Path Planning of Road Hazardous Material Transportation based on TransCAD

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Abstract

A risk assessment model is constructed for the hazardous materials (hazmat) road transportation combining features of TransCAD traffic forecasts, and based on traffic planning network of spatial analysis and attribute process, the database for path planning of hazmat transportation was set up. Based on the TransCAD platform, this research analyzes the risk value of hazmat transportation in each section of the network, and found the optimal route for hazmat transportation. The rationality of the model and the feasibility of the algorithm are proved by the research.

Keywords: Hazardous Material; Trans-CAD; Road Transportation; Route Optimization

1. Introduction

The accident of hazardous materials (hazmat) transportation has great harm to human safety and environment. This has become a social problem, which has attracted public and governmental abroad attention. Management of hazmat transportation is the most important aspects of transport route planning. A reasonable choice of transport routes is obviously important to reduce the accident risk, to increase the speed of an accident rescue and to reduce the degree of surrounding damages [1, 2, 3, 4].

The traffic conditions and road conditions are all unknown in the transportation route planning process [5, 6, 7]. By using of TransCAD for traffic distribution forecast, you can get these attribute data [8, 9]. TransCAD is the only model of the GIS with transportation planning and logistics applications fully integrated package, which can handle all types of traffic data and transport model [10, 11, 12]. [3, 13] And it has a powerful geographic information systems and comprehensive data of transportation, geographic information and population resources [14, 15]. With the traffic forecasting function, the transportation planning model can be set up for planning area traffic forecasting and distribution [16, 17, 18], and it also has strong development language that can be used to create a macro language program, embedded applications, server applications, common interface, related products and network applications [19, 20, 21, 22, 23].

A risk assessment model is constructed for the hazardous materials (hazmat) road transportation combining features of TransCAD traffic forecasts, and based on traffic planning network of spatial analysis and attribute process, the database for path planning of hazmat transportation was set up. Based on the TransCAD platform, this research analyzes the risk value of hazmat transportation in each section of the network, and found the optimal route for hazmat transportation. The rationality of the model and the feasibility of the algorithm are proved by the research.

2. Path planning step of road Hazmat transportation based on TransCAD

2.1. Path model of road hazmat transport

Hazmat road transport route planning is in the transport network to find a set of minimum risk and minimum transportation costs, and to meet the requirements of the basic attribute. An optimization model for route choice is built with dual goals constrained, which are risk-based transportation costs and transportation costs.

1) The temporal risk model
For highway, explosives for all possible risk said the risk and losses caused these accidents combined. The temporal risk model which similar to the model putted by Fabiano et al[4], [5], [6], etc. is expressed as:

\[ D_r = \sum_i f_{r,i} N_{r,s} P_s \]  

where: \( f_r \) - frequency of accident on the arc \( r \); 
\( N_{r,s} \) - number of fatalities caused by the accident evolving according to a scenario \( S \) on the arc \((i, j)\) at timer; 
\( P_s \) - probability of evolving scenarios of type \( S \), following the accident initialiser. 

where \( N_{r,s} \) is the total number of fatalities according to:

\[ N_{r,s} = (A^n_{r,s} k + A^f_{r,s} d_r) P_{r,s} \]

where:
\( A^n_{r,s} \) is the in-road number of fatalities on the arc \( S \); 
\( A^f_{r,s} \) is the off-road number of fatalities on the arc \( S \).

2) The cost of vehicle transport

Usually, link costs are determined by travel distance or travel time. Explosives, the total cost of road transport should include: vehicle transportation costs and penalties for delay in shipment costs. Cost of vehicle transport is road transport vehicles, the distance between each of the actual driving distance multiplied by the average unit cost of transportation.

\[ F_s = \sum_{i=1}^{n} C d_i \]

where:
\( F_s \) - vehicle transportation costs; 
\( C \) - the average transportation cost per unit distance; 
\( d_i \) - the i road vehicle with the actual driving distance.

3) The punishment for delay in shipment cost

Arrive on time according to customer delivery requirements. When customers order, it often provides time of arrival of goods. If the goods cannot arrive on time, you have to pay a penalty fee delay in shipment. Extension penalty fee equals to the extension of the goods time and average unit-time product.

\[ F_L = C_L (T - LT) \]

where:
\( F_L \) - Punishment for delay in shipment cost, per; 
\( C_L \) - Did not request an extension to the customer the goods to the average penalty cost per unit time; 
\( T \) - Failed to request an extension of the goods to the time spent; 
\( LT \) - Customer the maximum arrival time.

4) Objective function

An optimization model for route choice is built with dual goals constrained, which are risk-based transportation costs and transportation costs.

Objective function:

\[ opt = \min \sum (W_1 * TC + W_2 * RC) \]

where:
\( TC = R * Length * Ton \)
\[ RC = RAR \times \text{Ton} \times DR \times (TATF \times PC + VC + PerRC) \]  
(7)

\[ RAR = AR \times \text{Time} \times \text{Length} \]  
(8)

Constraint Condition:

\[ \sum_{i=1}^{n} L_i \leq \land L \]

\[ \sum_{i=1}^{n} p_i \leq \land P \]

\[ \text{Max} F_L \leq F_{\text{lim},i} \]

\[ \text{Max} PR_L \leq PR_{\text{lim},i} \]

where \( opt \) -Objective optimization value; \( W_1, W_2 \) -Transport costs and transport costs, the risk ratio of weight, \( W_1 + W_2 = 1; TC \) -Road costs, Yuan; \( RC \) -Costs of risk, Yuan; \( R \) -Unit transportation rate, take 9.8; \( Length \) -Road length; \( Ton \) -The total transport of dangerous goods; \( RAR \) is Road accident rate; \( DR \) is De radius; \( TATF \) is the average travel factor; \( PC \) is cost of individual deaths; \( PerRC \) is cost per unit length of road; \( VC \) is unit cost of vehicles; \( AR \) is national Statistics accident rate, \( \land L \) is the total length of route; \( \land P \) is limit the total number of deaths; \( F_L \) is social risk; \( PR_L \) is personal risk.

### 2.2. Building the database

TransCAD uses the concept of layers to manage, store and analyze information, and then put the superposition of different layers together to achieve the study area of information visualization. In this article, the whole transport network is abstracted in three layers.

1) Node layers: small dots stand for line intersection, the nodes in the graph;
2) The network layer: store the road network;
3) The traffic zone level: store traffic zone.

TransCAD will automatically generate some basic information in the process of building road network layer, the cell layer and layer of nodes. This basic information is showed in table 1 & table 2.

#### Table 1. Basic information of the layer

<table>
<thead>
<tr>
<th>Attribute field</th>
<th>Property code</th>
<th>Data types</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Longitude</td>
<td>ID</td>
<td>Integer (4 bytes)</td>
<td>-</td>
</tr>
<tr>
<td>Dimension</td>
<td>Longitude</td>
<td>Integer (4 bytes)</td>
<td>-</td>
</tr>
<tr>
<td>-</td>
<td>ID</td>
<td>Integer (4 bytes)</td>
<td>-</td>
</tr>
<tr>
<td>Length of the sections</td>
<td>Length</td>
<td>Real (8 bytes)</td>
<td>Km</td>
</tr>
<tr>
<td>-</td>
<td>ID</td>
<td>Integer (4 bytes)</td>
<td>-</td>
</tr>
<tr>
<td>Area of the district</td>
<td>area</td>
<td>Real (8 bytes)</td>
<td>m²</td>
</tr>
</tbody>
</table>

#### Table 2. Data structure table for transportation planning

<table>
<thead>
<tr>
<th>Attribute field</th>
<th>Data types</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Width</td>
<td>Integer (4 bytes)</td>
<td>m</td>
</tr>
<tr>
<td>level</td>
<td>Integer (4 bytes)</td>
<td>-</td>
</tr>
<tr>
<td>lanes</td>
<td>Integer (4 bytes)</td>
<td>-</td>
</tr>
<tr>
<td>speed</td>
<td>Integer (4 bytes)</td>
<td>m/s</td>
</tr>
<tr>
<td>Time</td>
<td>Real (8 bytes)</td>
<td>h</td>
</tr>
<tr>
<td>capacity</td>
<td>Integer (4 bytes)</td>
<td>ren</td>
</tr>
<tr>
<td>name</td>
<td>Character</td>
<td>-</td>
</tr>
<tr>
<td>POP</td>
<td>Integer (4 bytes)</td>
<td>ren</td>
</tr>
<tr>
<td>GDP</td>
<td>Integer (4 bytes)</td>
<td>Yuan</td>
</tr>
<tr>
<td>Industry</td>
<td>Integer (4 bytes)</td>
<td>Yuan</td>
</tr>
<tr>
<td>Agriculture</td>
<td>Integer (4 bytes)</td>
<td>Ren</td>
</tr>
</tbody>
</table>
In order to fulfill the need of the dual objectives of optimal constrained model for hazmat transportation route. The following attributes are added to the original database of TransCAD and network layers.

After setting up the network layer data structure, the attributes of other layers are determined, and then all data structures of the physical layer are completed for spatial database of TransCAD platform. Fig. 1 shows the road network layer data structure:

<table>
<thead>
<tr>
<th>Attribute field</th>
<th>Units</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Opt</td>
<td>Yuan</td>
<td>Optimized value</td>
</tr>
<tr>
<td>Te</td>
<td>Yuan</td>
<td>Road cost</td>
</tr>
<tr>
<td>Re</td>
<td>Yuan</td>
<td>Costs of risk</td>
</tr>
<tr>
<td>Ton</td>
<td>T</td>
<td>Transport Tonnage</td>
</tr>
<tr>
<td>RAR</td>
<td>accident/year</td>
<td>National Statistics accident rate</td>
</tr>
<tr>
<td>AR</td>
<td>accident/km/cars/year</td>
<td>The average travel factor</td>
</tr>
<tr>
<td>TATF</td>
<td>-</td>
<td>Death radius</td>
</tr>
<tr>
<td>DR</td>
<td>m</td>
<td>The cost of individual deaths</td>
</tr>
<tr>
<td>PC</td>
<td>Yuan</td>
<td>Unit cost of vehicles</td>
</tr>
<tr>
<td>VC</td>
<td>Yuan</td>
<td>Cost per unit length</td>
</tr>
<tr>
<td>PerRC</td>
<td>Yuan</td>
<td>Road cost</td>
</tr>
<tr>
<td>RoadC</td>
<td>Yuan</td>
<td>Weight of transport costs</td>
</tr>
<tr>
<td>W1</td>
<td>-</td>
<td>Cost of risk weights</td>
</tr>
<tr>
<td>W2</td>
<td>-</td>
<td>Correction factor</td>
</tr>
<tr>
<td>H1-5</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>

The data from traffic police, Statistical Yearbook of the planning area and the report literature from local government official website, the data are operated in the window of network layer, using the Edit-Fill command, using single-value filling or the formula to add the data, to edit the road network attribute values, using TransCAD compute risk value of road sections. After filling and saving the data, TransCAD automatically calculated the risk value of each section and store in the attribute field RC domain.

The formulas are used in the following table:
2.3. Excluding high-risk road sections of road network

The high-risk sections will be removed by using of Disable Links of the TransCAD network. By the Disable equation editor you can delete some sections which in the road network conditions are higher than the fixed date. Fig.2 shows that the model will remove the sections, in which RC (risk costs) exceed 1000.

![Image of Disable Links Equation Editor]

**Figure 2.** Disable Links Equation Editor

2.4. To work out the shortest path in the network

TransCAD can find the shortest path or best path from one point another in a network. The following formulas are added to the database.

<table>
<thead>
<tr>
<th>Attribute field</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>Opt</code></td>
<td><code>w1*TC+w2*RC</code></td>
</tr>
<tr>
<td><code>TC</code></td>
<td><code>R*Length*Ton</code></td>
</tr>
</tbody>
</table>

Click Networks / Paths-Shortest Path, you can access the shortest path kit

![Image of Shortest path Toolbox]

**Figure 3.** Shortest path Toolbox

Starting point, end point and intermediate points, the shortest path should be marked on the map, with the toolbox to solve the shortest path problem. In the drop-down list in Minimize, select the minimal cost variable. TransCAD will automatically generate the path with minimal expense road in the network.
3. Case study and evaluation of results

Based on traffic plan of Tangshan City in 2015, the analysis is carried on by choosing any two sites as the beginning and end of the path in the route of hazmat transportation in the completed road path planning database. Transportation plan of Tangshan city in 2015 is shown in Figure 4[11]. Other basic data are shown in Figure 5. The optimum paths of minimal transportation cost, minimal risk cost and minimal synthetic cost are obtained, which are shown in Fig.6.

Figure 4. The transportation plan of Tangshan in 2015

The statistics of transportation costs, risk costs and synthetic costs in three routes are shown in Figure 6.

<table>
<thead>
<tr>
<th>Indicators</th>
<th>Minimum transport costs</th>
<th>Minimum cost risk</th>
<th>Minimum overall cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transport costs</td>
<td>Low:16102.0192</td>
<td>18585.6110</td>
<td>16202.6058</td>
</tr>
<tr>
<td>Risk costs</td>
<td>Medium:380.9304</td>
<td>195.8774</td>
<td>289.3501</td>
</tr>
<tr>
<td>Synthetic cost</td>
<td>High:3525.1481</td>
<td>3873.8242</td>
<td>3472.0015</td>
</tr>
</tbody>
</table>

4. Conclusion

Transportation costs will be only considered when the costs are as the optimization goal alone, in this situation although the transport costs are less than the other two transport routes for shorter travel distance, but it has the highest risk cost. Generally speaking, the route for hazmat transport chosen by drivers themselves has much higher risk cost than the one chosen by the model calculating. If you only consider the risk factors, the risk premium of the line is as the optimization goal, which will greatly
reduce the risk of transportation, but transportation costs also increased significantly, as for-profit transportation companies, this is a very serious problem. The use of hazmat transport planning model database can be a good solution to this problem, we can see the model of the chosen line, by which the minimum overall costs and moderate risk costs are achieved.

![Figure 6. The Comparison Chart of Three Transportation Routes](image)

5. Acknowledgement

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6. References


