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A Bi-objective Location-Routing Problem for Hazardous Materials Transportation

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ABSTRACT

Nowadays transporting hazardous materials (Hazmat) through city roads increases and according that, risks of the transportation of Hazmat have grown up and attracted researchers’ focuses. This paper provides a mathematical model for location-routing problem (LRP) to reducing two important objectives in hazardous materials transportation. The model locates facilities to establish and selects the best paths reaching customers to minimizing two objectives of the problem. Risk is first objective and in prior for all the Hazmat transportation studies. Risk is the probability of Hazmat transportation and population exposure around facilities location and during transportation routes. The second objective is minimizing total costs that contain costs of establishment of located facilities and costs of Hazmat transportation between facilities to customers. Mathematical model minimizes the two objectives for management decisions to satisfy governments, society, environment concerns and reducing probability of fatalities may cause by transportation of hazardous materials. The proposed model is mixed-integer linear programming that coded and solved in GAMS. Applicability of the model determined by a numerical example that showed at the end of the paper.

Keywords: Hazardous Materials; Transportation; location-routing problem; bi-objective model;

1. INTRODUCTION

Huge amount of transshipment Hazmat through roadways and among cities causes that transportation of Hazmat plays important role in roadway transportation. Irreparable possible effects after incident on public and environment make governments, insurance companies, environmental organizations and researchers to focus on this type of transportation business. Working on Hazmat management divided in four categories. First vehicle routing/scheduling to find the safest or shortest path [1]. Second Risk assessment [2]. Third sitting or location [3]. Forth management of hazardous waste [4]. Researches may focus on only one research category of this field or combine two or more of them together. Locating best place for hazmat to store or produce Hazmat and then routing them to reaching customers in order to reduce total risks and costs is called as location-routing problem for Hazmat transportation [5] that mixed two topics of Hazmat management. In [5] they minimize weighted risks and costs in one objective.

In this paper a bi-objective model introduce that minimize total risks and costs separately in two objectives to show the practical results for decision makers, and contribute the mathematical model by limiting risk on each particular route between nodes by permitted upper bound for risk. Separating 2 main objective can make better and solution closer than real world. Solution also can prioritize by degree of importance, so the most important objective can have the better answer. Limitation of risk forbids some high risk paths. Due to that the most important goal (risk), in this kind of problem decreases.
1.1 Risk analysis

Selection of the safest routes is the main focus research in this field and the most important objective in this type of problem is risk. There are different kinds of method to assessing risk like probability of accident, population exposure around Hazmat in determined radius, probability of release and spread Hazmat after accident and … Risk is the primary ingredient that separates hazmat transportation problems from other transportation problems. In this section we will provide a detailed treatment of how risk is incorporated into hazmat transport models, starting with the basic building blocks and moving our way into risk assessment along a route. In the context of hazmat transport, risk is a measure of the probability and severity of harm to an exposed receptor due to potential undesired events involving a hazmat. The exposed receptor can be a person, the environment, or properties in the vicinity. The undesired event in this context is the release of a hazmat due to a transport accident. The consequence of a hazmat release can be a health effect (death, injury, or long-term effects due to exposure), property loss, an environmental effect (such as soil contamination or health impacts on flora and fauna), an evacuation of nearby population in anticipation of imminent danger, or stoppage of traffic along the impacted route. Risk assessment can be qualitative or quantitative. Qualitative risk assessment deals with the identification of possible accident scenarios and attempts to estimate the undesirable consequences. It is usually necessitated by a lack of reliable data to estimate accident probabilities and consequence measures. The goal is to identify events that appear to be most likely and those with the most severe consequences, and focus on them for further analysis. It may be the only option in the absence of data – for example, assessing the risks due to the location of a permanent nuclear waste repository. While hazmat transport analysts are known to complain about the quality of their data, they do have access to considerable historical information on accident frequencies and fairly accurate consequence models for hazmat releases in case of accidents in many developed countries. [6]. In this paper risk is population exposure around facilities and on the roads or around roads with particular radius, during the transportation.

Model definition

The proposed model is a mixed-integer linear (MIP) model, so as to determine the minimum of risk and cost. Risk defined as population exposure around located facilities nodes and during transshipment between chosen paths [6]. Total cost is sum of costs for establishing facilities and particular cost for each selected rout between nodes that assumed completely separate from risk en route and for facilities. The model determined an upper bound for risk on each rout to avoid entering path with high risk. At brief the MIP model find the best place to locate facility nodes then select safest and shortest path so as to minimize total risk and cost, assuming that paths with high risk must not selected any way. The model designed for a network that starts from many facilities, visit intermediate nodes and end in customer nodes. Transshipment between facilities together and customers together not allowed. Intermediate nodes can link to each other. The notations and mathematical model are as follows:

Indices

\[ i, j, k \in \{1, \ldots, n\} \quad \text{Nodes of networks} \]
\[ h \in \{1, \ldots, H\} \quad \text{Potential nodes of facilities} \]
\[ c \in \{1, \ldots, C\} \quad \text{Customer nodes} \]
Parameters

\( f_h \) : Annual cost of establishing facility
\( r_p_h \) : Establishment Risk of facility \( h \) in terms of exposed population within given impact area
\( r_s \) : Upper bound for Risk of the transportation
\( r_{ij} \) : Risk of the serving customer via the link which connects node \( i \) to \( j \)
\( \text{Cost}_{ij} \) : Cost of the serving customer via the link which connects node \( i \) to \( j \)

Decision variables

\( X_{ij} \) : 1 if the link between node \( i \) and \( j \) is a part of rout from facility to customer; 0 otherwise
\( Z_{hc} \) : 1 if the opened facility \( h \) assigned to customer \( c \); 0 otherwise
\( Y_h \) : 1 if the facility \( h \) established; 0 otherwise
\( W_j \) : 1 if the node \( j \) is visited; 0 otherwise

Mathematical model

Minimize

\[
Z_1 = \sum_{h=1}^{H} r_p_h X_h + \sum_{i=1}^{n} \sum_{j=1 \neq i}^{n} r_{ij} X_{ij} \\
Z_2 = \sum_{h=1}^{H} f_h Y_h + \sum_{i=1}^{n} \sum_{j=1}^{n} \text{Cost}_{ij} X_{ij}
\]  

(1)

Subject to

\[
\sum_{j=\neq h}^{n} X_{jh} = Y_h, \quad \forall h
\]  

(2)
\[
\sum_{i \neq j}^n X_{ij} = \sum_{k \neq j}^n X_{jk}, \quad \forall j
\]  
(3)

\[
\sum_{i \neq j}^n X_{ic} = 1, \quad \forall c
\]  
(4)

\[
\sum_{c \neq j}^C Z_{hc} \leq Y_h, \quad \forall h
\]  
(5)

\[
\sum_{h \neq c}^H Z_{hc} = 1, \quad \forall h
\]  
(6)

\[
X_{hh} = 0, \quad \forall h
\]  
(7)

\[
X_{cc} = 0, \quad \forall c
\]  
(8)

\[
r_jX_{ij} \leq rs, \quad \forall i, j
\]  
(9)

\[
\sum_{j \neq k}^n X_{jk} = W_k, \quad \forall k
\]  
(10)

\[
\sum_{j \neq j}^n X_{ij} = W_i, \quad \forall i
\]  
(11)

\[
X(h,c) + \sum_{j \neq i}^n X_{ij} + \sum_{j \neq c}^n X_{jc} \leq 2 + Z_{hc}, \quad \forall h, c
\]  
(12)

\[
X_{ij} \in \{0,1\}
\]

\[
Y_h \in \{0,1\} \quad \forall i, j, h, c
\]

\[
W_j \in \{0,1\}
\]

\[
Z_{hc} \in \{0,1\}
\]  
(13)
The first section of objective (1) represents the minimization of location risk and the second part minimizes the transportation risk between nodes. In the second objective of (1) at first part annual fixed cost of location calculates and in the other section minimizes the cost of each rout. Constraint (2) notices that if a facility node established then trip start from it. Constraint (3) is flow conservation for intermediate nodes. Constraint (4) ensures that all the customers must be served. Constraint (5) assures that each customer must be assigned to an established and located facility. Constraint (6) guarantees that all customers must assigned to facilities. Constraints (7) and (8) notice that transshipment between facility nodes together and customer nodes together is not permitted. Constraint (9) limits the risk of the each route and don’t allow the model to move Hazmat in high risk nodes. Constraints (10) and (11) determine visited nodes during the chosen paths. Constraints (12) notices that a customer assigns to a facility when there was a selected route between them. Constraints (13) define the variable types.

3. Numerical example

In this section a small example solved to validate and help understanding. In the example we suppose 3 facilities, 3 intermediate nodes and 2 customers. All the customers should assign to facilities. Facilities also must serve all the customers. We assume that we should have a facility node per customer. Facilities reached customers by a route that minimized both total risks and costs at a time. In the example transshipment through the routes that have high risk are not allowed to assign. Amount of risk between each two nodes showed in Table 1. Cost of each possible path is provided in Table 2. Table 3 shows fix annual costs for all facilities and also determined the upper bound for risk.

<table>
<thead>
<tr>
<th>( r_{ij} \times 10^5 )</th>
<th>J4</th>
<th>J5</th>
<th>J6</th>
<th>J7</th>
<th>J8</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>9</td>
<td>5</td>
<td>11</td>
<td>28</td>
<td>57</td>
</tr>
<tr>
<td>12</td>
<td>10</td>
<td>8</td>
<td>9</td>
<td>24</td>
<td>25</td>
</tr>
<tr>
<td>13</td>
<td>4</td>
<td>11</td>
<td>9</td>
<td>24</td>
<td>39</td>
</tr>
<tr>
<td>14</td>
<td>-</td>
<td>2</td>
<td>13</td>
<td>9</td>
<td>12</td>
</tr>
<tr>
<td>15</td>
<td>8</td>
<td>-</td>
<td>1</td>
<td>11</td>
<td>4</td>
</tr>
<tr>
<td>16</td>
<td>17</td>
<td>19</td>
<td>-</td>
<td>3</td>
<td>18</td>
</tr>
</tbody>
</table>
Table 2. Cost between nodes

<table>
<thead>
<tr>
<th>Cost_{ij} \times 10^5</th>
<th>J4</th>
<th>J5</th>
<th>J6</th>
<th>J7</th>
<th>J8</th>
</tr>
</thead>
<tbody>
<tr>
<td>I1</td>
<td>24</td>
<td>15</td>
<td>11</td>
<td>78</td>
<td>91</td>
</tr>
<tr>
<td>I2</td>
<td>17</td>
<td>98</td>
<td>19</td>
<td>244</td>
<td>45</td>
</tr>
<tr>
<td>I3</td>
<td>46</td>
<td>81</td>
<td>61</td>
<td>224</td>
<td>134</td>
</tr>
<tr>
<td>I4</td>
<td>-</td>
<td>24</td>
<td>13</td>
<td>49</td>
<td>112</td>
</tr>
<tr>
<td>I5</td>
<td>58</td>
<td>-</td>
<td>15</td>
<td>31</td>
<td>29</td>
</tr>
<tr>
<td>I6</td>
<td>77</td>
<td>19</td>
<td>-</td>
<td>43</td>
<td>46</td>
</tr>
</tbody>
</table>

Table 3. Location Fix cost and Location Risk

<table>
<thead>
<tr>
<th>Location cost and Risk</th>
<th>H1</th>
<th>H2</th>
<th>H3</th>
</tr>
</thead>
<tbody>
<tr>
<td>f_k</td>
<td>115</td>
<td>418</td>
<td>210</td>
</tr>
<tr>
<td>rp_k</td>
<td>21</td>
<td>47</td>
<td>18</td>
</tr>
</tbody>
</table>

The example is solved by GAMS 24.1.2. For this example goal programming used as method in GAMS. In Table 4 the best routes founded. Table 5 showed which facilities must be established. Table 6 assigned each customers to facilities. In Table 7 objective functions, risk and cost showed separately. In Fig1. Numerical example transportation network and optimal selected routes from facilities to customers have showed.

Table 4. selected path (i,j)

<table>
<thead>
<tr>
<th>X_{ij}</th>
<th>J4</th>
<th>J5</th>
<th>J6</th>
<th>J7</th>
<th>J8</th>
</tr>
</thead>
<tbody>
<tr>
<td>I1</td>
<td>-</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>I2</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>I3</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>I4</td>
<td>-</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>I5</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>I6</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>-</td>
</tr>
</tbody>
</table>
Table 5. Established facility $h$

<table>
<thead>
<tr>
<th>Location cost and Risk $Y_h$</th>
<th>H1</th>
<th>H2</th>
<th>H3</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td>1</td>
</tr>
</tbody>
</table>

Table 6. Assigned customer $c$ to established facility $h$

<table>
<thead>
<tr>
<th>$Z_{hc}$</th>
<th>C7</th>
<th>C8</th>
</tr>
</thead>
<tbody>
<tr>
<td>H1</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>H2</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>H3</td>
<td>1</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 7. Risk and Cost

<table>
<thead>
<tr>
<th>Risk</th>
<th>58</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td>497</td>
</tr>
</tbody>
</table>

Fig 1. Numerical example network and selected routes
4. Conclusion

The Hazmat transportation problem could be very important for companies that produce, store and distribute Hazmat as environmental and economic aspects. A mathematical model proposed that find the best possible route and between located facility as a starting node to customer as an ending node. At final we made a simple example to validate and showed the result of the solved model. By solving the model we have found that each customer served by low risk and low cost facilities (low risk and low cost facilities must should establish), and hazardous materials have transported to customers by the least risks and costs.

References


