Route Selection Based on Soft MODM Framework in Transportation of Hazardous Materials

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Abstract

Route selection could be a part of most transportation planning scenarios from transportation planning for metropolitan areas to transportation of goods and materials. Meanwhile, as the importance of the subject of transportation increase, the sensitivity of the route selection procedure increase meaningfully. Due to the risk that is tied with transportation of hazardous material (Hazmat Shipment), developing algorithms to find safest route of transportation of such these goods could be very vital. There are two basic concerns exist in hazmat shipment: first is to define the risk of transportation and second one is to develop proper algorithm for route selection that minimize the risk of transportation. In fact, hazmat shipment is a Multi Objective Decision Making (MODM) problem. In this paper a soft framework is proposed to define and solve the problem. Genetic Algorithm is used as a tool to solve the problem and different scenarios are tested to evaluate the proposed framework.

Keywords: Route Selection, Hazardous Materials, Transportation Modeling, Genetic Algorithm, MODM, Soft Framework

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1. Introduction

Transportation of hazardous material (Hazmat Shipment) is a new emerging problem of the modern societies and specially industrialized countries. The main topic of such problems is to minimize the risk of the shipment. Although it is obvious that we want to minimize the risk of shipment but there is no comprehensive definition of risk while this definition robustly tied to our objectives. For example if the object country is in peace the risk of hazmat could be defined dependent on the accidents consequences but if the probability of terrorist attacks exists in the object country, then the robbery of hazmat products will be placed in a high potential risk category. In a hazmat shipment problem the main objective is to find the best path to transport hazardous materials such as explosives, gases, flammable liquids and solids, oxidizing substances, poisonous and infection substances, radioactive materials, corrosive substances and hazardous wastes. Because of the nature of these kinds of transportations and due to high impact of probable incidents that could be occurred in hazmat shipments, it is a sensitive area for decision making and it is very important for producers of hazmat products, consumers, transporters, local governments, insurance companies and specially for the people that live alongside of the selected path and also in the region of these transportations.

The modeling of transportation problems is a popular application in Operation Research (OR). In most transportation planning models, the objective is to move products from origins to destinations at minimal cost. However, for hazmat shipment, a cost minimizing objective usually is not suitable. The risk associated with hazmat products make these problems more complicated (and also more interesting) than many other transportation problems. Reflection of the risk in hazmat transport models is not merely an academic exercise and in real world it has first priority for many other official entities. For example, the Hazardous Material Transportation Uniform Act (HMTUSA) of 1990 requires the US department of transportation to determine standards for designating the routes to be used for hazmat shipment [7].

Some researchers believe that research in this area focuses on two basic issues, the first one is related to assessing the risk induced on the population by hazmat vehicles traveling on various segments of the road network, and the second one involves the selection of safest routes to take [3]. Different works have been done in this area based on different criteria and various definition of risk. Abkovitz, for example, defined the risk based on transported substance and transport modality [1]. Environmental conditions is also had entered in definition of risk and formed the risk model by evaluation of environmental condition of hazmat shipment [12].

Erkut and Varter used incident probabilities on unit segments of a network and applied different risk models for a given route to determine the route risk. In this paper some similarity indices have been modified and base on these indices, the similarity between routes that are selected by different criteria are computed. It is also highlighted that one
Route selection based on soft MODM framework

of the most popular risk model used by researchers and practitioners is societal risk, that’s being the product between the incident probability per unit length and the incident consequence, which is evaluated as the population area [7]. Designating hazardous materials routes in and through a major population center has been also considered by researchers of hazmat shipment to minimize the total risk of transportation [6].

Meanwhile, the role of information systems is vital to optimize the hazmat shipment problem. Using information systems such as GIS and DSS also has been considered as an alternative to find optimal path for hazmat shipment [14]. For repeated shipments where the arc incident in a route between a pairs of points probabilities are unknown, different strategies has been proposed such as use a mix of routes. A simple heuristic solution based on a shortest path algorithm and the method of successive averages is proposed. Connections to game theory provide useful insights into the nature of the solution [2].

Multi-objective optimization is also considered in hazmat shipment researches such as to minimize maximum population exposure and to minimize total travel time [5].

As it described before, the main problem is to find the route with minimum risk while the definition of the risk differs from case to case. For example we could minimize the accident probability but in this case the population exposure would be increased. In recent works, some models have been proposed for determining path of minimum total risk while guaranteeing equitable risk spreading [4,9,10]. In fact we face to a MODM (Multi Objective Decision Making) model with inconsistence objective, since the mentioned works did not use a soft MODM approach to form and solve the risk model.

Novelties of proposed method

Although hazmat shipment is a multi objective optimization problem in nature, but Due to our best knowledge, a soft decision framework based on risk definition has never been reported in literature before.

In this paper we have tried to eliminate the absence of a flexible MODM approach and developed a soft MODM model to satisfy different and even inconsistence objectives based on priorities and weights. Although the weights of decision criteria in this problem could be determined based on weight assigning such as entropy, but enjoying dynamic nature of the proposed model, the weights could be changed depending on priorities of decision maker.

There are different methods exist to solve MODM models such as goal programming, penalty method and also soft computing techniques. In this paper we have applied Genetic Algorithm as a branch of soft computing techniques to solve MODM model in hazmat shipment.

Problem definition, methodology and Genetic Algorithm are presented in section 2. Section 3 is presented model development and also the result of developed model. At the end, the results are aggregated in conclusion section.
2. Problem Definition and Methodology

Problem definition and methodology that has been used to solve the problem are introduced in this section. Hazmat shipment, risk definition and Genetic Algorithm (GA) are addressed in this section.

2.1 Hazmat Shipment

There is no global definition of risk but in general, risk deals with two basic subjects:

1. Probability of an undesired event
2. Consequence of an undesired event

Using the traditional risk definition, the risk of transporting hazmat $B$ over a unit segment (such as one kilometer) can be written:

$$ R_{ab} = P_{ab} C_{ab} $$

Where:
- $P_{ab}$ is probability of an incident on the unit road segment $A$ for hazmat $B$ and
- $C_{ab}$ is population along the unit road segment $A$ within the neighborhood associated with hazmat $B$.

In this field the impact area should be defined. The impact area is a circle with impact radius that the transporter of hazmat product is located in its center. Based on the hazmat type, this circle and consequently its impact would be defined. Figure 1 illustrates this concept.

![Impact Area](image)

Figure 1- Impact Area

Although the risk of incident in hazmat shipment is very important but there are other kinds of risks exist in this area such as robbery or terrorist attacks. Due to these new emerging threats, the objective of route selections could be changed inconsistently. For example, if we want to transport radioactive garbage, what criteria should be used to
select the best path? Minimum accident probability, minimum incident, safest path or the lowest populated path?

The answer to this question leads us to select objectives to form the logical and mathematical model. In this paper we have selected the 6 following objectives and tried to combine them in unique MODM model. The selected objectives and the proper definition of each objective are presented in table1. It is obvious that any other criteria could be inserted to model by decision maker.

Table1. The Objectives of path Selection

<table>
<thead>
<tr>
<th>Objective</th>
<th>Calculation Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shortest Travel Distance</td>
<td>Path length</td>
</tr>
<tr>
<td>Minimum population Exposure</td>
<td>The average population in impact area</td>
</tr>
<tr>
<td>Minimum Societal Risk</td>
<td>$L \times AR \times CR \times Pd \times \pi \times r^2$ (expected number of people to be impacted in one trip of hazmat truck)</td>
</tr>
<tr>
<td>Minimum Accident Probability</td>
<td>Average accident probability for the path</td>
</tr>
<tr>
<td>Safest Road (minimum Robbery Rate)</td>
<td>Average Robbery probability for the path</td>
</tr>
<tr>
<td>Minimum Terrorist Attacks</td>
<td>Average Terrorist Attacks probability for the path</td>
</tr>
</tbody>
</table>

Where:

$L$ : Length of the path
$AR$ : Accident Rate (probability) on the path (per kilometer)
$CR$ : Conditional Release given an accident
$Pd$ : Population density in the neighborhood of the path (person per kilometer-sq)
$r$ : Impact Radius

2.2 Genetic algorithm

Genetic Algorithm (GA) is a kind of search and optimized algorithm that have been produced from simulating biologic heredities and long evolutionary processes of creatures. It stimulates the mechanism of “survival competitions; the superior survive while the inferior are eliminated, the fittest survive.” The mechanism searches after the optimal subject by means of a successive iterative algorithm. From the late 80s, GA, as a new cross discipline which has drawn people’s attention, has already shown its increasing vitality in many fields [13]. GA has demonstrated substantial improvement over a variety of random and local search methods. The GA is based on the laws of natural selection in genetics. The principal idea is to search for optimal solution in a large population. It uses a fixed length binary string called a chromosome to represent a possible solution or individual for a given problem domain. Usually a simple GA consists of three operations:

- Selection
- Crossover
- Mutation
The population comprises a group of chromosomes from which candidates can be selected as a solution of a given problem. The initial population (set of possible solutions) consists of member solutions. Each one has a fixed member of randomly selected features from a feature pool. The fitness (a measure of appropriateness of the solution of each chromosome) is evaluated by fitness function.

The selection operator selects chromosomes in the population based on fitness. Individuals with higher fitness have more chance for being selected as parents. A couple of selected chromosomes or parents are then crossed over and their information is exchanged to generate new chromosomes or offsprings.

Mutation fills the value of all or some bits of randomly selected chromosome. This operation increases exploration of search space and prevents converging to a local optimum point. The process runs cyclically until a stopping criterion is reached. Each cycle is called a generation.

The key assumption of parent selection is to give preference to fitter individuals. Here we use the Roulette Wheel selection scheme [8]:
1. Computing cumulative fitness of individuals.
2. Generating a random number $n$ between 0 and total fitness.
3. Returning the first individual that its cumulative fitness is greater than or equal to $n$.

In this paper the Uniform crossover scheme is used. That is, each bit position 1 to $L$, is randomly picked from either of the two parents’ strings. This means that each bit is inherited independently from other bit and that there is, in fact, no linkage between bits. After crossover and mutation, there are two groups of candidates: the parents and the offsprings. Each of these groups contributes a fraction of new generation. We have used the elitist selection strategy to transfer a copy of a few fittest individuals in present generation to next generation to ensure crucial convergence of algorithm [11]. While any successful application of genetic algorithm for solving a problem is greatly dependent on finding a suitable method for encoding the possible solutions to chromosomes, the creation for the appropriate fitness function is important to have a successful training process.

3. Model Development and Results

In this paper we have formed a MODM model base on 6 different objectives that are presented in table 1. Each of 6 different objectives could be determine by associated weights as $w_1, w_2, w_3, w_4, w_5, w_6$ respectively. The presented model is dynamic and the proper codes have been written in MATLAB™ language that can get the priorities from decision maker, calculate the results and then select the best path base on input weights. Though, the decision maker could change the weights due to the situation and based on his/her priorities. The only constraint is:
Where;

is the weights of 6 different objectives respectively.

The conceptual framework of the model is illustrated in figure 2. As it shown in figure 2, the output of the model is the best path based on decision maker’s priorities. The soft and flexible framework of the model allows decision maker to revise the priorities and the resulted weights based on output feedback.

![Conceptual model framework](image)

Figure 2. Conceptual model framework

Here, Genetic Algorithm is used as a tool to solve the MODM model based on input weights (priorities). As it is shown in table 2, eight paths between a proposed Origin Destination (O-D) pair with determined calculation criteria are used to feed to model.
Table 2 – Eight different paths between a proposed origin-destination pair

Due to the dynamic nature and implementation of the model, the input weights could be subject of change. The input data have been preprocessed by normalizing each set. Then, the GA parameters have been set. Since GA is a heuristic algorithm, its parameters should be set based on the case problem. The parameters of the GA that used to solve MODM model are presented in table 3.

Table 3 - GA Parameters

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population Type</td>
<td>Bit String</td>
</tr>
<tr>
<td>Population Size</td>
<td>100</td>
</tr>
<tr>
<td>Selection Function</td>
<td>Roulette</td>
</tr>
<tr>
<td>Crossover Function</td>
<td>Single point</td>
</tr>
<tr>
<td>Mutation Function</td>
<td>Uniform</td>
</tr>
<tr>
<td>Mutation Rate</td>
<td>0.01</td>
</tr>
</tbody>
</table>

Now we are ready to check the model and select the best path for transportation of hazardous materials. Due to this fact that weights are determined based on decision maker’s priorities, different scenarios are considered here to run the model. The results are presented in table 4.
Table 4- Results of Scenario test

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Weights Combination</th>
<th>Selected Path</th>
<th>Convergence Diagram</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$w_1 = w_2 = w_3 = w_4 = w_5 = w_6$</td>
<td>5</td>
<td><img src="image" alt="Convergence Diagram 1" /></td>
</tr>
<tr>
<td>2</td>
<td>$w_1 = 0.1, w_2 = 0.3, w_3 = 0.3,$ $w_4 = 0.1, w_5 = 0.1, w_6 = 0.1$</td>
<td>5</td>
<td><img src="image" alt="Convergence Diagram 2" /></td>
</tr>
<tr>
<td>3</td>
<td>$w_1 = 0.1, w_2 = 0.1 w_3 = 0.1,$ $w_4 = 0.1, w_5 = 0.3, w_6 = 0.3$</td>
<td>8</td>
<td><img src="image" alt="Convergence Diagram 3" /></td>
</tr>
<tr>
<td>4</td>
<td>$w_1 = 0.1, w_2 = 0.1, w_3 = 0.1,$ $w_4 = 0.5, w_5 = 0.1, w_6 = 0.1$</td>
<td>5</td>
<td><img src="image" alt="Convergence Diagram 4" /></td>
</tr>
<tr>
<td>5</td>
<td>$w_1 = 0.3, w_2 = 0.1, w_3 = 0.1,$ $w_4 = 0.3, w_5 = 0.1, w_6 = 0.1$</td>
<td>5</td>
<td><img src="image" alt="Convergence Diagram 5" /></td>
</tr>
</tbody>
</table>
We have tested 6 different scenarios to select the path. It means that 6 different combinations of weights are used for path selection.

Conclusions

Hazmat shipment is a problem of industrialized societies and due to sensitive nature of these kinds of problems many works have been done in this area. As it was mentioned in literature review, most of these works did not look at this problem as a flexible MODM model and their formulation and model formation, strongly tied with their definition of risk in hazmat problems. In this paper we had tried to propose a soft and flexible MODM approach and suitable dynamic GA based model to making proper decisions about path selection in hazmat shipment. Flexible definition of the problem and also the soft GA capabilities give us a new vision to hazmat shipment problem that let us to make decisions quicker in complex cases.

References


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