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DEVELOPING STRATEGIES TO REDUCE THE RISK OF HAZARDOUS MATERIALS TRANSPORTATION IN IRAN USING THE METHOD OF FUZZY SWOT ANALYSIS

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Abstract. An increase in hazardous materials transportation in Iran along with the industrial development and increase of resulted deadly accidents necessitate the development and implementation of some strategies to reduce these incidents. SWOT analysis is an efficient method for developing strategies, however, its structural problems, including a lack of prioritizing internal and external factors and inability to consider two sided factors reducing its performance in the situations where the number of internal and external factors affecting the risk of hazardous materials is relatively high and some factors are two sided in nature are presented in the article. Fuzzy SWOT analysis is a method the use of which helps with solving these problems and is the issue of employing an effective methodology. Also, the article compares the resulted strategies of the fuzzy method with the strategies developed following SWOT in order to show the relative supremacy of the new method.

Keywords: hazardous materials, transportation, strategy development, SWOT, fuzzy.

1. Introduction

'Hazardous materials' refer to substances that seriously endanger human lives and/or the environment (Jovanović *et al*. 2009; Ghazinoory and Kheirkhah 2008; Batarlienė 2007 and 2008; Briedytė 2000; Leonelli *et al*. 2000). These materials are usually grouped into 9 categories including gases, flammable liquids, flammable no liquids, oxidants, explosives, acidic materials, poisonous and contaminated materials, radioactive substances and other hazardous materials.

Iran's social environment is becoming increasingly exposed to these materials and their transportation: on the one hand, the growth rate of industry is higher than that of the other sectors, whereas on the other hand, Iran is oil producing country the oil and gas resources of which must be transported for domestic consumption and export purposes. Meanwhile, Iran is situated on the transit route of several Central Asian states, most of which produce oil. An increase in the number of automobiles and the chronic shortage of adequate roads and railroads has intensified this problem. In addition, the process of de-industrialization in the industrial countries leads to the transfer of hazardous industries to such countries as Iran.

Under circumstances of the above described situation, the necessity of paying more attention to the root causes of the problem, developing strategies and planning preventive actions or shortly developing a national strategic plan is felt. One of the most important methods of strategic planning is the SWOT analysis method (Learned *et al*. 1965). In our previous paper (Ghazinoory and Kheirkhah 2008), we applied the SWOT method for developing risk reduction strategies for hazardous material transportation in Iran. These strategies were laid out based on the non quantitative analysis of effective factors and by taking the advantage of the experiences and intuitive judgments of managers and decision makers.

Despite its wide applications, the SWOT method has also a number of problems 7 of which are mentioned by Hill and Westbrook (1997), but the most important ones are as follows:

1. usually only a qualitative examination of environmental factors is considered;
2. it considers no priority for various factors and strategies;
3. if the number of factors is higher, the number of the adopted strategies will be exponentially increased (for example, if the number of each set of the factors of S, W, O, T is equal to 5, the

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resulting number of the combined strategies will be around 100 which would make the selection of the appropriate strategy very difficult);

4. it does not consider the vagueness of the factors.

In the evaluation of the major factors affecting the risk of hazardous materials transportation in Iran (Ghazinoory and Kheirkhah 2008), we can see that it is not possible to clearly differentiate the factors either they are strengths or weaknesses and/or opportunities or threats. For example, devising new regulations and the increased government's focus on the transportation of HM over recent years (for the first time) is strength, however, to some degree it could be considered as weakness (as first time regulations have unforeseen consequences). Another example illustrates that the increased level of technology and standards adopted by auto manufacturers in Iran may be both an opportunity and a threat (it has a direct positive effect on the rate of road accidents and a direct effect on liar confidence in the safety of vehicles and thus an indirect negative effect on the accident rate).

Therefore, in such ambiguous cases, the use of fuzzy sets is justified to be applied. In fact, a factor with a certain membership value belongs to one of the S, W, O, T categories. The purpose of this article is to use this concept to combine internal and external factors so that SWOT analysis could consider the uncertainty of factors and determine the priority of strategies. In this way, the effectiveness of SWOT methodology is increased and more effective strategies are developed.

2. Research Methodology

Fuzzy set (Zadeh 1965; Peldschus and Zavadskas 2005; Hui *et al.* 2009; Krylovas and Kosareva 2008) is a core concept in this article. A fuzzy set is a generalized version of a classical set (or a crisp set). A crisp set A can be defined by a 'membership function' μ_A that can assume the only values 0 and 1: for each $x \in U$, when $\mu_A = 1$, x is declared to be a member of A, and when $\mu_A = 0$, x is declared as a non member of A. A fuzzy set does not divide elements between two groups, members and non members; in contrast, it allows the membership function to assume all values between 0 and 1 thus expressing different grades of the membership of each element $x \in$ U in A.

A fuzzy set can be fully and uniquely represented by its α-cuts. Given a fuzzy set defined on U, an α-cut is the crisp set that contains all the elements of U the membership grades of which in A are greater than or equal to the specified value of α.

If a fuzzy set A defined on the set of all real numbers, R has the following three properties:

- A is a fuzzy set the largest membership grade of which is 1;
- the α-cuts of A, for every $\alpha \in (0,1]$, are closed single intervals;
- the strong α-cut for $\alpha = 0$ is bounded and called a 'fuzzy number'.

Based on the above concepts, many methodologies have been developed for planning under uncertainty (Lee and Lin 2008; Lin and Hsieh 2004; Pap *et al.* 2000; Bonvicini *et al.* 1998). Fuzzy SWOT analysis (Ghazinoory *et al.* 2007) is applied in this article with minor changes and includes the following steps that can be described as:

- scaling factors,
- aggregating membership functions,
- evaluation, prioritization and extracting strategies.

2.1. Scaling Factors

To evaluate the intensity of the weakness or strength of a factor, a range of real numbers between –10 to 10 is considered. A negative number shows the weakness and a positive number signifies the strength of a factor. As each factor may exhibit two sided meaning, instead of a real number, a fuzzy number is used for evaluation. Fig. 1 for instance, illustrates such scaling. The same statement is also true for the external factors.

Fig. 1 illustrates how the two sided nature of a factor is described by a fuzzy number demonstrating the value of approximately 5 and shows that the membership function value for strength +5 is 1 and for weakness –1 is 0.1. ($\mu(x)$ stands for the membership function value for numbers between –10 to +10).

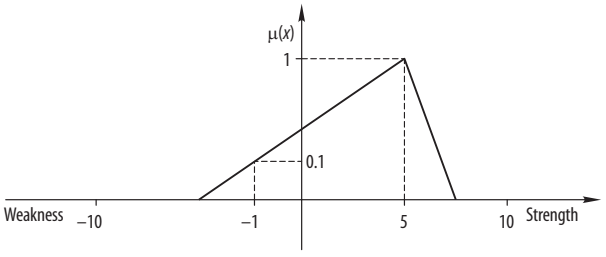

Fig. 1. A fuzzy number representing a fuzzy value of an internal factor

A tri angle fuzzy number can be described by 3 parameters presented below:

$$y = \text{triangler}\left(x; x^p, x^m, x^o\right) = \begin{cases} 0, & x \le x^p \\ \left(x - x^p\right)/\left(x^m - x^p\right), & x^p \le x \le x^m \\ \left(x^o - x\right)/\left(x^o - x^m\right), & x^m \le x \le x^o \\ 0, & x^o \le x \end{cases}$$

In this article, x^p, x^m and x^o stand for the pessimistic, probable and optimistic aspects of an internal/external factor respectively.

Strengths, weaknesses, opportunities and threats can be listed. The distinction between this method and normal SWOT analysis is that applying a new method, 3 questions should be asked from decision makers:

What value to be allocated in the range from –10 to +10 for pessimistic (*xp*), *probable* (*xm*) *and optimistic* (*xo*) *situations for an internal factor* (*–10 to 0 for the intensity of weakness and 0 to +10 for the intensity of strength*)*?*

Therefore, each decision maker would allocate a fuzzy number to each internal/external factor. Eventu-

ally, the final value of a factor can be identified by calculating the average of all numbers from all decision makers based on the below formula:

$$\overline{y} = \left(\frac{\sum_{j=1}^{n} x_j^p}{n}, \frac{\sum_{j=1}^{n} x_j^m}{n}, \frac{\sum_{j=1}^{n} x_j^o}{n} \right).$$

In the above formula, n stands for the number of decision makers and j for each decision maker.

The same spread of –10 to 10 is also assumed for the external factors by the same way of questions and a triangular membership function would be obtained for each factor.

2.2. Aggregating Membership Functions

To extract strategies, each pair of the internal and external factors should be compared one by one. Each pair of the internal and external factors (after aggregation) is located in the 3D fuzzy SWOT matrix. The Aggregated Membership function can be extracted from merging the membership function of the internal and external factors using the below formula:

$$\mu_s(x,y) = \min\left\{\mu_I(x), \mu_E(y)\right\},$$

where: $\mu_S(x, y)$ is the membership function of the fuzzy SWOT matrix and $\mu_I(x)$ and $\mu_E(y)$ are the membership functions of the internal and external factors respectively.

A sample of the 3D fuzzy SWOT matrix is presented in Fig. 2.

2.3. Evaluation, Prioritization and Extracting Strategies

To evaluate the importance of a pair of the internal/external factors for strategy extraction, we need to know where the location of the point which is the result of aggregation is. The closer the points are to the corners, the more important they are. As it was mentioned before, in the fuzzy approach, the result of merging factors is a fuzzy set of points (a fuzzy area) not a point. By using an appropriate α-cut, we can have a smaller area and ease the conducted evaluation (Fig. 3). The more is α,

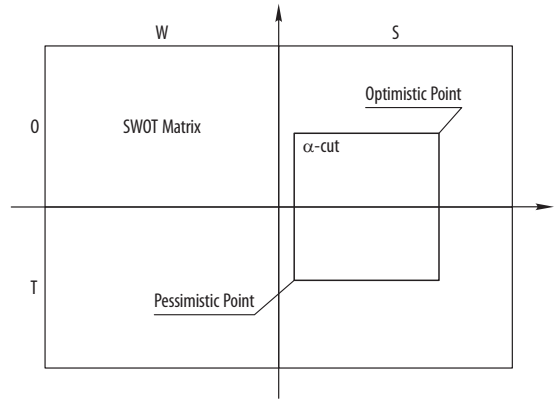

Fig. 3. Quantified SWOT matrix

the more we ignore information on the case. Therefore, the determination of α should be done by the final decision maker.

Each value of α can create an area in the SWOT matrix and the question is which point of this area should be taken into account to determine importance. This determination depends on the pessimism and optimism of a decision maker. For instance, if a decision maker is pessimistic, s/he would choose the minimum value for the internal and external factor, so the chosen point would be closer to the left down corner of the matrix (–10, –10) and in case of an optimistic decision maker, it would be in the opposite side. In this article, both the optimism and pessimism approach would be evaluated and prioritized and eventually, strategies would be extracted based on both approaches.

3. Extracting Risk Reduction Strategies

3.1. Identification of Factors and Fuzzy Values

The internal and external factors regarding hazardous materials transportation have been identified in (Ghazinoory and Kheirkhah 2008). In this article, a fuzzy value related to each factor by interviewing and calculating average has been specified and illustrated in the below Table 1.

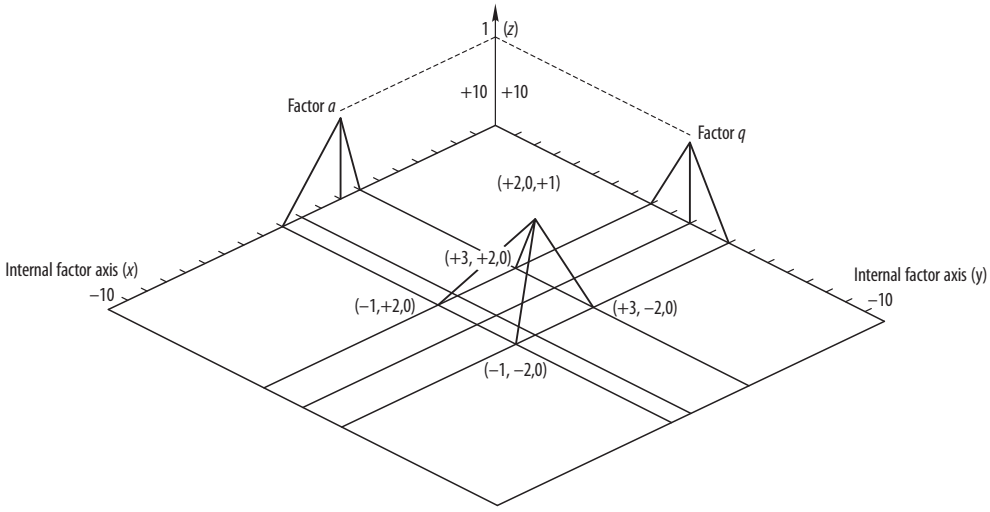

Fig. 2. The aggregation of the membership functions of factors *a* and *q*

Table 1. Internal and external factors and fuzzy values

	Internal factors	Values
i1	Devising new regulations and the increased government's focus on the transportation of HM over recent years;	(–1,6,8)
i2	The separation of the government (monitoring role) and private sector (contractor) in the transportation field as opposed to other governmental economic sectors in Iran (Ghazinoory and Huisingh 2006; Ghazinoory 2005);	(–2,7,9)
i3	The implementation of a number of training programs for road transportation companies over the past few years	(0,3,5)
i4	Numerous deadly accidents over past years	(–3,0,3)
i5	The obsolescence of the transportation fleet	(–4,–2,0)
i6	The absence of or weak safety management systems in companies transporting dangerous materials	(–8,–5,–3)
i7	The weakness of the detailed operational plans (methods of danger measurement and a definition of criteria for danger level)	(–7,–6,–2)
i8	Weak research organization and information gathering on the transportation of hazardous materials	(–5,–3,0)
	External factors	Values
e1	The introduction of new technologies (GIS, ITS, …)	(3,5,6)
e2	Greater public opinion sensitivity towards environmental issues	(–1,2,3)
e3	An increased level of technology and standards adopted by auto manufacturers in Iran;	(–1,1,3)
e4	Vast plans of railway development throughout Iran;	(–0.5,4,7)
e5	A duty on resolving the accident-prone areas of the transportation network established by the government.	(0,2,3)
e6	Very poor road safety in Iran.	(–4,-3,1)
e7	A sharp increase in the number of automobiles;	(–1,0,1)
e8	Increased transit of goods, especially petrochemical and chemical materials to the neighbouring countries	(–7,–5,–2)
e9	The sharp development of the industrial sector, especially petrochemical and chemical industries	(–6,–4,1)
e10	Private ownerships of trucks dimming a chance of legal follow-up further to accidents (involving the death of the driver/owner).	(–2,–1,0)

3.2. Evaluation and Prioritization

As described in Chapter 2.2, the value of each pair of the internal and external factors has been aggregated and then compared, evaluated and prioritized using the pessimism and optimism approach. The results are reported in Table 2.

3.3. Extracting Strategies

After merging the internal and external factors, the first 20% of the most important merged factors are considered to define the strategies the relative factors of which are reported in Table 3.

Eventually, by merging pessimistic and optimistic strategies, the following 7 ones can be proposed:

1. to establish training and legislation on the private companies transporting hazard material by railway;
2. to promote new technologies in private companies transporting hazard material;
3. to oblige companies transporting hazard material to achieve management safety standard;
4. environment and safety evaluation of private companies and a public declaration;
5. research and operational planning on creating and establishing chemical industries (hazard industries) and a method of transporting their material;
6. to research whether transportation to the foreign countries is economically efficient and operational planning;
7. to use railway and pipe rather than roadway.

4. Discussion

4.1. Analysis of the Extracted Strategies

In this section, the details and implications of the above mentioned strategies are described:

1. One of the best ways to reduce the risk of hazmat transfer is using railway. Nevertheless, as the railway system in Iran is state and governmental, the use and application of railway is low and also the cost of transfer by railway is much higher than by road. As a result, the formation, training and standardization of private companies to transfer hazmat using the railway system can reduce costs.
2. Although the use of modern and new technology reduces the risk of hazmat, yet the private sector tends more to use cheap labour. Furthermore, the transfer and diffusion steps of technologies usually need investment and governmental support. There are strategies that can be efficient and helpful in achieving this goal.

Table 2. The priority of the internal-external pair of factors

Minimum distance of area corner (Optimistic approach)					
Priority	Factors	Distance	Priority	Factors	Distance
1	(i2,e4)	3.862642	41	(i8,e1)	10.29563
2	(i1,e4)	4.326662	42	(i7,e8)	10.32473
3	(i2,e1)	4.427189	43	(i7,e3)	10.32473
4	(i1,e1)	4.837355	44	(i4,e2)	10.469
5	(i3,e4)	6.489992	45	(i4,e5)	10.469
6	(i3,e1)	6.841053	46	(i5,e1)	10.47855
7	(i2,e2)	7.334848	47	(i4,e8)	10.60754
8	(i2,e5)	7.334848	48	(i4,e3)	10.60754
9	(i6,e4)	7.517978	49	(i3,e7)	10.66771
10	(i2,e8)	7.531268	50	(i3,e6)	11.18928
11	(i2,e3)	7.531268	51	(i3,e10)	11.18928
12	(i1,e2)	7.589466	52	(i6,e7)	11.32254
13	(i1,e5)	7.589466	53	(i3,e9)	11.36486
14	(i1,e8)	7.77946	54	(i7,e7)	11.68247
15	(i1,e3)	7.77946	55	(i6,e6)	11.81524
16	(i6,e1)	7.823043	56	(i6,e10)	11.81524
17	(i7,e4)	8.049845	57	(i8,e2)	11.84061
18	(i7,e1)	8.335466	58	(i8,e5)	11.84061
19	(i4,e4)	8.409518	59	(i4,e7)	11.93315
20	(i4,e1)	8.683317	60	(i8,e8)	11.96328
21	(i3,e2)	9	61	(i8,e3)	11.96328
22	(i3,e5)	9	62	(i6,e9)	11.98165
23	(i3,e8)	9.160786	63	(i5,e2)	12
24	(i3,e3)	9.160786	64	(i5,e5)	12
25	(i2,e7)	9.305912	65	(i5,e8)	12.12106
26	(i1,e7)	9.507891	66	(i5,e3)	12.12106
27	(i6,e2)	9.767292	67	(i7,e6)	12.16059
28	(i6,e5)	9.767292	68	(i7,e10)	12.16059
29	(i2,e6)	9.899495	69	(i7,e9)	12.32234
30	(i2,e10)	9.899495	70	(i4,e6)	12.40161
31	(i6,e8)	9.915644	71	(i4,e10)	12.40161
32	(i6,e3)	9.915644	72	(i4,e9)	12.56025
33	(i8,e4)	10.06578	73	(i8,e7)	13.15295
34	(i1,e6)	10.0896	74	(i5,e7)	13.29662
35	(i1,e10)	10.0896	75	(i8,e6)	13.5794
36	(i2,e9)	10.09752	76	(i8,e10)	13.5794
37	(i7,e2)	10.18234	77	(i5,e6)	13.7186
38	(i7,e5)	10.18234	78	(i5,e10)	13.7186
39	(i5,e4)	10.2528	79	(i8,e9)	13.72443
40	(i1,e9)	10.28397	80	(i5,e9)	13.86218

End of Table 2

Minimum distance of area corner (Pessimistic approach)					
Priority	Factors	Distance	Priority	Factors	Distance
1	(i6,e8)	4.280187	41	(i2,e9)	10.74244
2	(i7,e8)	4.669047	42	(i8,e3)	10.84066
3	(i6,e9)	5.110773	43	(i8,e4)	11.01454
4	(i7,e9)	5.440588	44	(i8,e2)	11.01454
5	(i8,e8)	6.381222	45	(i8,e5)	11.01454
6	(i6,e6)	6.723095	46	(i4,e10)	11.18034
7	(i8,e9)	6.96563	47	(i5,e7)	11.20714
8	(i7,e6)	6.977105	48	(i3,e6)	11.26055
9	(i6,e1)	7.093659	49	(i5,e3)	11.3719
10	(i5,e8)	7.247068	50	(i1,e6)	11.42804
11	(i7,e1)	7.334848	51	(i3,e1)	11.48564
12	(i5,e9)	7.766595	52	(i5,e4)	11.53776
13	(i8,e6)	8.221922	53	(i5,e2)	11.53776
14	(i4,e8)	8.325863	54	(i5,e5)	11.53776
15	(i8,e1)	8.527602	55	(i2,e6)	11.59655
16	(i6,e10)	8.602325	56	(i1,e1)	11.64989
17	(i4,e9)	8.781799	57	(i2,e1)	11.81524
18	(i7,e10)	8.802272	58	(i4,e7)	11.93315
19	(i5,e6)	8.910668	59	(i4,e3)	12.08801
20	(i5,e1)	9.193476	60	(i4,e4)	12.24418
21	(i6,e7)	9.560335	61	(i4,e2)	12.24418
22	(i7,e7)	9.740637	62	(i4,e5)	12.24418
23	(i6,e3)	9.752948	63	(i3,e10)	12.47397
24	(i4,e6)	9.80816	64	(i1,e10)	12.62537
25	(i8,e10)	9.81835	65	(i2,e10)	12.77811
26	(i7,e3)	9.929753	66	(i3,e7)	13.15295
27	(i6,e4)	9.945853	67	(i3,e3)	13.29361
28	(i6,e2)	9.945853	68	(i1,e7)	13.29662
29	(i6,e5)	9.945853	69	(i3,e4)	13.43577
30	(i3,e8)	9.995999	70	(i1,e3)	13.43577
31	(i4,e1)	10.06578	71	(i3,e2)	13.43577
32	(i7,e4)	10.11929	72	(i3,e5)	13.43577
33	(i7,e2)	10.11929	73	(i2,e7)	13.44173
34	(i7,e5)	10.11929	74	(i1,e4)	13.57645
35	(i1,e8)	10.1843	75	(i1,e2)	13.57645
36	(i2,e8)	10.37304	76	(i1,e5)	13.57645
37	(i3,e9)	10.37882	77	(i2,e3)	13.5794
38	(i5,e10)	10.40192	78	(i2,e4)	13.7186
39	(i1,e9)	10.5603	79	(i2,e2)	13.7186
40	(i8,e7)	10.66771	80	(i2,e5)	13.7186

Table 3. Merged factors and considered strategies

Optimistic strategy	Internal factor	External factor
To form private companies transporting hazard material by train (railway transportation) under state supervision	e4	i2
Legislation on hazard material transportation by railway	e4	i1
To promote the use of new technologies (GIS, GPS, …) in private companies	e1	i2
To develop new laws relating to the use of new technologies	e1	i1
To train private companies how to exploit railway system	e4	i3
To train private companies how to use new technologies	e1	i3
To inform public community about the environmental performance of private companies.	e2	i2
Pessimistic strategies	**Internal factor**	**External factor**
To oblige companies transporting to/from the neighbourhood countries to comply compulsory standards	i6	e8
Operational planning for chemical transportation companies	i7	e8
To oblige chemical transportation companies to comply quality management standard	i6	e9
Operational planning for creating and establishing chemical industries and their product transportation	i7	e9
Precise scientific investigation on determining whether transport is economically efficient considering risk	i8	e8
To maximize the use of other transportation methods apart from road transport (e.g. railway, pipe, …)	i6	e6
Research on creating and establishing chemical industries and their product transportation	i8	e9

3. Although the industrial sector in Iran has progressed considerably well, new and modern security management and environment (like ISO 1400, ISO 18000) have remained less prevalent. Using these kinds of management systems in transportation companies can lead to reducing hazmat risk.
4. As long as the state sector is responsible for controlling and managing affairs, competition would be meaningless. As a result, the costumers have to transfer their hazmat loads (consignment) by paying too much and accepting high risks. By developing the private sector in this field, these companies have to be constantly assessed, and results must be publicly announced so that the susceptibility of the society will arise and the companies will be obliged to deliver high standardized work.
5. An interesting point is that the price factor and hazmat transfer risk have been ignored in feasibility studies done to fund industries which is due to the law amounts of transfer costs and also not taking a serious assessment of the possible consequences for transfer.

   As the present government has decided to reduce energy subsides and society is more cautious toward the events and consequences, we can consider hazmat transfer risk in making industry plans, material transfer and their products as a result of the new plans that can be made.
6. As Middle East countries and Afghanistan do not have any access to open seas, a great part of their business is transferred through Iran. Although receiving oil from these countries is done by a swap or exchange, yet heavy traffic can be usually noticed on the roads in Iran.

   It seems that adjusting the tariff of goods transit and conducting transit trucks to move in less crowded roads can be a good and useful solution.
7. Although using railway and pipes needs more investment than transferring by truck, yet if we consider the cost necessary to make new roads, this additional investment will be satisfied.

As indicated above, seven points of the strategies driven from the phase SWOT are based on evidence and implications, and therefore their validity will be confirmed.

4.2. Comparison of the Strategies Resulting from two Approaches

If we compare the strategies resulting from fuzzy SWOT presented in this article with the normal SWOT in the previous article, we will find out difference in 50%. This can have a good result because it was not predicted that the phase approach was able to make such difference in the results on SWOT analysis.

The most important and newest points that one may observe in phase strategies is paying attention to the private sector and developing the railway system. Both areas have been recently regarded and considered by policy makers in Iran and privatization has remained the key point of the economical policy of the government.

In 2006, the Supreme Leader, Ayatollah Ali Khamenei decreed a renewed effort to privatize economy. He

issued policies on the implementation (and in fact revision) of Article 44 of the Constitution according to which the government shall not be permitted to engage in economic activities outside those envisaged in Article 44. Moreover, it is obliged to relinquish any activity, including continuation and operation of the previous activities covered by Article 44 and cede them at a minimum rate of 20% annually to private and cooperative sectors.

5. Conclusions

The fuzzy SWOT approach was developed and applied in this article in order to make strategies to reduce the dangers of transporting hazardous material in Iran. In fuzzy SWOT, the internal and external factors are fuzzy valued, so there is a possibility of the priority of each internal or external pair to extract and make strategies. This approach also makes possible the interference of the factors having two sided nature. These two characteristics are especially important in planning the transportation strategy of harmful material.

Regarding the deployment and expansion of this subject (variation in harmful material, packaging and loading methods, transportation styles and transportation environment, the variety of companies, organizations and decision making institutions etc.), a lot of internal and external factors must be considered in analyzing the problem and as a result, strategies must be made according to the limited amount of the most important internal and external pair factors. Due to the dangerous nature of transferring dangerous materials, each factor can act in both positive and negative directions.

Therefore, the factors extracted in the previous article are revalued in fuzzy terms in this article and using the above discussed approaches, new strategies are made. The obtained results confirmed the importance of using the fuzzy SWOT approach. The new strategies differed in 50% in comparison to the previous ones. In fact, simplifying a complicated problem using fuzzy logic will help us to find more real solutions.

The main contribution of this article is to improve approaches to the analysis of developing strategies to reduce the consequences of hazardous material transportation. Besides, the process of analyzing factors, the ways of extracting factors and the ways of interacting with experts and decision makers in the transportation area are of high importance in designing and executing useful strategies. Therefore, when applying the suggested approach, future researches can be focused on developing comprehensive assessments, analyzing factors and extracting strategies for the transportation systems of hazardous materials.

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