to arterial route accidents. Kessler also added some additional routing options. He wanted to reconsider the
proximity of routes to local businesses. Kessler discovered that some of the routes presented maneuvering difficulties for large trucks. In addition, he wished to address the issue of evacuation procedures and emergency vehicle access in the case of a hazardous material accident.

By using ratios to compare freeways against arterial routes, Kessler discovered that truck accident severity is two-thirds higher for freeways than arterial routes. The Dallas Fire Department, however, was still concerned about emergency response capabilities.

This concern prompted Kessler's third study, "Analysis of Arterial Routing Options for Hazardous Materials Truck Shipment in the Dallas Central Business District Area" in 1987. This study addressed the same issues as the 1986 study. Kessler used the same variables, however additional routes were included in his new analysis.

The study suggested some safer alternative routes, however the travel time tended to increase as safety increased. This conclusion also presented the dilemma of having hazardous material transports travel a greater distance, possibly exposing more people to danger in an accident situation. Kessler's final conclusion emphasized that several problems and variables associated with hazardous material routing are in need of further investigation. A selection of these problems and variables are the focus of the study that will be described in the following pages.
SECTION II: GOALS OF STUDY

The initial decision in the routing study was to declare the most significant and influential factors or variables when considering a routing problem. These factors would be the subject of a statistical analysis in order to determine their effects and influences on the overall risk assessment for a route or segment. After defining a method of calculating segment risk, a logical model will be created that will allow for the assessment of the safest route (theoretical) for a given transport to take between any two points, or nodes, in the Central Business District of Dallas. Ideally, the model will be flexible enough to accommodate studies in other cities with similar or very different routing patterns.

SECTION III: DATA INVENTORY

The North Central Texas Council of Governments provided an abundance of statistical data and general information concerning the routes of the Central Business District. Much of the data had been generated by the Texas Department of Highways. Specific data judged to be a significant contribution to the overall risk level of roadways was filtered from the data mass. The significant data included applicable segment names and lengths, average annual accidents for each segment, and average daily traffic for each segment. Summary statistics of tractor-trailer accidents, and the severity of these accidents, were also used. Finally, population figures were drawn from the data. The total population figure was broken down into three categories, the residents in proximity of
the segment, the individuals employed in proximity of the segment, and the average vehicle occupants at a given moment of time during the day. The vehicle occupants figure is weighted to reflect a daytime average that is two times that of the night average. The above data must be converted from its raw state into an aggregate risk level that will accurately reflect the effects of all pertinent factors incorporated into its calculation. For the purpose of producing additive input values for the routing model, a level, as opposed to a factor, will be more appropriate.

SECTION IV: RISK LEVEL CALCULATION

The risk level calculation is a multi-step process that incorporates the raw data at various stages. (A simplified representation of the calculations can be found in Appendix A.) The first step entails the multiplication of the average daily traffic by the number of days in a calendar year (365). This number was selected for the purpose of simplicity; however, a weighted figure (weighted for weekdays or working days) could be substituted if more applicable to the specific study being conducted. The product of this calculation is an average annual traffic value. This value is then multiplied by the segment length giving the annual vehicle miles travelled (VMT) value. Dividing the VMT, first by one million and, second, by the average number of semi-truck accidents per year yields the truck accident probability per million VMT, which will be used in a later calculation. From the accident statistic data, the number of injury or fatality semi-truck accidents is divided by the total number of semi-truck
accidents. The resulting semi-truck accident severity adjustment factor is based on the assumption that an injury or fatality accident is generally capable of resulting in the release of hazardous materials. By multiplying the adjustment factor by the previously determined truck accident probability per million VMT, an adjusted truck accident probability per million VMT is produced. At this point, the population values for the segment are combined to provide a total exposure or accident consequence value. The value is multiplied by the segment length to provide a total exposure miles product, \( \lambda \) value with people X miles as a unit. The final step of the risk level calculation involves the multiplication of the total exposure miles by the adjusted truck accident probability per million VMT. The product of this operation is the exposure risk level, which will be used in the routing model. The spreadsheet used for the above series of calculations can be found at the end of Appendix A.

The exposure risk level was judged satisfactory by its ability to accurately reflect the population associated with the segment, the segment length, and the accident characteristics and probabilities for the segment. Because the level will be additive for vehicles travelling over more than one segment, it is a suitable input for many types of least-cost or shortest-distance routing models.
SECTION V: ROUTING MODEL NETWORK DEFINITION

The Central business District area of Dallas has numerous freeways feeding in and out of it, frequently used by hazardous materials transports. This characteristic made the area an ideal candidate for a network analysis. The freeway routes used in the analysis are: I-35, I-30, I-45, U.S. 75 Central Expressway, and Spur 386 or Woodall Rogers. Figure 1 shows the freeway routes used in our analysis. The arterial routes used in the analysis are: Continent/Industrial, Industrial, Industrial/Corinth/Lamar, Corinth/Central Expressway/Pearl Expressway, Good Latimer/U.S. 75, and Canton/1st Avenue/2nd Avenue/Parry/Peak. Figure 2 shows the arterial routes used in our analysis. A schematic of all of the routes, both arterial and freeway, is presented in Figure 3. Several pairs of nodes, Node 1 and Node 2, Node 2 to Node 3, Node 6 to Node 5, and Node 6 to Node 7, have more than one possible route between them. By referring to the previously calculated exposure risk levels, the route in each pair with the highest risk level was eliminated from the network. The route which was retained is highlighted in bold in Figure 4. Routes A3, A4, F3 and F4 all have unique links and were, therefore, required to remain in the network. No alternate route exists for Woodall Rodgers (F7), designating the freeway a vital link in the network. The elimination of routes F1, F2, A5 and A6 resulted in our revised network, Figure 5, with one risk level between any two pair of nodes.
FREEWAY ROUTES THROUGH
DALLAS CENTRAL BUSINESS DISTRICT

FIGURE 1
ALL POSSIBLE ROUTES THROUGH THE
DALLAS CENTRAL BUSINESS DISTRICT
# FIGURE 4

## RISK LEVELS ON CBD ROUTES

<table>
<thead>
<tr>
<th>A1</th>
<th>Continent/Industrial</th>
<th>1,001</th>
</tr>
</thead>
<tbody>
<tr>
<td>F1</td>
<td>I-35 Stemmons</td>
<td>3,969</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A2</td>
<td>Industrial</td>
<td>486</td>
</tr>
<tr>
<td>F2</td>
<td>I-30, I-35 Common</td>
<td>1,790</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A3</td>
<td>Industrial/Corinth/Lamar</td>
<td>3,279</td>
</tr>
<tr>
<td>F3</td>
<td>I-30</td>
<td>14,474</td>
</tr>
<tr>
<td>A4</td>
<td>Corinth/Central Expwy/Pear Expwy</td>
<td>9,466</td>
</tr>
<tr>
<td>F4</td>
<td>I-45</td>
<td>5,191</td>
</tr>
<tr>
<td>A5</td>
<td>Good Latimer/U.S. 75</td>
<td>12,123</td>
</tr>
<tr>
<td>F6</td>
<td>U.S. 75</td>
<td>6,561</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A6</td>
<td>Canton/1st Ave./2nd Ave./Parry/Peak</td>
<td>6,759</td>
</tr>
<tr>
<td>F5</td>
<td>I-30 E. R.L. Thorton</td>
<td>4,928</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F7</td>
<td>Spur 386/Woodall Rogers</td>
<td>10,057</td>
</tr>
</tbody>
</table>
LEAST RISK ROUTES THROUGH THE
DALLAS CENTRAL BUSINESS DISTRICT
SECTION VI: ANALYSIS OF THE NETWORK

To determine the minimum risk for travel between all pairs of nodes in the network, an algorithm called Floyd's algorithm (Figure 6) was implemented. \( L_{ij} \) is defined as the risk level between node \( i \) and node \( j \). If nodes \( i \) and \( j \) are not directly adjacent, \( L_{ij} \) receives a value of infinity (\( \infty \)), a number that will prevent the route from being considered a possibility. The risk level between any node and itself is defined as zero (0). The algorithm uses a series of imbedded "do loops" which run from \( k, i, \) and \( j \) to \( N \) where \( N \) is the number of nodes in the network. The primary operation of the algorithm is similar to matrix multiplication, however, addition replaces multiplication operations and minimization replaces addition operations.

Floyd's algorithm was coded into Fortran by Dr. Dick Helgason. A listing of the actual code can be found in Appendix B. The program requires the following inputs: the number of nodes in the network (eight in the current study), a list of information about the network including all adjacent node pairs, the risk level assigned to the arc between these node pairs, and an indicator telling if the arc is uni- or bi-directional, using a "1" or "2" respectively. In the Central Business District network, all the risk levels are the same between nodes \( i \) and \( j \) in either direction. Therefore, the input was minimized by listing the arcs only once and by declaring them bi-directional. Input for this study is listed in Appendix C.

The program output contains the path of minimum risk between every two nodes in the network. Nodes which are next to one
FLOYD'S ALGORITHM

\[ L_{ij} = \begin{cases} \\
\text{length of arc between node } i \text{ and } j \\
+\infty \text{ if no link between node } i \text{ and } j \\
\end{cases} \]

\[ L_{ii} = 0 \]

\[ k = 1 \text{ to } N \]
\[ i = 1 \text{ to } N \]
\[ j = 1 \text{ to } N \]

where \( N \) is the number of Nodes in the Network

\[ L_{ij}^{(k)} = \min(L_{ij}^{(k-1)}, L_{ik}^{(k-1)} + L_{kj}^{(k-1)}) \]
another are indicated by the words, "is a link". The risk level on
the arc is then provided. When the path from one node to another
involves the use of intermediary nodes, the intermediary nodes are
listed in the order that they would be encountered, along with the
risk level incurred travelling to each. The risk levels incurred
along the path are added together, the sum being the total risk
level for the path between the start and end nodes. The output
file for the study network data is displayed in Appendix D.

SECTION VII: ANALYSIS OF PROGRAM OUTPUT

The path with the maximum risk is the path between Node 1 and
Node 5 with a risk level of 14,885. This path uses the links A1
(west on Continent and south on Industrial), A2 (south on
Industrial), A3 (south on Industrial to Corinth, and south on Lamar
to I-45), F4 (I-45 north), and F5 (I-30 east bound). The same
links are used between any intermediary node and the start or end
node. For instance, the path between Node 2 and Node 5 uses the
same intermediary arcs as the path between Node 1 and Node 5. This
property is consistent throughout the network. Also, because of
the bi-directional nature of the arcs, the path between Node 1 and
Node 5 is the same as the path between Node 5 and Node 1; this
holds true for any pair of nodes in the network. The arcs F3 (risk
level 14,474) and A4 (risk level 9,466) are never selected as paths
because of their high risk levels. Examples of several route paths
are given in Appendix E.
SECTION VIII: RELATED ISSUES

The effects of altering the input factors can be approximated through an informal sensitivity analysis. Using the risk level calculation spreadsheet, input data can be easily altered. The ripple effects of the changes appear as risk level variation. By performing this type of analysis, it was determined that segment length has the least effect on the risk level outcome. An increase in the segment length increases the annual VMT. If the number of accidents remains constant for the segment, the accident probability per million VMT will decrease. The result is a risk level that is nearly unchanged. Because the population figures are a direct multiple in the risk level calculation, altering their values has a direct relationship to the final risk level value. Increasing or decreasing the number of annual accidents per segment has the greatest effect on the resulting risk level (a direct relationship). Because the number of accidents is used early in the risk level calculation procedure, (during the accident probability determination), slight increases or decreases have a significant effect on the risk level.

The results of the network portion of this study can also be altered by modifying the node structure. When considering paths which require the transition from a freeway to an arterial route (or the opposite), a cost or risk level can be assigned to the intermediary node. This is achieved by splitting the intermediary node into two "dummy" nodes. An appropriate risk level will then be assigned to the new arc between the "dummy" nodes.
SECTION IX: CONCLUSIONS

The hazardous material transport routing study has illustrated a method of determining the safest routes between locations in the Central Business District of Dallas. Raw data has been converted into an aggregate risk level that serves as an input to a network analysis model. The risk level calculation process and the network routing program are flexible enough to be applied to the routing scenarios that exist in different locations. The procedure can be modified by incorporating additional factors and characteristics unique to specific locations.
Appendix A

Risk Level Calculation for Segments
## RISK LEVEL CALCULATION

### THE PROCESS BEGINS...

- For each segment included in the study:

<table>
<thead>
<tr>
<th>STEP 1</th>
<th>( \text{Average Daily Traffic} \times 365 ) (days/year) = ( \text{Average Annual Traffic} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>STEP 2</td>
<td>( \text{Average Annual Segment Length} \times \text{Vehicle Miles Travelled (VMT)} )</td>
</tr>
<tr>
<td>STEP 3</td>
<td>( \frac{\text{Annual Vehicle Miles Travelled (VMT)}}{\text{Segments}} ) ÷ ( \frac{\text{Average Annual Semi-truck Accidents} + 1}{\text{MILLION}} ) = ( \text{Truck Accident Probability Per Million VMT} )</td>
</tr>
<tr>
<td>STEP 4</td>
<td>( \frac{\text{Number of Injury or Fatality Semi-truck Accidents}}{\text{Total Semi-truck Accidents}} ) = ( \text{Semi-truck Accident Severity Adjustment Factor} )</td>
</tr>
<tr>
<td>STEP 5</td>
<td>( \frac{\text{Truck Accident Probability Per Million VMT (Step 3)}}{\text{Semi-truck Accident Severity Adjustment Factor (Step 4)}} \times \text{Adjusted Truck Accident Probability Per Million VMT} )</td>
</tr>
</tbody>
</table>

* Data provided
RISK LEVEL CALCULATION

THE PROCESS CONTINUES ...

STEP 6: *Total Employment + *Population Residing + *Average Vehicle + Total Exposure or X Length Accident Occupants or Per Segment Consequence (67% day, 33% night)

STEP 7: Total Exposure or Accident Consequence (Step 6) X *Segment Length = Total Exposure Miles (People* miles)

STEP 8: Total Exposure Miles (Step 7) X Adjusted Truck Accident Probability Per Million VMT (Step 5) = Exposure Risk Level (Used in model)

* Data provided
## Risk Level Calculation Spreadsheet

### Step 1
- **Annual Traffic Estimate**
  - (Av. daily traffic x 365 days)

### Step 2
- **Annual Vehicle Miles Traveled**
  - (Ann. traffic)

### Step 3
- **Original Semi-truck Accident Prob. per Million VMT**
  - (Orig. factor)

### Step 4
- **Accident Severity Factor**
  - Adj. factor

### Step 5
- **Total Accident Risk**
  - (67 day Accident Consequence)

### Step 6
- **Population Residing in Segment**
  - (33% night Average Vehicle Occupants per segment)

### Step 7
- **Exposure Miles**
  - (Total Exp. miles)

### Step 8
- **Risk Level**
  - (Total Accident Prob.)

<table>
<thead>
<tr>
<th>ROUTE</th>
<th>ROUTE DESCRIPTION</th>
<th>Segment Length (Miles)</th>
<th>Average Annual Traffic (Av. daily traffic x 365 days)</th>
<th>Annual Vehicle Miles Traveled (Ann. traffic)</th>
<th>Original Semi-truck Accident Prob. per Million VMT (Orig. factor)</th>
<th>Accident Severity Factor Adj. factor</th>
<th>Total Accident Risk</th>
<th>Population Residing in Segment</th>
<th>Exposure Miles (Total Exp. miles)</th>
<th>Risk Level (Total Accident Prob.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>Continent</td>
<td>1.31</td>
<td>8,020,000</td>
<td>10,519,300</td>
<td>0.1901</td>
<td>0.1765</td>
<td>0.034</td>
<td>22,034</td>
<td>630</td>
<td>103</td>
</tr>
<tr>
<td>A2</td>
<td>Industrial</td>
<td>0.70</td>
<td>8,530,000</td>
<td>6,132,000</td>
<td>0.5219</td>
<td>0.1765</td>
<td>0.092</td>
<td>7,319</td>
<td>182</td>
<td>7,541</td>
</tr>
<tr>
<td>A3</td>
<td>Ind./Corinth/Lamar</td>
<td>3.41</td>
<td>6,570,000</td>
<td>22,463,700</td>
<td>0.1875</td>
<td>0.1765</td>
<td>0.033</td>
<td>19,956</td>
<td>9,016</td>
<td>90</td>
</tr>
<tr>
<td>A4</td>
<td>Corinth/Cent./Pearl</td>
<td>1.70</td>
<td>4,745,000</td>
<td>8,066,500</td>
<td>0.2727</td>
<td>0.1765</td>
<td>0.048</td>
<td>100,951</td>
<td>5,539</td>
<td>180</td>
</tr>
<tr>
<td>A5</td>
<td>Good Lat./US 75</td>
<td>1.52</td>
<td>3,265,000</td>
<td>4,993,200</td>
<td>0.6068</td>
<td>0.1765</td>
<td>0.106</td>
<td>70,085</td>
<td>4,236</td>
<td>119</td>
</tr>
<tr>
<td>At</td>
<td>Canton/1st/2nd/</td>
<td>2.36</td>
<td>2,920,000</td>
<td>6,891,200</td>
<td>0.2322</td>
<td>0.1765</td>
<td>0.041</td>
<td>51,946</td>
<td>17,765</td>
<td>127</td>
</tr>
<tr>
<td></td>
<td>Fairy/Peat</td>
<td>1.62</td>
<td>6,752,500</td>
<td>107,364,750</td>
<td>0.2291</td>
<td>0.3138</td>
<td>0.072</td>
<td>33,464</td>
<td>622</td>
<td>34,720</td>
</tr>
<tr>
<td>F1</td>
<td>IH 75 Stamos</td>
<td>1.59</td>
<td>67,255,000</td>
<td>107,364,750</td>
<td>0.2291</td>
<td>0.3138</td>
<td>0.072</td>
<td>33,464</td>
<td>622</td>
<td>34,720</td>
</tr>
<tr>
<td>F2</td>
<td>IH 35/1H 35 Cronan</td>
<td>1.17</td>
<td>67,160,000</td>
<td>78,577,200</td>
<td>0.4581</td>
<td>0.3138</td>
<td>0.144</td>
<td>10,111</td>
<td>105</td>
<td>428</td>
</tr>
<tr>
<td>F3</td>
<td>IH 35</td>
<td>2.31</td>
<td>50,725,000</td>
<td>117,197,850</td>
<td>0.4709</td>
<td>0.3138</td>
<td>0.126</td>
<td>43,751</td>
<td>5,577</td>
<td>629</td>
</tr>
<tr>
<td>F4</td>
<td>IH 45</td>
<td>3.50</td>
<td>29,200,000</td>
<td>102,200,000</td>
<td>0.1037</td>
<td>0.3138</td>
<td>0.033</td>
<td>30,324</td>
<td>14,783</td>
<td>462</td>
</tr>
<tr>
<td>F5</td>
<td>IH 70 E. R.T.</td>
<td>1.49</td>
<td>46,720,000</td>
<td>99,379,200</td>
<td>0.3027</td>
<td>0.3138</td>
<td>0.095</td>
<td>20,910</td>
<td>13,603</td>
<td>424</td>
</tr>
<tr>
<td>F6</td>
<td>IH 345/US 75</td>
<td>2.40</td>
<td>39,025,000</td>
<td>93,036,725</td>
<td>0.0877</td>
<td>0.3138</td>
<td>0.028</td>
<td>88,858</td>
<td>10,258</td>
<td>467</td>
</tr>
<tr>
<td>F7</td>
<td>SH 386/Mall Rogers</td>
<td>2.23</td>
<td>22,650,000</td>
<td>50,351,750</td>
<td>0.1390</td>
<td>0.3138</td>
<td>0.044</td>
<td>97,146</td>
<td>6,219</td>
<td>244</td>
</tr>
</tbody>
</table>

### MILES
- **Cars**
- **Car-Miles**
Appendix B

Program Using Floyd’s Algorithm
PROGRAM MAIN
Program to compute shortest paths using Floyd's algorithm.
Written by R. Helgason
3/15/92
Modified by R. Helgason
4/21/92
Will now detail the link composition of the shortest paths.
IMPLICIT NONE
INTEGER ORIGD(20,20)
INTEGER PATHD(20,20)
INTEGER USING(20,20)
INTEGER HOW(2,20)
INTEGER MAXNOD,NODES
INTEGER I,J,K,L,M,Q,D,W,BIG
REAL SUM

MAXNOD = 20

WRITE(*,*) 'Input Number of Nodes:'
READ(*,*) NODES
WRITE(*,*) NODES,' Nodes'
IF(NODES.GT.MAXNOD) STOP 'Too Many'
DO 20 I=1,NODES
DO 10 J=1,NODES
  ORIGD(I,J) = -1
  CONTINUE
  ORIGD(I,I) = 0
  CONTINUE
WRITE(*,*) 'Input From Node, *To Node, Distance, 1 or 2 (way) Quadruples *(0 0 0 0 Ends Input):'
SUM = 0
DO 30 I=1,NODES
DO 20 J=1,NODES
  IF(ORIGD(I,J).EQ.1) THEN
    PATHD(I,J) = BIG
    USING(I,J) = -1
  ELSE PATHD(I,J) = ORIGD(I,J)
  ENDIF
  CONTINUE
  IF(D.LT.0) STOP 'Neg. Distance'
  IF(W.NE.0) THEN
    ORIGD(I,J) = D
    IF(W.EQ.2) ORIGD(J,I) = D
    SUM = SUM+D
  ENDIF
  CONTINUE
BIG = 10**(1+IFIX(ALOG10(SUM)))
DO 50 I=1,NODES
DO 40 J=1,NODES
  IF(ORIGD(I,J).EQ.-1) THEN
    PATHD(I,J) = BIG
    USING(I,J) = -1
  ELSE
    PATHD(I,J) = ORIGD(I,J)
  ENDIF
  CONTINUE
END
USING(I,J) = 0
ENDIF
CONTINUE
CONTINUE

WRITE(*,200) (I,I=1,NODES)
WRITE(*,300) ('-----',I=1,NODES)
DO 55 I=1,NODES
  WRITE(*,400) I,(PATHD(I,J),J=1,NODES)
  CONTINUE
WRITE(*,300) ('-----',I=1,NODES)

DO 80 K=1,NODES
WRITE(*,100) K
Compute Best Path Distance
Using Nodes 1,...,K as Intermediate Nodes
DO 70 I=1,NODES
  DO 70 J=1,NODES
    D = PATHD(I,K)+PATHD(K,J)
    IF(D.LT.PATHD(I,J)) THEN
      WRITE(*,*) ' YES: UPDATE'
      PATHD(I,J) = D
      USING(I,J) = K
    ENDIF
  CONTINUE
WRITE(*,200) (I,I=1,NODES)
WRITE(*,300) ('-----',I=1,NODES)
DO 75 I=1,NODES
  WRITE(*,400) I,(PATHD(I,J),J=1,NODES)
  CONTINUE

WRITE(*,200) (I,I=1,NODES)
WRITE(*,300) ('-----',I=1,NODES)
DO 85 I=1,NODES
  WRITE(*,400) I,(USING(I,J),J=1,NODES)
  CONTINUE

DO 99 I=1,NODES
  DO 98 J=1,NODES
    WRITE(*,'(K',I5,1)')
  CONTINUE
  DO 98 K=I+1,NODES
    WRITE(*,'(K',I5,1)')
  ENDDO
  CONTINUE
98 FORMAT(14,1:1,20I5)
99 FORMAT(5X,' USING\TRACE)
100 FORMAT(5X,'THE PATH FROM ',I5,' TO ',I5,': ',I5,' USES:\TRACE)
101 FORMAT(5X,'THE PATH FROM ',I5,' TO ',I5,': ',I5,' IS A LINK')
102 FORMAT(5X,' NO PATH FROM ',I5,' TO ',I5,': !!!\TRACE)
103 FORMAT(5X,' LINK FROM ',I5,' TO ',I5,': ',I5,')
104 FORMAT(5X,46('-'))

DO 99 I=1,NODES
  DO 98 J=1,NODES

IF(I.EQ.J) GO TO 98
WRITE(*,710)
ENDIF
L = USING(I,J)
IF(L.EQ.-1) THEN
  WRITE(*,620) I,J
  GO TO 98
ELSEIF(L.EQ.0) THEN
  WRITE(*,610) I,J,PATHD(I,J)
  GO TO 98
ELSE
  WRITE(*,600) I,J,PATHD(I,J)
  Q = 0
  K = I
  M = J
ENDIF
CONTINUE
Separate
Q = Q+1
HOW(1,Q) = L
HOW(2,Q) = M
Q = Q+1
HOW(1,Q) = K
HOW(2,Q) = L
CONTINUE
IF(Q.EQ.0) GO TO 98
K = HOW(1,Q)
M = HOW(2,Q)
Q = Q-1
L = USING(K,M)
IF(L.EQ.0) THEN
  WRITE(*,700) K,M,ORIGD(K,M)
  GO TO 92
ELSE
  GO TO 91
ENDIF
CONTINUE
STOP 'ok'
END
Appendix C

Input to Floyd's Algorithm Program
Appendix D

Output from Floyd's Algorithm Program
<table>
<thead>
<tr>
<th>THE PATH FROM</th>
<th>1 TO 2 @ 1001 IS A LINK</th>
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<tbody>
<tr>
<td>THE PATH FROM</td>
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<td>2 TO 3 @ 486</td>
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<tr>
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<td>2 TO 3 @ 486</td>
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<td>3 TO 8 @ 1640</td>
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- LINK FROM 2 TO 3 @ 486
- LINK FROM 3 TO 8 @ 1640

THE PATH FROM 3 TO 1 @ 1487 USES:
- LINK FROM 3 TO 2 @ 486
- LINK FROM 2 TO 1 @ 1001

THE PATH FROM 3 TO 2 @ 486 IS A LINK

THE PATH FROM 3 TO 4 @ 3279 USES:
- LINK FROM 3 TO 8 @ 1640
- LINK FROM 8 TO 4 @ 1639

THE PATH FROM 3 TO 5 @ 13398 USES:
- LINK FROM 3 TO 8 @ 1640
- LINK FROM 8 TO 4 @ 1639
- LINK FROM 4 TO 6 @ 5191
- LINK FROM 6 TO 5 @ 4928

THE PATH FROM 3 TO 6 @ 8470 USES:
- LINK FROM 3 TO 8 @ 1640
- LINK FROM 8 TO 4 @ 1639
- LINK FROM 4 TO 6 @ 5191

THE PATH FROM 3 TO 7 @ 11544 USES:
- LINK FROM 3 TO 2 @ 486
- LINK FROM 2 TO 1 @ 1001
- LINK FROM 1 TO 7 @ 10057

THE PATH FROM 3 TO 8 @ 1640 IS A LINK

THE PATH FROM 4 TO 1 @ 4766 USES:
- LINK FROM 4 TO 8 @ 1639
- LINK FROM 8 TO 3 @ 1640
- LINK FROM 3 TO 2 @ 486
- LINK FROM 2 TO 1 @ 1001

THE PATH FROM 4 TO 2 @ 3765 USES:
- LINK FROM 4 TO 8 @ 1639
- LINK FROM 8 TO 3 @ 1640
- LINK FROM 3 TO 2 @ 486

THE PATH FROM 4 TO 3 @ 3279 USES:
- LINK FROM 4 TO 8 @ 1639
- LINK FROM 8 TO 3 @ 1640

THE PATH FROM 4 TO 5 @ 10119 USES:
- LINK FROM 4 TO 6 @ 5191
- LINK FROM 6 TO 5 @ 4928

THE PATH FROM 4 TO 6 @ 5191 IS A LINK

THE PATH FROM 4 TO 7 @ 11752 USES:
- LINK FROM 4 TO 6 @ 5191
- LINK FROM 6 TO 7 @ 6561

THE PATH FROM 4 TO 8 @ 1639 IS A LINK
THE PATH FROM  5 TO  1 @ 14885 USES:
LINK FROM  5 TO  6 @ 4928
LINK FROM  6 TO  4 @ 5191
LINK FROM  4 TO  8 @ 1639
LINK FROM  8 TO  3 @ 1640
LINK FROM  3 TO  2 @ 486
LINK FROM  2 TO  1 @ 1001

THE PATH FROM  5 TO  2 @ 13884 USES:
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LINK FROM  6 TO  4 @ 5191
LINK FROM  4 TO  8 @ 1639
LINK FROM  8 TO  3 @ 1640
LINK FROM  3 TO  2 @ 486

THE PATH FROM  5 TO  3 @ 13398 USES:
LINK FROM  5 TO  6 @ 4928
LINK FROM  6 TO  4 @ 5191
LINK FROM  4 TO  8 @ 1639
LINK FROM  8 TO  3 @ 1640

THE PATH FROM  5 TO  4 @ 10119 USES:
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LINK FROM  6 TO  4 @ 5191

THE PATH FROM  5 TO  6 @ 4928 IS A LINK

THE PATH FROM  5 TO  7 @ 11489 USES:
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LINK FROM  6 TO  7 @ 6561

THE PATH FROM  5 TO  8 @ 11758 USES:
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LINK FROM  4 TO  8 @ 1639

THE PATH FROM  6 TO  1 @ 9957 USES:
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LINK FROM  2 TO  1 @ 1001

THE PATH FROM  6 TO  2 @ 8956 USES:
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LINK FROM  8 TO  3 @ 1640
LINK FROM  3 TO  2 @ 486

THE PATH FROM  6 TO  3 @ 8470 USES:
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THE PATH FROM  6 TO  4 @ 5191 IS A LINK

THE PATH FROM  6 TO  5 @ 4928 IS A LINK

THE PATH FROM  6 TO  7 @ 6561 IS A LINK
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LEAST RISK ROUTE FROM NODE 2 TO NODE 5
(E. BOUND 1-30 TO E.BOUND 1-30)
LEAST RISK ROUTE FROM NODE 3 TO NODE 5
(N. BOUND 1-35 TO E. BOUND 1-30)
LEAST RISK ROUTE FROM NODE 8 TO NODE 5
LEAST RISK ROUTE FROM NODE 4 TO NODE 5
(N. BOUND 1-45 TO E. BOUND 1-30)
LEAST RISK ROUTE FROM NODE 6 TO NODE 5
(E. BOUND 1-30 CONTINUING E. BOUND 1-30)
LEAST RISK ROUTE FROM NODE 5 TO NODE 7
(W. BOUND 1-30 TO N. BOUND U.S 75)
LEAST RISK ROUTE FROM NODE 4 TO NODE 7
(N. BOUND I-45 CONTINUING TO N. BOUND U.S 75)
LEAST RISK ROUTE FROM NODE 8 TO NODE 7
LEAST RISK ROUTE FROM NODE 7 TO NODE 3
(N. BOUND I-35 TO N. BOUND U.S. 75)