Using Tolerated Risk for Solving Hazardous Material Routing Problem by Preemptive Goal Programming Approach

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***Abstract*— Route determination for hazardous material (Hazmat for short) transportation is a main concern in Hazmat management in which transport risk and cost are considered as the main attributes. The pre-defined priorities for risk and cost cause different mathematical models developed to determine the best routes which are not necessarily the shortest paths. In this paper, a tolerated risk usage is utilized to develop mathematical model for selecting the best route for carrying hazardous materials according to risk and path distance. Mathematical model has been developed using preemptive goal programming approach in which transport risk is considered more important than distance at the first step for developing model and route distance is minimized subject to pre-defined risk tolerance at the second stage. Experimental data including eighty-nine nodes and one-hundred and one links in a real network has been selected for numerical analysis and results have been discussed. Results revealed that there are some alternative routes when risk tolerance is getting to be increased or long distance paths used for hazardous materials transportation. In addition, using tolerated risk can satisfy both national/local authorities in hazmat management and transport companies as well.**

***Keywords*— Risk Analysis, Preemptive Goal Programming, Hazardous Materials, Mathematical Programming, Transportation**

I. INTRODUCTION

According to United Nations recommendation on road traffic safety promotion, hazardous materials (Hazmat for short) are classified into nine classes of explosives, gases, flammable liquids, flammable solids, oxidizing substances, toxic substances, radioactive materials, corrosive substances, and miscellaneous dangerous goods [1]. Hazardous material transportation, or hazardous materials management in global concern, is a main concern of decision makers in both industrialized [2] and developing countries [3] in which Hazmat transport covers a large part of economic activities. It may be considered more important when the third category of Hazmat named flammable liquids or fuels which are used for consuming purposes in agriculture, industries, private cars and house warming [4]. Hazmat transportation problem becomes a double-sided consideration problem because on the one hand, huge amounts of hazardous materials movement make their management is known as an extremely complex issue involving a multitude of environmental, engineering, economic, social and political concerns [3] and on the other hand, Hazmat incident impacts, associated to road accidents which may have chaotic behavior [3], are also serious attributes for Hazmat management. In this case, the main concern for hazmat management is to satisfy both national/local authorities and transport companies.

A. Hazmat Routing Problem

Following the above mentioned, determining route for carrying hazardous materials, known as Hazmat Routing Problem (HRP), is getting to be more serious rather than cargo transport. As mentioned before, while transport companies, suppliers and carriers are interested in minimizing transport cost and local/national authorities are interested in minimizing public risk, HRP is defined as a double-sided consideration problem [5]. If transport risk and cost attributes of hazmat management are defined as a trade-off manner [6, 7], various combinations of risk and cost are consequently used for developing mathematical models to determine the best route which is not necessarily the shortest path. In addition, different combinations of risk and cost make researchers to use different methods for solving the above problem [8, 9] while different priorities for risk and cost or travel time change results on the routes determined for hazardous material transportation [3].

There are several methods to obtain a proper solution for satisfying both transport companies and authorities who follow the opposite considerations. It is a common method when local authorities specify restricted regional network for Hazmat transportation. Using this method has two advantages, both for better enforcement and improving road safety and determining the best route using a limited network which makes decision makers have to solve HRP under network constraints [10, 11]. Although other attributes such as the nature of hazardous materials [2, 12, 13], public security [11], vehicles capacity planning [14, 15], Hazmat delivery time [2, 16], emergency response [9, 13] are known important attributes for developing HRP models, but the main consideration for developing mathematical models lies on risk and cost trade-off in which transport cost may be represented by travelling distance.

B. Premmptive Goal Programming

Goal programming is a mathematical modeling technique in which conflicting or opposite objective functions are simultaneously considered in the process of developing and running mathematical modeling [17]. There are two well-known methods for solving goal programming models. The weights method forms a single objective function consisting of the weighted sum of goals while the preemptive method optimizes the goal one at a time starting with the highest priority goal and terminating with the lowest one. In fact, preemptive goal programming approach breaks down the multi-objective function problem into many single objective function problems in which the solution of the higher priority is considered as a constraint for the lower priority one. The process is carried out such that the solution obtained from a lower-priority goal never degrades any higher-priority solutions [17]. Since, the risk and distance are conflicting attributes in hazardous material transportation problem preemptive goal programming is a good technique to solve the problem in which the risk is defined in higher priority and distance (represents cost) as the lower priority attribute.

C. Vision

Transport risk which is including accident, population, environment and infrastructure components [3] usually considered as a main attribute for determining routes for hazardous material transportation. On the other hand, transport companies may argue the specific routes determined by minimizing risk in which there is no alternative route to minimize distance (cost). In this case, it is a common way if mathematical model developed considering the risk as a higher priority goal and the transport distance as a lower priority goal. In the real world, it is so difficult to consider pre-defined risk as a rigid constraint for determining routes so the created problem may be solved in a trade-off consideration manner, in which a risk tolerance is used for the second phase of HRP to determine the shortest path. The shortest path is determined at the second stage subject to a tolerated risk obtained minimizing risk. Therefore, this paper develops a trade-off model considering minimizing risk at the first stage and considering tolerated one in the second stage to determine the shortest path for hazardous material transportation.

This paper is organized into five sections. After introduction, the process of developing mathematical model utilizing preemptive goal programming approach is discussed followed by description of case study and numerical analysis. More discussions are available in numerical analysis section where as a brief description on what has been followed in the paper as well as some recommendations for further research are discussed in the last section entitled summary and conclusion.

II. Developing Mathematical Model

Assume that a road network (graph) G(n, e) including a number of nodes (n) and edges (e) is pre-defined. Each node can be recognized as origin or destination node, so the others are known as connecting nodes. The main concept is to define transporting hazardous materials from an origin node to another node called destination node through connecting nodes located in the road network. Connecting nodes are located in the best path which is determined by mathematical model. In this case, the best path is determined considering risk and length associated to each link (edge). Length of link may be substituted by cost in the models in which the length may be defined as cost [3]. Developing goal programming model guarantees minimizing transport risk at the first stage and minimizing the length of path (finding shortest path) at the second stage subject to obtained risk at the first stage. This concept leads decision makers to utilize preemptive goal programming approach. Preemptive goal programming approach requires that the determined objective function from the first stage should be considered as a constraint for the second stage. At the second stage, the best path, which is known as the shortest path in this paper, is selected considering that objective function of the first stage not to be exceeded the optimized one while finding the shortest path is objective function.

Following the concept discussed in the previous paragraph, the first objective function is to minimize transport risk for each origin-destination pairs. Minimizing transport risk is formulated by equation (1), where Xij is a binary variable. Xij is equal to 1 if link (i, j) is located in the selected path for each origin-destination pairs, otherwise it is equal to 0. Transport risk is donated as Rij which is primarily associated to link (i, j).

$$Min\ Z_1 = \sum_{(i,j)\epsilon\ G} R_{ij} \times X_{ij} \tag{1}$$

There is a main constraint to develop mathematical model. This is to define an equation which guarantees the existence of continuousness in the selected path. Equation (2) guarantees the above constraint and insures the existing continuousness of the nodes which are located in the selected path. The above equation should apply for all nodes defined in the road network both located in the selected path or not. The left side of equation (2) is the defined balance of binary variables which are connecting to the specified node j. The equation defines the balance between sum of outgoing links from node j and entering links to j. It is obvious that if the balance is equal to 1, the specified node is an origin node, else if the balance is equal to -1, the specified node is a destination node, otherwise (the balance is equal to 0), the corresponding node is a connecting node in determined path or a node which is defined in road network but it is not located in shortest path. More discussion on the above concept is available at [3]. It is interesting that the above constraint is enough to satisfy all concerns may be defined in hazmat routing problem [4]. Running the above model will determine the minimum risk for the selected route which will be considered as a constraint for the second stage.

$$\sum_{k\ from\ j \in G} X_{jk} - \sum_{k\ to\ j \in G} X_{kj} = \begin{Bmatrix} 1\ if\ j\ is\ origin \\ -1\ if\ j\ is\ destination \\ 0\ \ otherwise \end{Bmatrix} \qquad \forall j\ \in G \tag{2}$$

Following the above mentioned, the second part of mathematical model can be defined as equation (3) where the length of each link is donated as Lij which is associated to link (i, j). Decision variable (Xij) is defined as the same as one which is defined for the first objective function.

$$Min\ Z_2 = \sum_{(i,j)\epsilon\ G} L_{ij} \times X_{ij} \tag{3}$$

Equation (2) is also used for this stage with no change. As aforesaid, the first stage objective function should be considered as a constraint for the second part of the model. Therefore, equation (4) is defined to consider the minimum risk in the second stage while the shortest path is determined. In general, decision for selecting the shortest path may be made in flexible manner or viewpoint in which there is a pre-specified tolerance for risk. This concept is now defined by parameter (α) in equation (4). Parameter α defines the rate of tolerance which is a real number grater that 0. Having α=0 means that there is no tolerance for risk, and increasing that means the pre-specified tolerance is raised.

$$\sum_{(i,j)\epsilon\ G} R_{ij} \times X_{ij}\ \leq (1{+}\propto) \times Z_1 \tag{4}$$

In inter-city transport network, two-way edges are usually available, so equation (5) is defined to provide the above consideration in the proposed mathematical model.

$$(i,j), (j,i) \in G \tag{5}$$

Adding general constraint to define binary variable, the summarized mathematical model can be shown as below:

$$Min\ Z_1 = \sum_{(i,j)\epsilon\ G} R_{ij} \times X_{ij} \tag{6}$$

$$Min\ Z_2 = \sum_{(i,j)\epsilon\ G} C_{ij} \times X_{ij} \tag{7}$$

$Subjet\ to$:

$$\sum_{l\ from\ j \in G} X_{jl} - \sum_{l\ to\ j \in G} X_{lj} = \begin{Bmatrix} 1\ if\ j\ is\ origin \\ -1\ if\ j\ is\ destination \\ 0\ \ otherwise \end{Bmatrix} \qquad \forall j\ \in G \tag{8}$$

$$\sum_{(i,j)\epsilon\ G} R_{ij} \times X_{ij}\ \leq (1{+}\propto) \times Z_1 \tag{9}$$

$$(i, j), (j, i) \in G \quad (10)$$

$$X_{ij} \text{ is binary variable } (0, 1) \quad (11)$$

III. Case Study and Numerical Analysis

A. *Experimental Road Network*

The case study is the north-west of a Middle East country of Iran consisting of five provinces West Azerbaijan, East Azerbaijan, Adrabil, Kordestan, and Zanjan. The road network corresponding to case study consists of eighty-nine nodes and one hundred and one two-way links depicted in Figure 1. Some nodes are border nodes that connect research area to the other neighbor provinces. Nodes located in the area are listed in appendix providing a reference for further research and simulation. Vehicles are assigned to transport hazardous materials subject to minimizing total risk at the first stage and minimizing total distance at the second stage. Distances from each node to its connecting nodes have been set using a detailed road network map while risks associated to links are used following another research work. More details on risk assessment, in particular Hazmat risk components on transportation, are available at [3].

Fig. 1: The Case Study Road Network Map

B. *Analytical process*

Six different origin-destination pairs (O-D) have been selected for analytical process. Looking more details on the road network map, origin destination pairs have been selected from three categories of long, medium and short paths shown in table 1. Two origin-destination pairs have been selected from each category in order to check the variety of outputs. For each origin and destination the code of nodes are located beside their names. On the other hand, four different values of 0.05, 0.10, 0.25 and 0.50 for risk tolerance are also considered for selecting routes for considering 5, 10, 25 and 50 percent of risk tolerance, respectively. They are used in the second stage of the proposed mathematical model. Setting tolerance value as 0.05 means that the risk constraint, which is considered in the second stage of preemptive approach, has 5 percent tolerance comparing to the total risk determined in the first stage. Obviously, setting tolerance value as 0.50 means the above tolerance risk is 50 percent comparing to the first stage objective function.

TABLE I. Origin-Destination pairs used for analytical process

Row	Origin	Destination	Path Size
1	Parsabad (25)	Sanandaj (67)	Long
2	Bazargan (1)	Abhar (73)	Long
3	Marand (13)	Bijar (65)	Medium
4	Nir (37)	Oshnavieh (56)	Medium
5	Jolfa (15)	Orumieh (43)	Short
6	Marivan (66)	Dehgolan (69)	Short

Two stages of the proposed mathematical model have been run for all selected O-D pairs and four different values of risk tolerance and results tabulated in table II, III and IV corresponding to long, medium and short paths, respectively. As shown, the first column represents origin and destination pairs, the second and third columns represent the stage of running model and risk tolerance, notated by Alpha, and the rest columns represent model outputs. Model outputs consist of the selected routes and computed objective functions for each stage. For more details it should be mentioned that objective function for the first stage is just one value notated as Z1 while objective functions for the second stage are corresponding to various of risk tolerances notated by Z2.

TABLE II. DETERMINED ROUTES FOR LONG DISTANCE O-D PAIRS

(O-D)	Stage	Alpha	Route	Objective F.
25-67	**First**	-	25-77-23-22-15-16-13-76-9-10-11-43-84-54-53-58-61-64-85-67	Z1= 7.78
	Second	0.05	25-77-23-22-15-16-13-76-9-10-11-43-84-54-53-58-61-64-85-67	Z2= 1045
		0.10	25-77-23-22-24-20-18-17-14-12-10-11-43-84-54-53-58-61-64-85-67	Z2= 1023
		0.25	25-77-23-22-24-20-18-17-40-42-44-45-50-51-52-53-58-61-64-85-67	Z2= 774
		0.50	25-77-23-22-24-20-18-17-40-42-44-45-50-51-52-53-58-61-64-85-67	Z2= 774
1-73	**First**	-	1-2-3-5-7-76-9-10-11-43-84-54-53-59-60-65-72-75-89-73	Z1= 10.75
	Second	0.05	1-2-3-5-7-76-9-10-11-43-84-54-53-59-60-65-72-75-89-73	Z2= 995
		0.10	1-2-3-6-7-76-9-10-11-43-84-54-53-58-61-64-85-65-72-75-89-73	Z2= 979
		0.25	1-2-3-6-7-76-13-14-17-40-42-44-45-50-46-83-47-82-48-75-89-73	Z2= 861
		0.50	1-2-3-6-7-76-13-14-17-40-42-44-45-50-46-83-47-82-48-75-89-73	Z2= 861

TABLE III. DETERMINED ROUTES FOR MEDIUM DISTANCE O-D PAIRS

(O-D)	Stage	Alpha	Route	Objective F.
13-65	**First**	-	13-76-9-10-11-43-84-54-53-59-60-65	Z1= 4.73
	Second	0.05	13-76-9-10-11-43-84-54-53-59-60-65	Z2= 612
		0.10	13-76-9-10-11-43-84-54-53-59-60-65	Z2= 612
		0.25	13-76-9-10-11-43-84-54-53-58-61-64-85-65	Z2= 598
		0.50	13-14-17-40-42-44-45-50-51-53-59-60-65	Z2= 482
37-56	**First**	-	37-38-39-40-17-14-12-10-11-43-56	Z1= 6.62
	Second	0.05	37-38-39-40-17-14-12-10-11-43-56	Z2= 596
		0.10	37-38-39-40-17-14-12-10-11-43-56	Z2= 596
		0.25	37-38-39-40-17-14-12-10-11-43-56	Z2= 596
		0.50	37-38-39-40-42-44-45-50-51-52-53-54-84-55-56	Z2= 512

TABLE IV. DETERMINED ROUTES FOR HORT DISTANCE O-D PAIRS

(O-D)	Stage	Alpha	Route	Objective F.
15-43	**First**	-	15-16-13-76-9-10-11-43	Z1= 3.50
	Second	0.05	15-16-13-76-9-10-11-43	Z2= 297
		0.10	15-16-13-76-9-10-11-43	Z2= 297
		0.25	15-16-13-76-9-10-11-43	Z2= 297
		0.50	15-16-13-76-9-10-11-43	Z2= 297
66-69	**First**	-	66-67-69	Z1= 0.7
	Second	0.05	66-67-69	Z2= 193
		0.10	66-67-69	Z2= 193
		0.25	66-67-69	Z2= 193
		0.50	66-67-69	Z2= 193

C. Discussion

In order to summarize obtained results, the contents of the above mentioned tables have also been tabulated in table 5. More details are also depicted in figures 1 and 2. To clear depiction, risk is graphed by unit*100 in figure 1. Risk is depicted by dashed lines while distance is depicted in simple line. The average distance of determined routes are also depicted in figure 2 in which the horizontal axes is risk tolerance. As shown in table V and figures 1 and 2 when risk tolerance is increased, more routes are available to be determined as the best route, so mathematical model determines the shorter path rather than those risk tolerances are tight. Another observation is to find out the difference between long and short paths. More routes are available in long distance paths so mathematical model can determine many shortest routes when risk tolerance is getting to be wider.

TABLE V. OBJECTIVE FUNCTION VALUE FOR THE FIRST (Z1) AND THE SECOND (Z2) STAGES

Path Size	O-D Pairs	Z1	Z2			
			α = 0.05	α = 0.10	α = 0.25	α = 0.50
Long	25-67	7.78	1045	1023	774	774
	1-73	10.75	995	979	861	861
Medium	13-65	4.73	612	612	598	482
	37-65	6.62	596	596	596	512
Short	15-43	3.50	297	297	297	297
	66-69	0.70	193	193	193	193
Average			623	617	553	520

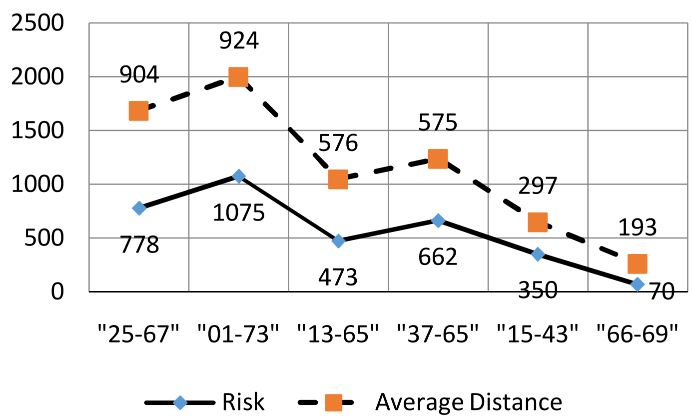

Fig. 2: Route distances (KM) for all O-D pairs

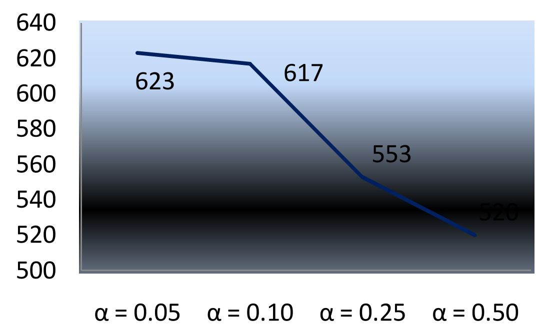

Fig. 3: Average distance (KM) based on α

IV. SUMMARY AND CONCLUSION

In this paper, preemptive goal programming approach has been utilized to develop a mathematical model for determining routes for hazardous material transportation. Risk and cost, which is represented by distance, are considered as main attributes and the first priority is set for risk and the second is set for distance. In this case, mathematical model is run in two stages. At the first stage the objective function is minimizing risk while the second objective function is minimizing route distance from each origin to destination. Mathematical model has been developed considering objective function value obtained from the risk minimization stage is considered as a constraint to the second stage. In other words, the second stage of the proposed matehatical model is solved subject to obtained risk from the first stage. In order to utilize practically, an experimental road network consists of 89 nodes and 101 links has been selected as case study as well as a risk tolerance has been defined for risk variation as a constraint and sensitivity analysis has been done based on different values of risk tolerance. Results revealed that there is difference between long and short paths. A number of routes may be determined using different risk tolerances over the network, but there is not chance to determine routes when short distance paths are selected. In addition, results showed that while risk tolerance is increased, shorter paths are determined by mathematical model. In other words, shorter paths will be obtained if the risk tolerance is considered wider. This conclusion is also been considered as a logical view, when tolerance is increased the model has more alternatives to determine as the shortest paths.

Whereas the developed mathematical model and utilized approach are useful to satisfy decision makers who are dealing with hazmat management in terms of risk and distance priorities, further researches are recommended to consider other important attributes in hazmat transportation and define a hierarchy priority for them in order to insure that all attributes are considered in a manner of goal programming.

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Appendix: List of nodes corresponding to the road network in case study

Code	Name	Code	Name	Code	Name	Code	Name
1	Bazargan	24	Kalibar	47	Hashtrud	70	Qorveh
2	Maku	25	Parsabad	48	Miyaneh	71	Khodabandeh
3	Shut	26	Bilesovar	49	Qareaghag	72	Zarinabad
4	Poldasht	27	Jafarabad	50	Bonab	73	Abhar
5	Chaldoran	28	Germi	51	Malekan	74	Soltanieh
6	Nazioliya	29	Razi	52	Lilan	75	Zanjan
7	Qareziyaedin	30	Meshkinshahr	53	Miyandoab	76	Serahimarand
8	Firorgh	31	Namin	54	Mahabad	77	Marz-Azarbayegan
9	Khoy	32	Astara	55	Naqadeh	78	Serahibilesovar
10	Salmas	33	Ardabil	56	Oshnavieh	79	Serahimeshkinshahr
11	Tazehshahr	34	Sarein	57	Piranshahr	80	DoriAhiardbil-Razi
12	Shabestar	35	Khalkhal	58	Bookan	81	To-Gilan
13	Marand	36	Koraeim	59	Shaeindej	82	Serahi-Hashtrud
14	Sofiyan	37	Nir	60	Takab	83	Serahi-Qarehaghag
15	Jolfa	38	Sarab	61	Saqez	84	Serahi-Mahabad
16	Hadishahr	39	Bostanabad	62	Baneh	85	Serahi-Bigar
17	Tarbiz	40	Khosroshahr	63	Sardasht	86	To-Hamedan1
18	Khajeh	41	Osko	64	Divandareh	87	To-Hamedan2
19	Varzaqan	42	Mameghan	65	Bigar	88	To-Qazvin
20	Ahar	43	Orumieh	66	Marivan	89	Serahi-Soltanieh
21	Haris	44	Azarshahr	67	Sanandag		
22	Soltanli	45	Ajabshir	68	Kamkariyan		
23	Aslandoz	46	Maragheh	69	Dehgolan		

BIOGRAPHY

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