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AN IMPROVED HAZARDOUS MATERIAL ROAD TRANSPORTATION ACCIDENT RATE ANALYSIS MODEL

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Abstract: Hazardous material road transportation routing based on risk analysis is one of the key methods that can achieve the reduction of hazardous material transportation risks and accident damages. The precondition of routing is the quantitative analysis of risk of every segment of road, of which the considered elements include injuries and fatalities, cleanup costs, property damage, evacuation, product loss, traffic incident delay, and environmental damage. Injuries and fatalities is regarded as the most important element, of which the precondition is the hazardous material road transportation accident rate analysis. This paper improved the traditional hazardous material road transportation accident rate analysis model through a careful analysis prior to the use of historical data, to achieve a more accurate accident rate. Historical data proved that the improved model can get results more close to the actual situation.

Key Words: Hazardous Material, Road Transportation, Accident Rate, Risk Analysis

I. INTRODUCTION

Most hazardous material accidents happen in transportation, according to statistics, more than 95% of hazardous material got involved in transportation[1], until end of 2008, the length of road network in China reached 3.73 million kilometers[2], the transportation accident rate and injuries and fatalities caused by road accidents stay at a high level. Hazardous material road transportation routing is one of the key methods that can achieve the reduction of hazardous material transportation risks and accident damages. The precondition of road routing is the quantitative risk analysis of every segment of the road. Currently most risk analysis focus on aspects including injuries and fatalities (or often referred to as population exposure), cleanup costs, property damage, evacuation, product loss, traffic incident delay, and environmental damage[3]. Injuries and fatalities is regarded as the most important aspect of which the precondition is the hazardous material road transportation accident rate analysis. Most researchers refer to historical data in the research of accident rate analysis, and consider actual situation factors like road condition, weather condition, and traffic condition. This paper improved the traditional model of accident rate analysis through study of the objective laws of road transportation accidents (especially the hazardous material road transportation accidents in the last decade) in China. Historical data proved that the improved model can reach a more accurate result of the accident rate, which can give an indispensable support to the hazardous material road transportation routing.

II. HAZARDOUS MATERIAL ROAD TRANSPORTATION RATE ANALYSIS MODEL

A. Traditional hazardous material road transportation rate analysis model

Hazardous material road transportation accident rate values about 10-6～10-8/km, and related data information is limited and not applicable. Moreover, the huge variety of hazardous material and the complexity of road network makes that we are lack of historical accident documents of a specific kind of hazardous material or a specific road segment. Most researchers adopt the accident data of all traffic vehicles. Hazardous material road transportation accident rate is related with the road type and the regions to get through, Harwood[1] studied heavy transporting vehicle accident rate of 3 states of USA and got the reference data of heavy transporting vehicle accident rate of different regions and road types (Table I). Saccomano[2] (Canada) made a statistical analysis of heavy transporting vehicle accident rate in the region of Ontario(Table II). Table III contains accident rate data of different regions/countries.

TABLE I HEAVY TRANSPORTING VEHICLE ACCIDENT RATE OF 3 STATES OF USA

Road type		Heavy transporting vehicle accident rate (accident/million vehicle-km)			
		California	Illinois	Michigan	Average
Countryside	Double lane	1.07	1.94	1.33	1.36
	Multi-lane (Not classified)	3.38	1.32	5.90	2.79
	Multi-lane (classified)	0.76	2.98	3.52	1.34
	Highway	0.33	0.29	0.73	0.40
Urban	Double lane	2.63	6.90	6.79	5.38
	Multi-lane (Not classified)	8.09	10.59	6.44	8.65
	Multi-lane (classified)	2.17	9.20	6.59	7.75
	Single lane	4.10	16.38	5.02	6.03
	Highway	0.99	3.62	1.74	1.35

TABLE II HEAVY TRANSPORTING VEHICLE ACCIDENT RATE OF ONTARIO

Road type	Accident rate (accident/million vehicle-km)
Urban	1.00
Suburb	0.76
Countryside	0.47

TABLE III HEAVY TRANSPORTING VEHICLE ACCIDENT RATE OF DIFFERENT COUNTRIES

Road type	Accident rate (accident/million vehicle-km)			
	California[4]	Holland	France	Norway
Urban	0.99	0.492	0.973	1.431
Countryside	0.33	0.164	0.324	0.477
Trunk road	1.548	0.768	1.522	2.238

As can be seen from the Table above, urban road accident rate is about 3 times the rural level, trunk road nearly 5 times the rural level. Commonly, heavy vehicle accident rate model of different road type is as follows:

$$TAR_i = \sum_j \frac{A_{ij}}{VKT_{ij}} \quad (1)$$

In the model above:

TAR_i = Heavy transporting vehicle accident rate of road type i (accident/million vehicle-km),

A_{ij} = Heavy transporting vehicle accident frequency on road segment j of road type i (case),

VKT_{ij} = Heavy transporting vehicle mileage on road segment j of road type i per year (vehicle*km).

If the data of rate of hazardous material vehicles out of all heavy trucks are available, then the hazardous material road transportation accident rate model is as follows:

$$P(A)_i = TAR_i \times \frac{N_{hazmat}}{N_v} \times l_i \times n \quad (2)$$

In the model above:

$P(A)_i$ = Heavy transporting vehicle accident rate on road segment i (accident/year),

N_v = the *number* of heavy vehicles on road segment i (vehicle), N_{hazmat} = the *number* of hazardous material transporting vehicles on road segment i (vehicle),

l_i = the *length* of road segment i (km),

n = the *number* of transporting vehicles on road segment i (vehicle).

B. Amended hazardous material road transportation accident rate analysis model

Hazardous material road transportation accident rate is not only related with the road type , but also related with some other factors including road line type, traffic condition, weather in the region and population exposure in the affected area along the road line. Researchers mostly adopt the reference data in Table III, but gaps between the reference data and the actual situation can be large. Thinking of this, Ren Changxing[1] modified the traditional accident rate model by considering hazardous material characteristics, road characteristics and traffic condition, inducted the hazardous material road transportation accident liability revising and risk amending modulus. For the hazardous material road transportation accident rate is very low, usually we use the transportation accident rate, the amended model is as follows:

$$f_i = \left(TAR_i B_1 \prod_{j=1}^{6} F_j \right) l_i n_i \quad (3)$$

In the model above:

f_i= hazardous material road transportation accident rate on road segment i(accident/year),

TAR_i = statistical analysis value of historical hazardous material road transportation accident rate on road segment i(accident/million km), or an adoption of the data in Table III, F_j = hazardous material road transportation risk expanding or reducing factor, j values 1 ~ 6, F_j includes 3 kinds of factors: inherent feature of the road, weather condition and traffic condition. As current hazardous material road transportation database is imperfect, we refer to the Italian hazardous material road transportation statistics as the influencing factors, shown in Table IV.

B_1=hazardous material road transportation accident liability revising modulus, decided by the hazardous material kind.

TABLE IV HAZARDOUS MATERIAL ROAD TRANSPORTATION ACCIDENT RATE INFLUENCING FACTORS

Influencing factors	Secondary influencing factors and relative weights		
Inherent feature of the road	F_1	straight road	1.0
		curve road R>200m	1.3
		curve road (R<200m)	2.2
	F_2	flat road	1.0
		Slope (gradient <5%)	1.1
		steep slope (gradient >5%)	1.2
		down slope (gradient <5%)	1.3
		Steep down slope (gradient >5%)	1.5
	F_3	two-lane each direction	1.8
		two-lane and emergency lane	1.2
		three-lane and emergency lane	0.8
	F_4	good lighting straight tunnel	0.6
		other tunnel	0.8
		bridge	1.2

Weather condition	F_5	good weather	1.0
		rain / fog	1.5
		snow / hailstone	2.5
Traffic condition	F_6	low density<500 vehicle/hour	0.8
		middle density <1250 vehicle/hour, heavy vehicle<125 vehicle/day	1.0
		high density >1250 vehicle/hour	1.4
		high density >1250 vehicle/hour, heavy vehicle>125 vehicle/day	2.4
Accident liability revising modulus	B_1	$B=2.91\alpha B/(B_{min}+B_{max})$ In the model, B is the actual accident liability value of the hazardous material, B_{min} is the minimum accident liability value of this grade hazardous material, B_{max} is the maximum accident liability value of this grade hazardous material, α is weight modulus of the main category the hazardous material belongs to.	

III. PROBLEM AND IMPROVEMENT OF ACCIDENT RATE ANALYSIS MODEL

A. Problem

Although Ren Changxing [1] revised the traditional model above by considering the hazardous material characteristics, road characteristics, weather conditions and traffic conditions, there are still improvements need to be done in the deal of historical data, especially in China. Road transportation of hazardous material has different characteristics during different historical periods. Road transportation of hazardous material is developing rapidly in China nowadays: the traffic amount is growing, the transport equipments are updating, the transport speed also continues to increase, and the transportation management policies and measures are also changing. Many aspects of influences bring changes to hazardous material road transportation on different roads and at different time. So there are differences among different time and different road segments. Statistics show that[5] road transportation safety situation in China during 1991-2005 can be divided into two development stages: during the first phase (1991-1997) high grade road security situation remained basically unchanged, the transportation security situation on the whole was good; in the second phase (1998-2005) security situation of high-grade road was deteriorating rapidly, the security situation on the whole became very grim. After comprehensive consideration of the development process of road transportation accidents in China (Figure I) and developed countries over the years, we can get the conclusion that although the level of road transportation safety in China in recent years is significantly better, but in general is still in the period of rapid growth of accidents. In the environment of rapid economic growth in China, vehicle ownership will be further enhanced, especially in the eastern developed regions. Statistics of countries around the world [6] show that when the level of motorization is between 011 and 014, road transportation safety condition is still in the stage of deterioration, deaths caused by road transportation accidents will continue to increase.

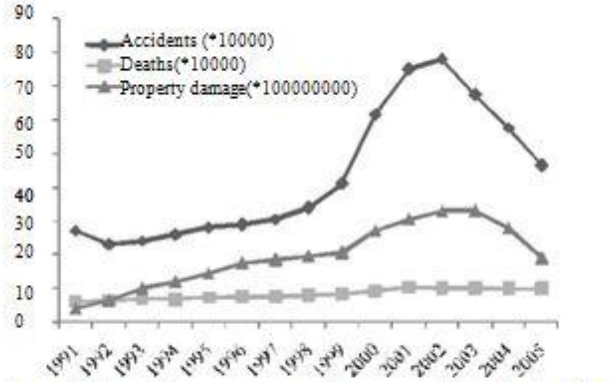

FIGURE I ROAD TRANSPORTATION ACCIDENTS DATA IN THE PAST YEARS

Basic changes of accident are closely related to changes of accident rate, the accident rates in different time periods have different patterns and characteristics. But at present, most researchers ignored the changes of accident rates at different times in the accident rate calculation process, just adopted a simple historical average value as the reference factor, results of this approach are not accurate. To make the computation result more close to reality, we must take the objective laws of accident rate variation during different periods of time into consideration; revise the model according to variation objective laws of historical road transportation accident rates.

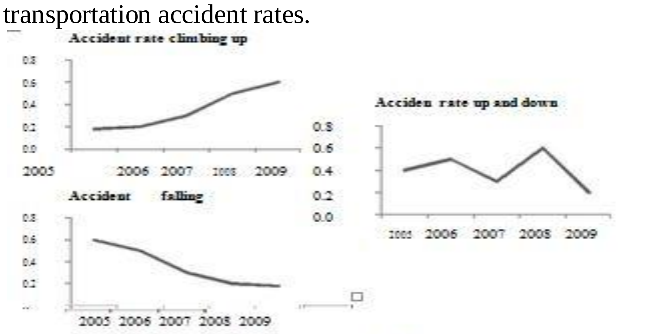

FIGURE II DIFFERENT ACCIDENT RATE VARIATION OBJECTIVE LAWS

B. Improved accident rate analysis model

First, we should select the recent but not all historical data to calculate the mean average of accident rate in the model, because the rapid development of transportation makes the age-old data little or no reference value. This paper takes historical data mean of the last five years. After selecting the data, the next step is to revise the model according to the recent data variation. In this paper, we put forward two kinds of forms of expression: The first one is to directly calculate the slope of accident rate change in calculation of the accident rate TAR_i, shown as follows:

$$f_i = \left(TAR_i' E_1 \prod_{j=1}^{6} F_j\right) l_i n_i \quad (4)$$

here:

$$TAR_i' = TAR_i\,(1 + \sum_{m=1}^{5} k_m/5) \quad (5)$$

In the model above:

k_m= the slope of accident rate change of *m* year(s) before, here we choose the data of the last 5 years, so *m* here values 1~5. And in the second expression, we revise the model by adding another factor into the model, here, we name the factor F_7. And then, the formula becomes:

$$f_i = \left(TAR_i B_1 \prod_{j=1}^{7} F_j\right) l_i n_i \quad (6)$$

TABLE V WEIGHT EXPRESSION OF F_7

Influencing factors	Relative weight	
Historical rate variation objective law	F_7	$(1 + \sum_{m=1}^{5} k_m)$

C. Examples of proof of the improved model

To prove the accuracy of the improved hazardous material road transportation accident rate analysis model, we adopt the historical data to validate. For the lack of specific road segment accident rate data, here we use historical road transportation accident frequency data to calculate the accident frequency in 2003.

TABLE VI ACCIDENT FREQUENCIES, DEATHS, MORTALITY RATE AND PROPERTY DAMAGE DURING 1991-2005

Year	Accidents (*10000)	Deaths (*10000)	Mortality rate	Property damage (0.1billion ¥)
1991	27.9	6.1	21.9%	4.1
1992	23.6	6.3	26.7%	6.5
1993	24.2	7.0	28.9%	10.2
1994	26.6	6.8	25.6%	12.3
1995	28.4	7.3	25.7%	14.6
1996	29.0	7.6	26.2%	17.1
1997	30.5	7.5	24.6%	18.5
1998	34.4	8.0	23.3%	19.6
1999	41.1	8.3	20.2%	20.9
2000	61.8	9.2	14.9%	27.4
2001	75.7	10.3	13.6%	30.3
2002	78.9	10.1	12.8%	33.3
2003	67.5	10.0	14.8%	33.7
2004	57.4	9.9	17.2%	28.6
2005	46.6	9.9	21.2%	19.3

Using mean average of historical accident data:

$$ACC_i = \frac{\sum_{n=1991}^{2002} ACC_n}{12} = 40.18 \quad (7)$$

Using the improved model:

$$ACC_i' = \frac{\sum_{n=1998}^{2002} ACC_n}{12}(1 + \sum_{m=1}^{5} k_m/5) = 71.22$$

The actual accident frequency in 2003 was 67.5(*10000), the result proved that the improved model is more accurate, more close to the real situation. Similarly, the data[7] shows that mortality rate of road transportation accident was also changing all the time, and there are also objective laws of the variation. The injuries and fatalities analysis model can also be improved to get a more accurate result in the calculation. The different changing trends during different time periods are shown in Figure III.

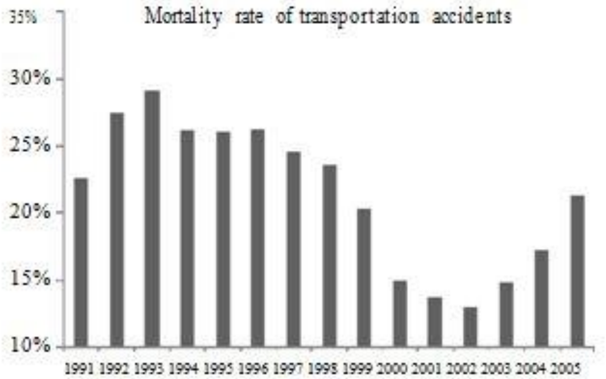

FIGURE III MORTALITY RATE OF TRANSPORTATION ACCIDENTS

Using mean average of historical accident data:

$$MRT_i = \frac{\sum_{n=1991}^{2002} MRT_n}{12} = 22.0\% \quad (9)$$

Using the improved model:

$$MRT_i' = \frac{\sum_{n=1998}^{2002} MRT_n}{12}(1 + \sum_{m=1}^{5} k_m/5) = 14.9\% \quad (10)$$

The actual mortality rate in 2003 was 14.9%, the improved model is much more accurate, more close to the real situation. Currently, very few researchers around the world are researching on long-term trends of hazardous material road transportation accident rate[8], the lack of historical hazardous material road transportation accident data is one of the reasons. But now countries are paying more and more attention to the work of hazardous material road transportation accident statistics, analysis, excavation and research. The perfection of analysis data will improve the level of accident rate analysis and hazardous material road transportation risk assessment.

IV. CONCLUSION

Statistics show that the improved hazardous material road transportation accident rate analysis model got a result closer to the actual situation. At the same time, it turns out to be a higher demand of the accident history data, particularly the recent accident data (including the traffic and transport accident statistics and the hazardous material road transportation accident statistics). So we say: research and development trend of the hazardous material road transportation accidents is not only to have a more accurate method of calculation, but also a more comprehensive data support. Analysis models and analysis data are two key factors that we need to focus on in order to reduce risks of hazardous material road transportation. In the next step of research, we will focus on further improvement of the model of hazardous material road transportation accident rate analysis and the injuries and fatalities risk analysis.

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