Analysis of Hazardous-Chemicals-Transportation Based on Interpretative Structural Modeling

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ABSTRACT: 235 transportation accidents occurred in the year of 2015 involving dangerous chemicals were analyzed from the time of the accident cause, occurrence, location of accident. Identify risk factors in the transportation process. It is classified for risk factors, attributed to seven major categories. To tease out the relationship of the risk factors in transport, and Interpretative Structural Modeling (ISM) for risk factors is built. Based on mutual relationships of these factors and different levels, analyze the existing main problems are analyzed in transportation of dangerous goods.
KEYWORD: Hghway Transportation; Risk factors; ISM; Hazardous materials; Accident

1 INTRODUCTION

The definition of dangerous chemicals in ”Catalog of Hazardous chemicals ” is that toxic chemicals or other chemicals that are toxic, corrosive, explosive, flammable and etc. The transportation of chemicals is not only increasing the number of it, but also the risk of it is more complex than before. According to relevant statistics, China's transport of dangerous chemicals involved in more than 95% of the total number of accounts for a large off-site transport. The number of dangerous chemicals transportation by road is about 200 million tons each year. As most of the dangerous goods have a strong explosive nature, safe operation of the storage and transportation work is very important. The threat of dangerous goods in transit can’t be ignored. For example, March 1, 2014, two tankers carrying methanol in Jinji highway rear-end caused blasting accident. This accident caused 40 people were killed and 12 people were injured (Carlos S, 2007).

2 RISK FACTORS ANALYSIS

This paper statistics 235 transportation accidents occurred in the year of 2015 involving dangerous chemicals. In this section, the main reason for the accident is divided into seven categories (Figure 1): The driver factors, vehicle or equipment factors, the collision by others, weather conditions, road conditions, management factors and the state of the goods. On the basis, we put the specific reasons for each category in the statistical classification, forming the cause of the accident statistics (Table 1).

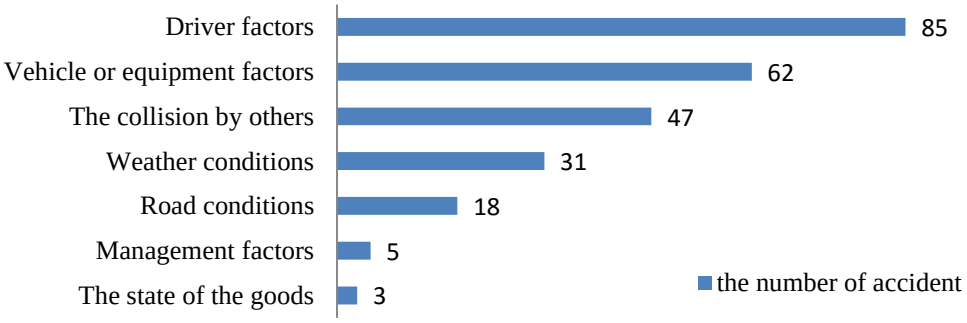

Figure1. Main factors in the dangerous chemical transportation

Note: Total number of the factors is greater than the total number of accidents, because one accident may be caused by one or more reasons.

From figure1, we can see that the reason in process of transportation caused by driver’s misconduct which accounts for 33.9% of the total is the first critical factor. What’s more, it is often associated with more casualties and property losses. Especially when driving in traffic better roads (highways, national highways, etc.), the vehicle speed is relatively fast and the larger volume of the

vehicle, the driver's misconduct may have their own and other vehicles greater impact. Therefore, standardizing driver's safe driving behavior is very important. The proportion of accidents caused by vehicle or equipment failure is 24.7%. Usually this type of accident will appear varying degrees of chemical spills, which is vital that can't be ignored in the transport process. The weather, road, cargo status and other factors belong to objective factors. When companies accept the transport task, we should take full account of these uncontrollable factors to choose the line to avoid bad weather and the complex terrain.

Table 1 Main factor in the dangerous chemical transportation

Accident type	Frequency	Rate	Specific reason	Frequency	Rate
The driver factors	85	33.9%	Improper avoid	35	41.2%
			Improper operation	26	30.5%
			Overspeed	14	16.5%
			Bad condition of driving	10	11.8%
vehicle or equipment factors	62	24.7%	Tire fault	19	30.6%
			Brake fault	12	19.3%
			Tank body breakage	10	16.2%
			fire	7	11.3%
			Valve fault	6	9.7%
			other*	8	12.9%
weather conditions	31	12.4%	Rain	14	45.2%
			Fog	10	32.2%
			Snow	7	22.6%
road conditions	18	7.1%	Sharp turn	8	44.4%
			Skidded	7	38.9%
			Bump	1	5.6%
			Long downhill	1	5.6%
			Narrow road	1	5.6%
the collision by other cars**	47	18.7%	/	/	/
management factors	5	2.0%	/	/	/
the state of the goods	3	1.2%	/	/	/

Note: *include worn circuit, loss of control, super high and so on.
**refer to the accident which cause by other cars.

3 RISK FACTORS ANALYSIS

Interpretative Structural Modeling is a structured model which is the most commonly used method. The system is a method for the analysis of complex social and economic issues developed by Professor J ▪ Warfield American in 1973.

In this section, we use ISM to build a multi-step structure to card the relationship of risk factors during transport of hazardous chemicals. We focus on the need for transportation companies. Help policy makers who should focus on the key point to find out direct and indirect risk factors. Then it will improve the decision-making efficiency (WU Zong-zhi et al, 2011) (YANG Jun-min et al, 2011) and reduce the number of accident.

3.1 *Analysis the relationship of the risk factors*

In this section, we select major risk factors during transportation of hazardous chemicals, using of the preliminary findings of the accident statistical analysis. Through discussing by expert consultation, questionnaire method and literature reference, relying on the "road safety risk prevention and control of key technology of high-risk passenger transportation" project, we analyze the relationship between these factors in depth. Finally, we confirm the key issues: the accident of hazardous chemicals during transport (D_1) and the interrelationship between 14 existing risk factors (D_i, i = 2,3, ..., 15). Specific risk factors are described in Table 2.

Table 2 The risk factors of hazardous chemicals during transportation

Key issues: the accident of hazardous chemicals during transport (D_1)		
Risk factors		
Risk factor	Specific describe	Type
D_2	Improper avoid	driver
D_3	Improper operation	
D_4	Over speed	
D_5	Bad condition of driving	
D_6	Tank body breakage	Vehicle or equipment
D_7	Tire fault	
D_8	Brake fault	
D_9	Fire	
D_{10}	Collide by other cars	Collide by other cars
D_{11}	Rain	Weather
D_{12}	Snow	
D_{13}	Fog	
D_{14}	Road-quality problems	Road
D_{15}	management failure	Management

3.2 *Establish adjacency matrix and reachability*

matrix

Adjacency matrix A is used to indicate whether there are problems in a direct relationship between the various elements of the system. Element aij in A can be defined as:

$$a_{ij}=\begin{cases} 1 & D_i \text{ can directly reach } D_j \\ 0 & D_i \text{ can't directly reach } D_j \end{cases} \quad (1)$$

The adjacency matrix A represented the relationship between the various risk factors for the transport of dangerous goods is as follow:

	D_1	D_2	D_3	D_4	D_5	D_6	D_7	D_8	D_9	D_{10}	D_{11}	D_{12}	D_{13}	D_{14}	D_{15}
D_1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
D_2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
D_3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
D_4	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
D_5	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
D_6	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
D_7	1	1	0	0	0	0	0	0	1	0	0	0	0	0	0
D_8	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
D_9	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
D_{10}	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0
D_{11}	0	1	1	0	0	0	0	0	0	0	0	0	0	1	0
D_{12}	0	1	1	0	0	0	0	0	0	0	0	0	0	1	0
D_{13}	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0
D_{14}	0	1	1	0	0	0	0	0	0	0	0	1	0	0	0
D_{15}	0	1	0	0	1	1	1	1	0	0	0	0	0	0	0

Reachability matrix R represents a direct or indirect relationship existing between any two different elements in the structure. It refers to the form of a matrix to describe the degree of each node in connection diagram can be reached. Reachability matrix has the most significant feature: the elapse. According to the following equation using the properties can be calculated reachability matrix R. Order Ai = (A +I)i, $1 \le i \le n-1$, Using Boolean arithmetic rule (0 + 0 = 0, 0 + 1 = 1, 1 + 0 = 1, 1 + 1 = 1, 0 × 0 =0, 0 × 1 = 0, 1 × 0 = 0, 1 × 1 = 1)

$A_1 \neq A_2 \neq \ldots \neq A_{r-1}=A_r$, $r \le n - 1$

In the formula: n is the matrix order,

$$A_{r-1}= (A + I)_{r-1} = R \quad (2)$$

By using MATLAB calculation, outputs to R:

	D_1	D_2	D_3	D_4	D_5	D_6	D_7	D_8	D_9	D_{10}	D_{11}	D_{12}	D_{13}	D_{14}	D_{15}
D_1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
D_2	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
D_3	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0
D_4	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0
D_5	1	1	1	0	1	0	0	0	0	0	0	0	0	0	0
D_6	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0
D_7	1	1	0	0	0	0	1	0	0	0	0	0	0	0	0
D_8	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0
D_9	1	0	0	0	0	0	1	0	1	0	0	0	0	0	0
D_{10}	1	0	0	0	0	1	0	0	0	1	0	0	0	0	0
D_{11}	1	1	1	0	0	0	0	0	0	0	1	0	0	1	0
D_{12}	1	1	1	0	0	0	0	0	0	0	0	1	0	1	0
D_{13}	1	1	1	0	0	0	0	0	0	0	0	0	1	1	0
D_{14}	1	1	1	0	0	0	0	0	0	0	0	0	0	1	0
D_{15}	1	1	1	0	1	1	1	1	1	0	0	0	0	0	1

3.3 *Reachability matrix decomposition*

Decompose the reachability matrix which calculated by MATLAB. The basic hierarchy was alternated by using decomposition matrix. According to the definition of the antecedence set Q (D_i) and reachability set R (D_i) of risk factor, R (D_i) in a multi-level structure of the first stage element Di must consist of itself and the strong connection element. The most advanced elements Q(Di)just consist by Di, reachability and strong connection elements in next level of D_i. It can be drawn the intersection table (Table 3). Top level unit Di must satisfy R (D_i) = R (D_i) ∩Q (D_i), then look for new top-level elements from the remaining reachability matrix. The basic hierarchical structure (Table 4) of risk factors obtained through continuous iterative.

Table 3 antecedence set Q (Di), reachability set R (Di) and their intersection set

i	$R(D_i)$	$Q(D_i)$	$R(D_i)\cap Q(D_i)$
1	1	1-15	1
2	1, 2	2, 7, 11, 12, 13, 14, 15	2
3	1, 3	3, 5, 11, 12, 13, 14, 15	3
4	1, 4	4	4
5	1, 2, 3, 5	5, 15	5
6	1, 6	6, 15	6
7	1, 2, 7	7, 15	7
8	1, 8	8, 15	8
9	1, 9	9, 15	9
10	1, 6, 10	10	10
11	1, 2, 3, 11, 14	11	11
12	1, 2, 3, 12, 14	12	12
13	1, 2, 3, 13, 14	13	13
14	1, 2, 3, 14	14	14
15	1, 2, 3, 5, 6, 7, 8, 9, 15	15	15

Table 4 Basic hierarchy of risk factors

Hierarchy	Risk factor
1	1
2	2, 3, 4, 6, 8, 9
3	5, 7, 10, 14
4	11, 12, 13, 15

3.4 *Construction of ISM*

According to the basic hierarchy which alternated by using decomposition matrix, we construct the structural model (Fig. 4). From the figure we can see that it divided into four levels: The first level is the key issue to be solved - accidents during transport of dangerous chemicals; Second level is direct factor causing traffic accidents which includes driver's driving behavior and vehicle equipment status. Meanwhile internal factors also influence each other, such as vehicle tires problem is always due to overheating of brake; The third and fourth level are indirect factors in transportation accidents, which includes road conditions, weather conditions,

crashed by other cars, management and other objective factors. These factors cause the accident through affecting the operation of the driver and vehicle equipment.

Although environmental factors are not the direct factor leading to the accident, it can't be ignored. For example, raining can cause road becoming slippery and muddy, resulting in the driver's view is not clear. It may lead to vehicle accidents. Mismanagement of people or vehicle will increase the probability of occurring fault and accident, such as not comprehensive training of driver and incomplete examination. Enterprise should be prepared to line-selection work to understand the information of destination along the road, weather conditions, terrain features and other information before performing transport tasks, thereby enhancing the safety factor during transport.

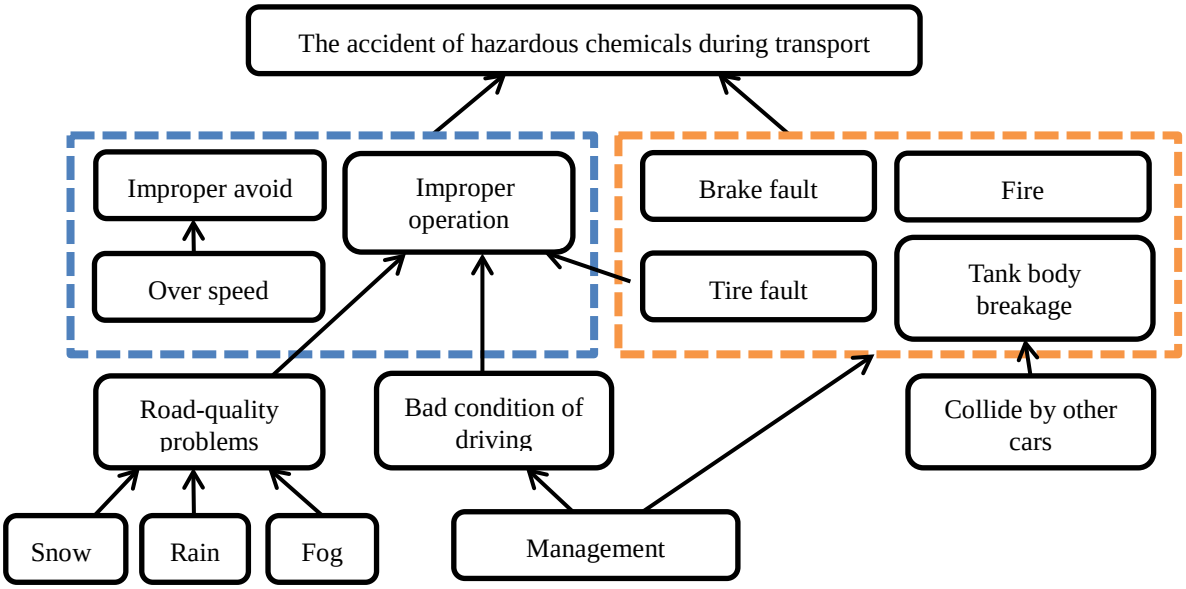

Figure4. The ISM of risk factors in transport of dangerous chemicals

4 SUMMARY

The results of the risk analysis evidenced driver behavior and vehicle or equipment factor is the primary factor causing the accident. Improving safety awareness and the level of the driver, strengthening inspection and maintenance of vehicles and equipment can be effective in reducing accidents especially dangerous leak or explosion caused ecological destruction.

Factor which caused accidents during transport do not exist independently but influence each other and are reciprocal causation. To decrease accidents effectively and reduce casualties and property losses, we should control risk factors in all aspects during transport, identifying the sources of danger in process fully and reasonably. What's more, the evaluation of harmful consequences of risk factors must be scientific and standard. Finally, given full consideration to sensitive receptors in the environment during transport is very important.

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