

A Fuzzy Bi-Objective Mathematical Model for Sustainable Hazmat Transportation

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Abstract

Today, transportation of hazardous materials (i.e., hazmat) is a very important issue for researchers due to the risk of this transit, which should be considered for development of industries and transportation. Therefore, a model that is useful should consider the risk and damage to humanitarian and environmental issues due to transit of hazmat materials. By considering the related cost, the reality and applicability of the model are also very important. In this paper, a bi-objective model is presented for routing rail-truck intermodal terminals with the cost and risk as objective functions by considering three sets of the effective factors that lead to hazardous materials transportation accidents in favor of sustainability. Additionally, a fuzziness concept is considered in the presented model. The model is first validated by the prevalent software using the authoritative solver to solve a numerical example. Furthermore, to help managers, an efficient fuzzy approach proposed in the literature is used. Finally, it is concluded that in this work a reality and sustainable model is suitable for hazmat transportation.

Keywords: Rail-truck intermodal, hazmat transportation, sustainable, fuzzy multi-objective method.

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1. Introduction

The economic aspect of activities have been considered in responding to increased demand and new emerging needs since the beginning of the twentieth century. After satisfying the desire for economic; There was concern about humanity, environmental pollution, overuse of resources, the possibility of living for the current generation and future generations. Therefore, considering both economic and environmental issues led to the so-called green subject. The third subject is sustainable, which is complete the above-mentioned subjects. This term considers the community in addition to economic and environmental aspects that the inter-generational and inter-generational equity is created.

The concern about social and environmental issues leads to a new tri-dimensional concept based on economic, environment and society, called sustainable development. [WCED, 1987] stated that “Sustainable development is the kind of development that provides the needs of the present generation without undermining the ability of future generations to meet their needs”.

Sustainable transportation is a significant issue in transportation that refers to a broad subject of transporting. It includes vehicles, energy, infrastructure, roads, railways, airways, waterways, canals, pipelines and terminals. The sustainability of transportation is largely measured by the effectiveness and efficiency as well as the environmental impacts of the transportation system. Transportation is divided into several branches. Hazardous materials (or hazmat) transportation belongs to a class of freight transportation and it is very important because of its risks. For example, if one shipment of hazmat materials has an accident, its accident releases gases that have a bad effect on the environment and the health

of human (i.e., society). The reader can imagine this occurrence for volumes of hazardous materials that move in a year. The transfer can be done by a truck, train or other vehicle that is appropriate for this subject. So, in this work, a bi-objective model with several factors, which can reduce the transportation risk in the combination of road and railway vehicle transportation, is improved. In fact, sustainable hazmat transportation is considered in a rail-truck transit network. Many things in the real world are not exact, so the fuzziness concept is considered in this model for closing the model to the real world.

The rest of this paper is structured as follows. Section (2) surveys the previous studies in this field. Section (3) presents the model with some new assumptions and description network and related factors. Section (4) shows the result of solving a numerical example and the use of the TH method for the presented model. The conclusion of this work is provided in section (5).

2. Literature Review

A number of researchers studied hazmat transportation from different aspects. [Dadkar et al. 2010] improved a non-linear game-theoretic model for the analysis of between terrorists, carriers and government agencies. They solved their model with a tabu search method. [Akgün et al. 2007] considered road hazmat transportation in the routing issue with time-dependent attributes by regarding to natural weather systems, because the weather system has an effect on accident probabilities and equity, costs and risks. They presented an exact method for small-sized problems and improved heuristic methods (i.e., MYOPIC and IWS) for large-sized problems. [Erkut and Gzara, 2008] focused the network design for hazardous materials by proposing a bi-objec-

tive (i.e., cost and risk) model and traded-off between them. They used a heuristic method for solving this model that finds a path with minimum risk for each commodity and a network with minimum risk. [Lozano et al. 2010] explored the accidents of Mexico City and analyzed of hazardous accident risk exposure and compared it with real data. The transportation of chlorine and gasoline as hazmat materials by a truck in Mexico City are considered by [Lozano et al. 2011]. They had several conclusions (e.g., if the band is wide the ratio of exposed is lower) and had a forecast for the accident that happened in this city.

[Schweitzer, 2006] investigated the risk of toxic release by using a combination of a statistical method (simulation-based hypothesis tests) and mapping of California as a case study for environmental justice. [Verma and Verter, 2007] focused on hazmat materials that are airborne in the incident of railroad transport. They presented a risk evaluation methodology that provides a valuable approach of railroad transport risk. They also considered a worst-case approach for adapting their parameters. [Bonvicini and Spadoni, 2008] presented a new model (namely, OPTI PATH) for solving of a multi-commodity routing problem in hazmat transportation due to satisfy the risk. Their case study is Ravenna; in fact they believed in hazmat transportation, the risk of transportation can be reduced by considering the routing. [Bianco et al. 2009] proposed a bi-level model for hazardous transportation by considering local and regional government authorities. They also presented the model in form of the mixed-integer programming by regarding to the follower and leader. To review the literature of hazmat transportation, readers can see [Erkut and Alp, 2007] and they refer to [Raemdonck et al, 2013] for analysis its risks. [Tavakkoli-Moghaddam et al. 2013]

developed a bi-criteria model by considering risk and cost for the hazmat shipment, whose objective is to find the best path for carrying hazardous material from origin nodes of suppliers to destination nodes of fuel stations in a road network of Mazandaran province. They considered linguistic variables to achieve road safety experts' view of points by questionnaires.

Although many researchers considered the risk of hazmat for safe transportation, the incident is unavoidable. In this case, the response time is very important and depends on the distance between the station of the response team and event location. [Berman et al, 2007] presented a novel methodology that maximizes the team's ability for responding to a hazmat event by determining the optimal location of team's site. [Tavakkoli-Moghaddam et al. 2011] considered a new multi-objective mathematical model for a vehicle routing problem with time windows of hazardous materials transportation with the human safety that minimizes the transportation cost and the accident risk. They proposed a well-known evolutionary algorithm, namely NSGA-II, to solve a real-case study for shipping the Chlorine gas capsules from the Water & Wastewater Company to municipal water treatment facilities in Tehran. [Agrawal et al, 2010] investigated public opinion in California as a case study for green tax. This tax has lower rates for less polluting vehicle and higher rates for a vehicle emitting more pollution. The green tax can help us to reduce pollution and increase transportation revenues. In fact, this study considered sustainable transportation. The interested readers may refer to [Zhou, 2012] for a comprehensive and up-to-date survey of sustainable transportation.

In this work, a bi-objective model is developed and presented that minimizes the cost of

transportation and exposure risk of shipping hazardous materials presented by [Verma et al, 2012]. This model is improved by considering three sets of factors that influence hazardous materials transportation accidents as mentioned in [Zhao et al, 2012]. In fact, if these factors have optimum values, the risk and cost will be reduced. In other words, by considering these factors, it can be said that this developed model is a sustainable model for hazmat transportation.

3. Model Description

This section presents a mathematical formulation by considering of a Bayesian network as described below. In fact; by this network, sustainability in rail-truck intermodal transportation (RTIM) of hazmat materials is considered. The assumptions of the base model are as follows. 1) The reliable delivery times are the most important aspect of RTIM and

there is no any congestion in the terminal; in fact, there is just-in-time transfer. 2) If the pre-specified time is greater than the total time that needs for completing of rail-haul and drayage activities, then the RTIM shipment is feasible. 3) The fleet of transportation is a homogenous and specified fleet.

Figure 1 depicts a rail-truck intermodal transport network consisting of three parts: 1) inbound stevedore from shipper i to origin intermodal terminal m . second, 2) rail transport between intermodal terminals m and n , and 3) outbound stevedore from destination intermodal terminal n to receiver j . Two problems in defining the flow variable must be considered as: (i) integrating the behavior of the risk curve that is non-linear for rail-haul and linear for drayage and (ii) arresting both the risk and cost for hazmat transportation especially when this load transit along with the regular load.

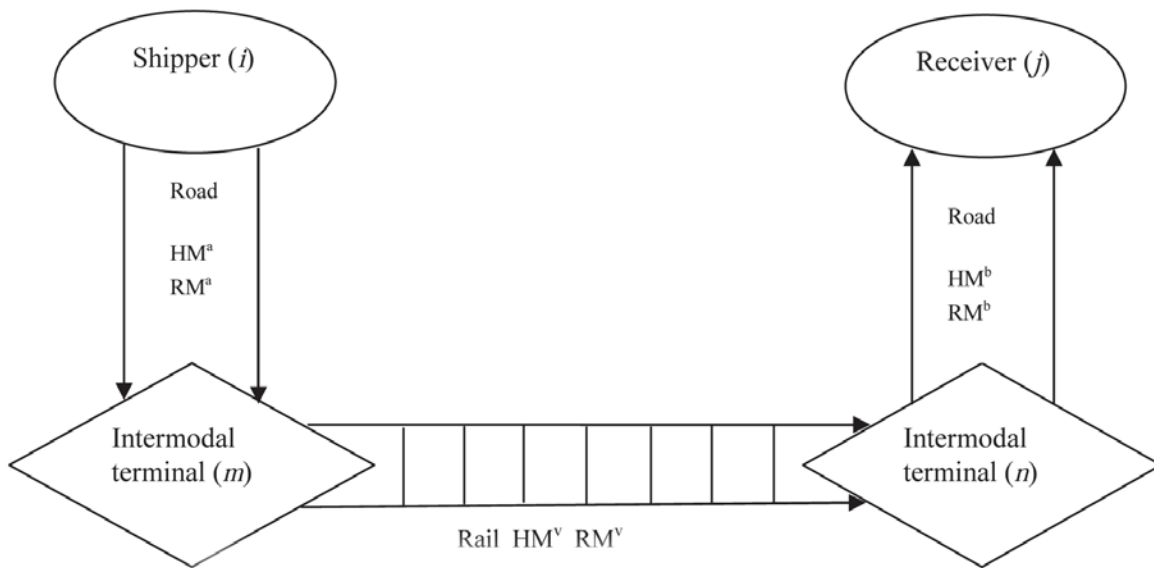


Figure 1. Rail-truck intermodal transportation network

[Zhao et al. 2012] considered 11 significant indirect and direct factors on accidents of hazardous transportation. According of definition and assumption, these factors establish the Bayesian network, which consists of two main sections (i.e., indirect and direct factors). Indirect factors include management, road condition and weather. Direct factors consist of two parts; namely, child and parent. The parent of direct factors include of human (H), transport vehicle (TA) and hazmat loading and packing (PA) that created by child direct factors. There are four assumptions as follows: (i) the indirect factors have any dependent each

other and parent direct factors (i.e., H, PA and TA) are also independent each other; (ii) similar to parent direct factors, child direct factors are independent each other; (iii) indirect factors directly affect on child direct factors; and (iv) accidents just are made by parent direct factors, in other words, accidents only depend on them. Thus, in this work, direct factors are considered (see Figure 2).

This is worthy to say that according to the objective function type, the cost and risk should be minimized. Thus, the value of factors is defined differently from [Zhao et al, 2012] as illustrated in Table (1).

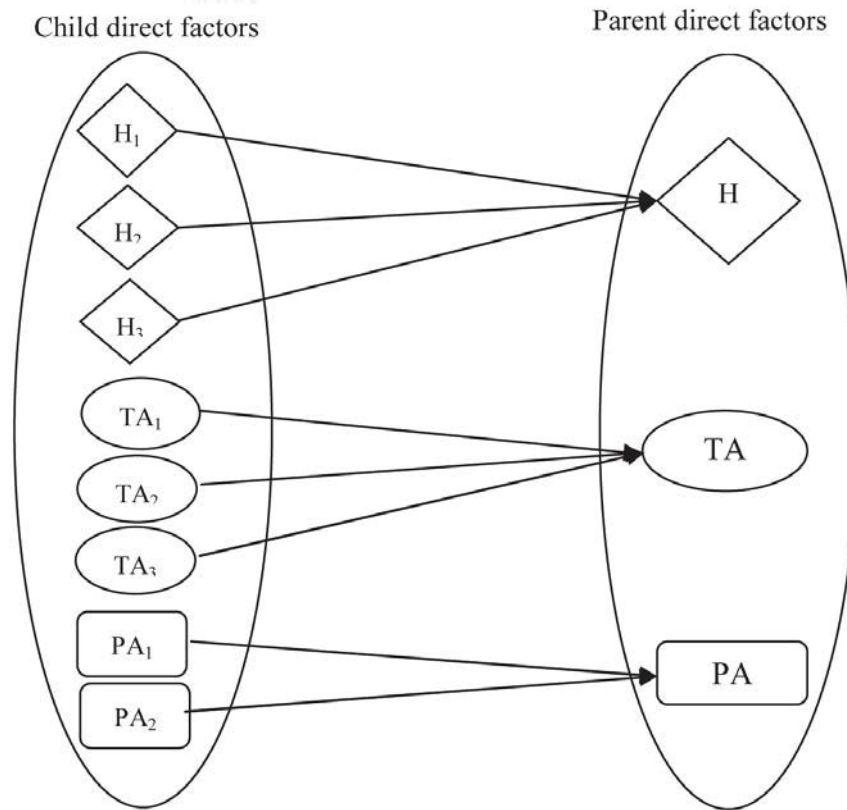


Figure 2. Direct factors and their relation in the Bayesian network

3.1 Points

Because of unavailability or uncertainty of the required data for some parameters, so these parameters are assumed fuzzy. In our model, fuzzy parameters include of the costs of transiting and population exposures as a result of transiting a hazmat material during network. Because of the most common and efficiency of triangular possibility distribution [Liang, 2006], this distribution is considered for uncertainty parameters of the model. Commonly, the degree of the happening of an event for inexact data is described as a possibility distribution. In Figure 3, Z^o , Z^m and Z^p show the most optimistic, possible and pessimistic values of $\tilde{Z}=(Z^p, Z^m, Z^o)$, respectively, as fuzzy numbers that the decision maker estimate them. In this model, the fuzzy symmetrical triangle is considered for uncertainty values.

Protective equipment (TA2) Is a vehicle prepared with the necessary protective equip

3.2 Indices

- I: Index of shippers, its set is I.
- m: Index of origin intermodal terminals, its set is M.
- n: Index of destination intermodal terminals, its set is N.
- j: Index of receivers, its set is J.
- f: Index of human factor (H), its set is F.
- g: Index of transportation factor (TA), its set is G.
- r: Index of packing factor (PA), its set is R.
- a: Index of inbound drayage that is from each shipper $i \in I$ to each origin terminal $m \in M$, so its set is A_{im} .
- b: Index of outbound drayage that is from each destination terminal $n \in N$ to each receiver $j \in J$, so it's set is B_{nj} .
- v: Index of an intermodal train that is services between each terminal pair $m _ n$, so its set is V_{mn} .

Table 1. State of direct factors in hazardous transportation accidents

Direct factors and their child	Description	Value
Human (H)		
Skill (H_1)	What is about skill?	Abnormal (0), normal (1)
Health (H_2)	What is about health?	Abnormal (0), normal (1)
Safety awareness (H_3)	What is about safety awareness?	Abnormal (0), normal (1)
Transport vehicle (TA)		
Transport vehicle (TA_1)	Is a vehicle suitable for hazardous transportation?	No (0), Yes (1)
Protective equipment (TA_2)	Is a vehicle prepared with the necessary protective equipment?	No (0), Yes (1)
Maintenance & monitor (TA_3)	Is a vehicle maintained repeatedly?	No (0), Yes (1)
Hazmat loading and packing (PA)		
Packing (PA_1)	Is packing complete?	No (0), Yes (1)
Loading & unloading (PA_2)	Is loading and unloading suitable for Hazmat?	No (0), Yes (1)

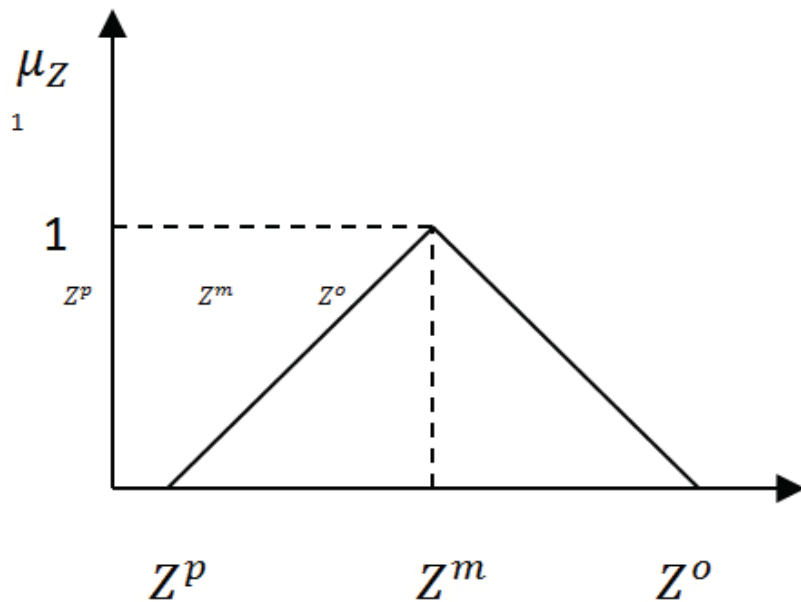


Figure 3. Triangular possibility distribution of fuzzy number (\tilde{Z})

3.3 Variables

HM^a Number of hazmat containers for inbound drayage using path a.

RM^a Number of regular containers for inbound drayage using path a.

HM^v Number of hazmat containers for rail-haul on train service of type v.

RM^v Number of regular containers for rail-haul on train service of type v.

HM^b Number of hazmat containers for outbound drayage that using path b.

RM^b Number of regular containers for outbound drayage that using path b.

N^v Number of intermodal train service of type v.

3.4. Indicator variables

$$Y^a = \begin{cases} 1, & \text{if } HM^a > 0 \text{ or } RM^a > 0 \\ 0, & \text{otherwise} \end{cases}$$

$$Y^v = \begin{cases} 1, & \text{if } HM^v > 0 \text{ or } RM^v > 0 \\ 0, & \text{otherwise} \end{cases}$$

$$Y^b = \begin{cases} 1, & \text{if } HM^b > 0 \text{ or } RM^b > 0 \\ 0, & \text{otherwise} \end{cases}$$

$$TA_g = \begin{cases} 1, & \text{Yes} \\ 0, & \text{No} \end{cases} \quad \text{See Table (1)}$$

$$PA_r = \begin{cases} 1, & \text{Yes} \\ 0, & \text{No} \end{cases} \quad \text{See Table (1)}$$

$$H_f = \begin{cases} 1, & \text{Normal} \\ 0, & \text{Abnormal} \end{cases} \quad \text{See Table (1)}$$

3.5 Parameters

$(CH)^{\tilde{a}}$ Transportation cost of one hazmat container for inbound drayage on path a.

$(CR)^{\tilde{a}}$ Transportation cost of one regular container for inbound drayage on path a.

$(CH)^{\tilde{v}}$ Transportation cost of one hazmat

container that using intermodal train service of type v.

$(CR)^v$ Transportation cost of one regular container that using intermodal train service of type v.

$(CH)^b$ Transportation cost of one hazmat container for outbound drayage on path b.

$(CR)^b$ Transportation cost of one regular container for outbound drayage on path b.

C_g Transportation cost of direct factor.

FC^v The operating fixed cost of intermodal train service of type v.

P^a Population exposures as a result of transiting one hazmat container for inbound drayage on path a.

\tilde{P}^v Population exposure as a result of transiting the number of hazmat containers on intermodal train service of type v.

\tilde{P}^b Population exposure as a result of transiting one hazmat container for out bound drayage on path b.

t^a The time of inbound drayage that using path a.

t^v The travel time of intermodal train service of type v.

t^b The time of outbound drayage that using path b.

DT Delivery time.

U^v Maximum containers that can be loaded on intermodal train service of type v.

DH Number of hazmat containers demanded.

DR Number of regular containers demanded.

NN Number of hazmat pack.

3.6 Mathematical Model

$$\text{Min } Z_1 = \sum_{a \in A_m} [\bar{C}H^a HM^a + \bar{C}R^a RM^a] + \sum_{v \in V_{mn}} [\bar{C}H^v HM^v + \bar{C}R^v RM^v] +$$

$$\sum_{b \in B_{nj}} [\bar{C}H^b HM^b + \bar{C}R^b RM^b] +$$

$$\sum_{v \in V_{mn}} FC^v N^v + \sum_{g=1}^3 C_g T A_g$$

$$\text{Min } Z_2 = \sum_{a \in A_m} \tilde{P}^a HM^a + \sum_{v \in V_{mn}} \tilde{P}^v HM^v +$$

$$\sum_{v \in V_{mn}} \tilde{P}^v HM^v + \sum_{b \in B_{nj}} \tilde{P}^b HM^b - \sum_{v \in V_{mn}} \sum_{r=1}^2 PA_r \times NN \times \tilde{P}^v -$$

$$\frac{1}{2} \left(\sum_{a \in A_m} \sum_{r=1}^3 H_r HM^a \tilde{P}^a + \sum_{b \in B_{nj}} \sum_{r=1}^3 H_r HM^b \tilde{P}^b \right)$$

$$\frac{1}{2} \left(\sum_{a \in A_m} \sum_{r=1}^2 PA_r \times NN \times \tilde{P}^a + \sum_{b \in B_{nj}} \sum_{r=1}^2 PA_r \times NN \times \tilde{P}^b \right)$$

s.t.

$$\sum_{a \in A_m} HM^a = \sum_{v \in V_{mn}} HM^v \quad \forall m \in M \quad (1a)$$

$$\sum_{a \in A_m} RM^a = \sum_{v \in V_{mn}} RM^v \quad \forall m \in M \quad (1b)$$

$$\sum_{v \in V_{mn}} HM^v = \sum_{b \in B_{nj}} HM^b \quad \forall n \in N \quad (1c)$$

$$\sum_{v \in V_{mn}} RM^v = \sum_{b \in B_{nj}} RM^b \quad \forall n \in N \quad (1d)$$

$$\sum_{b \in B_{nj}} HM^b = DH \quad (2a)$$

$$\sum_{b \in B_{nj}} RM^b = DR \quad (2b)$$

$$\left(\sum_{N^v} HM^v + RM^v \right) \leq U^v N^v \quad \forall v \in V_{mn} \quad (3)$$

$$t^a Y^a + t^v Y^v + t^b Y^b \leq DT \quad \forall a \in A_m, b \in B_{nj}, v \in V_{mn} \quad (4)$$

$$MMY^a \geq HM^a \text{ or } RM^a \quad \forall a \in A_m \quad (5a)$$

$$MMY^v \geq HM^v \text{ or } RM^v \quad \forall v \in V_{mn} \quad (5b)$$

$$MMY^b \geq HM^b \text{ or } RM^b \quad \forall b \in B_{nj} \quad (5c)$$

$$HM^a \geq 0, RM^a \geq 0 \quad \text{Integer} \quad \forall a \in A_m \quad (6a)$$

$$HM^b \geq 0, RM^b \geq 0 \quad \text{Integer} \quad \forall b \in B_{nj} \quad (6b)$$

$$HM^v \geq 0, RM^v \geq 0 \quad \text{Integer} \quad \forall v \in V_{mn} \quad (6c)$$

$$N^v \geq 0 \quad \text{Integer} \quad \forall v \in V_{mn} \quad (6d)$$

$$Y^a \in \{0,1\} \quad \forall a \in A_{im} \quad (6e)$$

$$Y^b \in \{0,1\} \quad \forall b \in B_{nj} \quad (6f)$$

$$Y^v \in \{0,1\} \quad \forall v \in V_{mn} \quad (6g)$$

$$TA_g \in \{0,1\} \quad \forall g \in G \quad (6h)$$

$$H_f \in \{0,1\} \quad \forall f \in F \quad (6i)$$

$$PA_r \in \{0,1\} \quad \forall r \in R \quad (6j)$$

$$MM \text{ is a large positive integer} \quad (6k)$$

The objective function has two sections; in fact, it is a bi-objective optimization model with the cost (Z_1) and the risk (Z_2) objectives. The first section is the cost objective that controls inbound stevedore cost, rail-haul cost, outbound stevedore cost, the operating fixed cost of different types of train services and cost of transportation factor. The second section related to risk that minimizes population exposure as a result of inbound and outbound stevedore and rail-haul in the network and it includes of human and packing factor that could decrease risks.

A set of Eq. (1) guarantee to balance in the flow of the network for accounting of hazmat and usual freight. It should be said that the hazmat and usual freight transportation is done separately so the transshipment constraints for them must be also distinguished separately. A set of Eq. (2) guarantee that the demands of each receiver for hazmat and usual freight are

fulfilled. A set of Eq. (3) show that the total number of containers to be transferred between two successive terminals determines the number of intermodal trains of a specific type. A set of Eq. (4) ensure that the total time of moving from shipper to customer location is less than delivery-times. A set of Eq. (5) assure the activation of indicator variables associated with different links. A set of Eq.(5) estimate the feasibility of including that link in forming an intermodal chain in Eq.(4). It is worthy say that MM refers to a large positive integer such that MM is greater than the sum of the demanded container's number of hazmat and usual materials. In the last, a set of Eq. (6) represent the sign constraint.

4. Solution Methodology

4.1 Results

In this section, the model is verified by solving a small-sized problem by GAMS. The result reached is the optimal result with zero gaps and minimum time by GAMS / CPLEX using computer-profile AMD A6, 2.7 GHz processor, whose results are shown in Table 2. This example includes two shippers (i) and two IMRT (m) and IMRT (n) and two receivers (j). The problem is considered and the change of the value of Bayesian network factors is analyzed (Table 2). It is worthy to say that the impact of factors is evaluated on the fuzzy model. For this purpose, the average method is used for dealing with fuzzy values.

Clearly, considering these factors increases safety and health in a small-sized problem. When there are some considered factors, the amount cost objective is more than when there are not any factors. The set of a transportation factor increases the cost, which do not affect on the amount of risk. The set of packing factors increases the cost less than transporta-

tion factors, but decreases the risk. The set of human factors increases the cost less than a transportation factor, but decreases risk more than packing factors. These results show that the human factors have most effect on risk. It means if there are the human factors, the people under risk are less. That is clear that the amount of risk dramatically decreases when there are both packing and human factors. Finally, it can be said that the best result is obtained by all factors. It should be said that two sections of objectives are assumed that have equal importance for management. In fact, a managerial problem is improved in order to minimize the transportation cost of usual and hazmat and its risk. However, we can mention that this model is suitable for helping to the decision maker in hazmat transportation. In overall, this model is proficient. Nowadays, risk is an important problem for government; actually the sustainability is also the important issue for management. It is worthy to say that the risk section does not change (26) with a double quantity of cost parameters in the instance that is mentioned; however, the cost objective is almost doubled (i.e., 41356). The decision between the importance of cost or risk and which one has more weight depends on management.

4.2 TH Method

[Torabi and Hassini, 2008] presented a mixed-integer linear programming (MILP) model for a supply chain that includes multiple suppliers, one manufacturer and multiple distribution centers. To solve their model, they proposed a novel interactive fuzzy approach and founded a preferred conciliation solution. They performed this solution method for numerical tests and observed good results. So, they mentioned that this method is very promising for any multi objective linear model, especially for a mixed-integer type. This method is based on triangular possibility distribution. In fact, this method can help the decision maker to make a final decision. The coefficient helps to the decision process that is computed according to a degree of satisfaction in this method. In summary, this method includes the following six steps:

- Step 1:** Find out an appropriate triangular possibility distributions for the inexact parameters.
- Step 2:** Convert the original fuzzy objectives into the equal crisp objectives (Z_1, Z_2).
- Step 3:** Formulate the fuzzy model to a crisp multi-objective MILP model by determining the minimum suitable possibility level for inexact parameters and converting the fuzzy

Table 2. Result of the improved model

The value of factors	Cost obj.	Risk obj. (people)	CUP time (s)
Without factor	20366	120	6485
Value of all binary factors is 1	20816	42	6952
Human factor is 1	20556	60	6528
Packing factor is 1	20560	96	6504
Transportation factor is 1	20936	120	6776
Human and packing factors is 1	20558	55	6589

constraints into the matching crisp ones.

Step 4: By solving the model of the previous steps, compute the positive ideal solution (PIS) as the best result for the objective and negative ideal solution (NIS) for each objective function.

Step 5: Determine a linear membership function for each objective function by considering of formulation in [Torabi and Hassini, 2008].

These steps are considered for the same small problem considered in the previous subsection. The results of the TH method for this example are showed in Table 3.

$\mu_i^{(v)}$, which is computed based on Step 5 of the TH method, indicates the fulfillment degree of the i-th section of the objective function for the solution. It can be said that the model and the result can satisfy both sections of the objective function by considering the TH method results. These good results show this transportation is safety with the minimum cost. This result is a consequence of considering of the Bayesian networks.

Step 6: Convert the MOMILP model into an equal single-objective MILP by using the following formulation:

$$\text{Max } \lambda(v) = 0.96\gamma + (1-\gamma)(0.99\theta_1 + 0.98\theta_2)$$

s.t.

$$\mu_h(v) \geq 0.96 \quad h=1,2$$

All constraints of the main model (1-6) and $\gamma \in [0,1]$

Controlling the minimum satisfaction section of the objective function is done by γ . In fact, the first and second sections of the above model show the feasibility and the optimality of results, respectively. γ and θ_h are determined by the decision maker. For each run of solving this model as MIP model, determine the coefficient of amendment γ and relative importance of θ . Stop, if the decision maker is satisfied with the current efficient solution; otherwise, try again.

5. Conclusion

The economic losses, casualties and environmental damage caused by hazardous materials transportation incidents cannot be ignored. Thus, safety is an important for transportation of hazardous materials. In this paper, a rail-truck hazmat transportation model is developed. In fact, a bi-objective model has been improved by considering factors of the Bayesian networks that increase safety. Actually, it could be mentioned that this model was a sustainable transportation model. In addition; the sustainability of the model, it made closer to the reality. A small numerical example is solved by the GAMS software using the CPLEX solver and then we analyze the result. The results showed that the best results would

Table 3. Results of the TH method

Results of the TH method	
$Z_1 = \text{min cost} = 20816$	$\mu_1 = \mu_1(v) = 0.99$
$Z_2 = \text{min risk} = 26$	$\mu_2 = \mu_2(v) = 0.98$

be obtained by considering all factors. However, it could be said when there was at least one factor, the results better than when all factors absent. Furthermore, the TH method was performed for helping the decision maker. In fact, it could be said that the model made closer to real life and was more fruitful by considering fuzzy model and using the TH method. Noting that the problem solved by the software was the biggest size; heuristic or meta-heuristic algorithms could be suggested for solving this model. These algorithms could reduce the solving time of large-sized problems. We can also offer usage of the model for a case study in future research.

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7. References

- Agrawal, A. W., Dill, J. and Nixon, H. (2010) "Green transportation taxes and fees: A survey of public preferences in California", *Transportation Research - Part D*, Vol. 15, pp. 189–196.
- Akgün, V., Parekh, A., Batta, R. and Rump, C.M. (2007) "Routing of a hazmat truck in the presence of weather systems", *Computers and Operations Research*, Vol. 34, pp. 1351–1373.
- Berman, O., Verter, V. Y. and Kara, B. (2007) "Designing emergency response networks for

hazardous materials transportation", *Computers and Operations Research*, Vol. 34, pp. 1374–1388.

-Bianco, L., Caramia, M. and Giordani, S. (2009) "A bilevel flow model for hazmat transportation network design", *Transportation Research - Part C*, Vol. 17, pp. 175–196.

-Bonvicini, S. and Spadoni, G. (2008) "A hazmat multi-commodity routing model satisfying risk criteria: A case study", *Journal of Loss Prevention in the Process Industries*, Vol. 21, pp. 345–358.

-Dadkar, Y., Nozick, L. and Jones, D. (2010) "Optimizing facility use restrictions for the movement of hazardous materials", *Transportation Research - Part B*, Vol. 44, pp. 267–281.

-Erkut, E. and Alp, O. (2007) "Designing a road network for dangerous goods shipments", *Computers and Operations Research*, Vol. 34, No. 5, pp. 1241–1242.

-Erkut, E. and Gzara, F. (2008) "Solving the hazmat transport network design problem", *Computers and Operations Research*, Vol. 35, pp. 2234–2247.

-Liang, T. F. (2006) "Distribution planning decisions using interactive fuzzy multi-objective linear programming", *Fuzzy Sets and Systems*, Vol. 157, pp. 1303–1316.

-Lozano, A., Muñoz, A., Macías, L., Pablo Antún, J., Granados, F. and Guarneros, L. (2010) "Analysis of hazmat transportation accidents in congested urban areas, based on actual accidents in Mexico", *Procedia Social and Behavioral Sciences*, Vol. 2, pp. 6053–6064.

- Lozano, A., Muñoz, A., Macías, L. and Pablo Antún, J. (2011) "Hazardous materials transportation in Mexico City: Chlorine and gasoline cases", *Transportation Research - Part C*, Vol. 19, pp. 779–789.
- Raemdonck, K. V., Macharis, C. and Mairesse, O. (2013) "Risk analysis system for the transport of hazardous materials", *Journal of Safety Research*, Vol. 45, pp. 55–63.
- Schweitzer, L. (2006) "Environmental justice and hazmat transport: A spatial analysis in southern California", *Transportation Research - Part D*, Vol. 11, pp. 408–421.
- Tavakkoli-Moghaddam, R., Mahmoud-Soltani, F. and Mahmoudabadi, A. (2013) "Bi-criteria hazmat routing problem under uncertainty – A case study of fuel shipment in Mazandaran province", *Journal of Transportation Research*, Vol. 4, No. 3, pp. 209–220. (in Farsi)
- Tavakkoli-Moghaddam, R., Salamatbakhsh, A., Norouzi, N. and Alinaghian, M. (2011) "Solving a new vehicle routing problem considering safety in hazardous materials transportation", *Journal of Transportation Research*, Vol. 2, No. 3, pp. 223–237. (in Farsi).
- Torabi, S. A. and Hassini, E. (2008) "An interactive possibilistic programming approach for multiple objective supply chain master planning", *Fuzzy Sets and Systems*, Vol. 159, pp. 193–214.
- Verma, M. and Verter V. (2007) "Railroad transportation of dangerous goods: Population exposure to airborne toxins", *Computers and Operations Research*, Vol. 34, pp. 1287–1303.
- Verma, M., Verter, V. and Zufferey, N. (2012) "A bi-objective model for planning and managing rail-truck intermodal transportation of hazardous materials", *Transportation Research - Part E*, Vol. 48, pp. 132–149.
- World Commission on Environment and Development (1987), Oxford.
- Zhao, L., Wang, X. and Qian Y. (2012) "Analysis of factors that influence hazardous material transportation accidents based on Bayesian networks: A case study in China", *Safety Science*, Vol. 50, pp. 1049–1055.
- Zhou, J. (2012) "Sustainable transportation in the US: A review of proposals, policies, and programs since 2000", *Frontiers of Architectural Research*, Vol. 1, pp. 150–165.