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A theoretical model for freeway safety

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Abstract

A theoretical model of system dynamics for freeway safety is established. According to the factors and sub-factors affecting freeway safety, the factors and sub-factors are assigned by using AHP method. According to the established system dynamics model, with the development of economy and other factors, the safety of freeway in the next 10 years is simulated. The sensitivity analysis of the key factors affecting expressway safety is also carried out. Finally, four conclusions are drawn: (1) Economic improvement will lead to highway safety improvement; (2) Periodic weather impact will always exist; (3) Long driving time is more sensitive to highway safety impact than economic development; (4) Driver safety awareness in the case of continuous investment, growth will also be reduced.

Keywords – freeway, safety, system dynamic

1. Introduction

Freeway is a kind of high standard special highway which is completely closed, multi-lane, controlled access, with central separation zone, centralized management and midway service area. It is an important transportation facility between cities. It has the characteristics of high speed and large capacity.

For the development of any country, industrialization process to mature stage, the large-scale construction of highways is inevitable, which has become the common law of the development of world transportation. In 1950s, western developed countries began to build highways on a large scale to meet the ever-increasing transportation demand. After the 1960s and 1970s, many developing countries with rapid economic growth also began to build highways on large scale. It also produces huge economic and social benefits. At present, China, the United States, Canada, Australia, Germany, France and other countries have the highest number of highways in the world.

Due to a series of measures taken by the highway, the accident rate of the highway is only 1 / 3-1 / 4 of the average highway. However, because of the high speed of the vehicles on the highway, once the traffic accident occurs, it is more serious than the ordinary highway accident, and the death rate of the highway is twice as high as that of the ordinary highway [1].

The research on road traffic safety in foreign countries started very early, and the research on the factors affecting the occurrence of accidents has been improved constantly in the research. The main research methods include linear regression, logistic regression, neural network model, decision tree model and so on.

Some researchers focus on the research of freeway safety. In recent years, due to the rapid development of freeway in China, Chinese researchers got lot merits in recent years in the study of freeway safety.

In this paper, a theoretical model of freeway safety is established to study the influence of main factors on expressway safety. By adjusting the weight of influencing factors, this paper studies the influence of main variables on freeway safety, in order to construct each influencing factor of freeway and reduce the probability of traffic accident.

In this paper, the important factors affecting freeway safety are analyzed, and the secondary sub-factors and the relationship between them are analyzed. The system dynamics model is established, and the variable weight is assigned by AHP method. By simulation and analysis of the system dynamics model, the sensitivity analysis of the factors affecting the safety of freeway is carried out, and some suggestions are given.

2. Literature review

Scholars used a variety of models to conduct a large number of research on freeway accidents, and analyzed the accident factors of people, cars, roads, and environment and so on. Early studies usually use regression models to analyze accidents. In order to avoid the limitation of accident classification, the binary regression model is gradually developed into a multivariate regression model. In recent years, this kind of research has gradually developed from descriptive analysis based on statistical method to multivariable complex model of non-statistical model.

Shankar et al. [2] explore the frequency of occurrence of highway accidents on the basis of a multivariate analysis of roadway geometrics weather, and other seasonal effects. Based on accident data collected in the field, a negative binomial model of overall accident frequencies is estimated along with models of the frequency of specific accident types. Chang and Chen [3] compare the prediction performance between the CART and the negative binomial regression models, demonstrate that CART is a good alternative method for analyzing freeway accident frequencies. Lin, et al. [4] point out the duration of freeway traffic is an important factor, which affects traffic congestion, environmental pollution, and secondary accidents. The problem with M5P for accident duration prediction, is linear regression assumes that the conditional distribution of accident durations is normally distributed, the distribution for a "time-to-an-event" is almost certainly nonsymmetrical. Wang et al. [5] using 10,762 accident records gathered from 2012 upstream loop detector data on a California interstate freeway, propose a dynamic method for more convincing and accurate classification based on traffic shock waves detected by the loop detectors.

Chung [6] presents a model for the purpose of accident duration prediction based on accurately recorded and large accident dataset from the Korean Freeway Systems. To develop the duration prediction model, Chung utilizes the log-logistic accelerated failure time (AFT) metric model and a 2-year accident duration dataset. Milenković and Glavić [7] analysis of relations between freeway geometry and traffic characteristics on traffic accidents. Wang and Zhang [8] improve the efficiency of emergency management, create evaluation method of severe traffic accidents' emergency management, and determine the level of the emergency management. An evaluation index system with three logical structures is established by analyzing typical server traffic accidents' disposal process and key steps. Cheng et al. [9] evaluate freeway crash risks by variable speed limit strategy using real-world traffic flow data. Liu and Tomizuka [10] point out the behavior of the automated vehicles should be carefully designed to interact with the environment and other vehicles efficiently and safely. Their research is focused on the learning and decision making methods for the automated vehicles towards safe freeway driving. Based on a multi-agent traffic model, the decision making problem is posed as an optimal control problem. Ding et al. [11] taking the Beijing-Tianjin-Tangshan expressway as an example, to study the relationship between expressway traffic accidents and meteorological condition. Their research shows that there are two peaks in the number of traffic accidents, the saddle-shaped peak from April to June and the second peak in October respectively. Relative to the number of traffic accidents, the correlation between meteorological condition and casualty is closer due to the adverse weather conditions always cause the drivers to lose the control of vehicle or to misjudge the situation. Qualitative factor analysis provides a very solid foundation for qualitative research, and the description of statistics provides a data reference for the mathematical model of accident. Qualitative research has been very adequate, qualitative countermeasures are relatively complete. Quantitative researchers have made a lot of attempts, but the level of highway construction, traffic flow, emergency response speed, high-speed environment, road design vary widely, and the mathematical model is not universal.

Therefore, the mathematical model parameters of freeway safety are usually based on one specific freeway, and the parameters of this freeway can't be directly applied to other highways. Therefore, in fact, the theoretical model may be more versatile.

3. Methods

3.1. Analysis

The causes of freeway traffic accidents can be divided into four categories: people, vehicles, roads and environment. Some foreign researches have classified these four factors into two categories: subjective factors and objective factors. Some studies have pointed out that the number of human-induced highway accidents is about 80%, and the number of accidents caused by cars, roads and environment is about 20.1%. According to a survey [12], it was also noted that factors were considered the most important factor in inducing highways, followed by vehicle factors.

Some scholars divide the safety factors of freeway into five categories: traffic participants, vehicles, roads, environment and management [13]. Because the freeway implements the completely closed traffic accident, the human reason in the traffic accident is mainly reflected in the responsibility of the participant in the vehicle, partly because of the illegal behavior of the traffic participant outside the vehicle [14].

In the paper of Yan [13], the freeway safety risk is divided into 5 subsystems, 10 secondary indexes and 16 corresponding sub-indexes to study the sensitivity of risk factors. The method used is AHP-TOPSIS-RSR method.

3.2. Hypothesis

The factors affecting freeway accidents are divided into six categories: pedestrian, driver, vehicle, weather, road, and management. The pedestrian factors affecting freeway traffic accidents mainly include local people who break traffic regulations and freeway maintainers and cleaners who walk across the freeway. Among them, the local people who cross the freeway illegally are the main factors, which is directly influenced by the level of social transportation education.

Tab.1 - Percentage of main factors in traffic accidents

Influencing Factor	Number of Accidents	Percentage
Human	150	82.42%
Vehicle	49	26.92%
Road	5	2.75%
Weather	14	7.69%

Tab. 2 - Ranking index scores of each section

time(second)	0	120	240	300	600
tired	0	0.1	0.5	0.8	1

Driver's safety consciousness is determined by two factors, one is driver fatigue and the other is road safety hint. The fatigue degree of driver consists of driving time and driving fatigue degree function. The driving fatigue table function is reported in table 2.

Vehicle safety is determined by distance, vehicle load, speed, and vehicle performance. The vehicle distance, vehicle load and speed [15] are affected by the driver's safety consciousness. The higher the driver's safety consciousness is, the more the distance, the vehicle load and the speed are inclined to improve the vehicle safety. The factors affecting road safety are road maintenance, lighting, communication equipment, road linearity and pavement performance [16]. Road maintenance, lighting, and communications equipment require a lot of money, and if a country's economy continues to improve, we assume that the government will also invest more in freeway safety [17]. The linearity of the road is determined by the natural conditions and the construction design, and the road performance depends on the engineering technical ability, so we set it as an external variable. The level of management consists of emergency response capacity and safety input, and we assume that these two aspects are also determined by country economy. Research shows that freeway accidents are closely related to the weather, bad weather is an important inducement that causes freeway traffic accidents [18]. We assume that January, February (snow season) and July (rainy season) are the worst months of the year.

3.3. System Dynamics model

The System Dynamics model is established as follows:

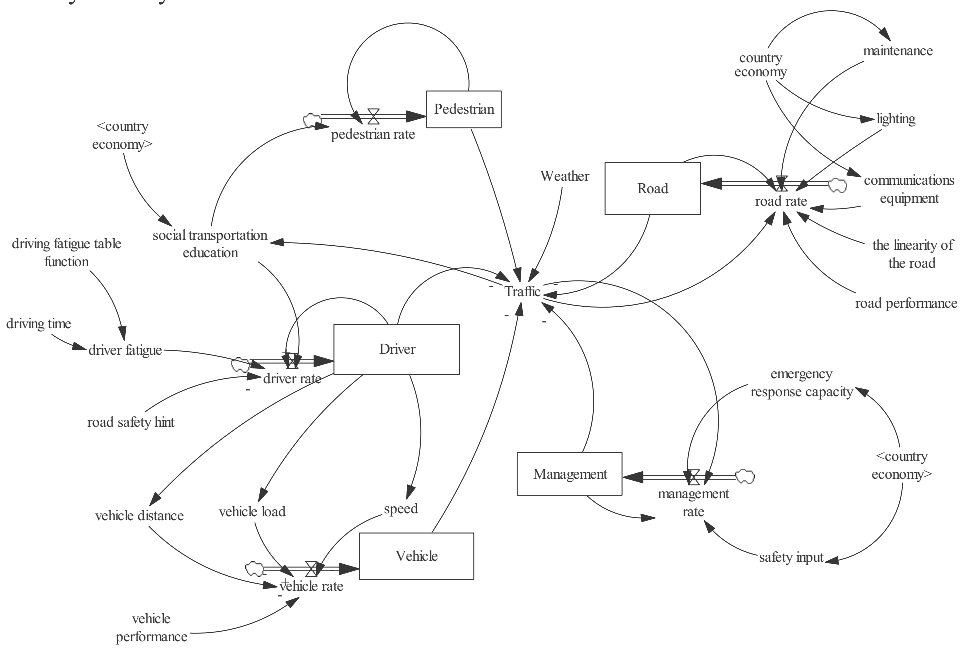

Fig. 1 - Freeway safety system dynamics model

3.4. System Dynamics model

The data is based on Analytic hierarchy process (AHP) to determine the weight of each factor. The factors are graded by experts and the initial value are input into the expression for simulation.

4. Results

The model is simulated with 120 steps, one step is one month, that is, 10 years. The results are as follows:

As shown in figure 2, with the growth of national economy, traffic accidents decrease gradually with the increase of time.We define January, February and July as the worst months of the year, and with Vensim we use the PULSE TRAIN function to simulate them. The result is shown in figure 3.

Tab. 3 - Main variables in freeway safety system and their expression

Variable	Type	Expression
Traffic	Auxiliary	1-(0.1*Weather+0.1*Management+0.1*Pedestrian+ 0.2*Vehicle+0.1*Road+0.7*Driver)
Pedestrian	Level	0.005*pedestrian rate, initial value=0.5
Driver	Level	0.08*driver rate, initial value=0.3
Vehicle	Level	0.01*vehicle rate, initial value=0.5
Road	Level	0.05*road rate, initial value=0.5
Management	Level	0.1*management rate, initial value=0.3
driver rate	Rate	IF THEN ELSE(Driver<=2, 0.03*social transportation education+0.04*road safety hint-0.25*driver fatigue, 0)
vehicle rate	Rate	6+0.02*(vehicle performance-100)+0.04*(vehicle distance-150)+0.03*(vehicle load-100)+0.04*(speed-100)
road rate	Rate	IF THEN ELSE(Road<=2, (maintenance*0.02+lighting*0.02+communications equipment*0.05+the linearity of the road*0.04+road performance*0.02)*Traffic, 1)
management rate	Rate	IF THEN ELSE(Management<=2, (0.01*safety input + emergency response capacity*0.02)*Traffic, 1)
country economy	Auxiliary	1+RAMP(0.01, 1 ,120), or 1.5 for sensitivity test

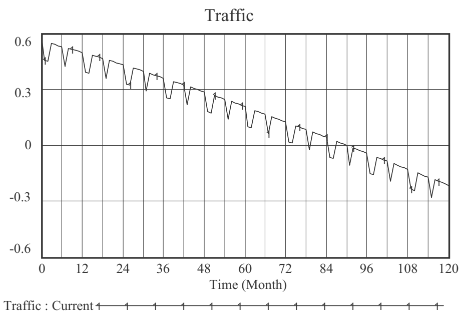

Fig. 2 - The simulate result of the traffic

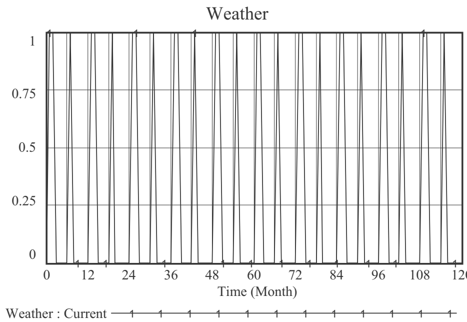

Fig. 3 - The simulate result of the weather

Driver rate rises first and then declines over time. This is because with the improvement of social transportation education, the safety awareness of drivers has been improved, fewer accidents have occurred, causing the drivers to slack, so the increase of safety awareness has decreased. Shown as figure 4. And the driver simulation is shown as figure 5.

As a result of the development of the country economy, the investment in road construction has been continuously strengthened, but the quality of the road is affected by the ceiling effect, that is, the quality of the road reaches a certain level, even if more funds are invested in the construction. The quality of the road is also unable to rise accordingly. As a result, road rate has declined. Road rate simulated as Figure 6. As drivers' safety awareness and vehicle performance improve, the vehicle simulations are shown in figure 7. From figure 8 and figure 9, we can see that, the country economy and driving time are sensitive to the Traffic.

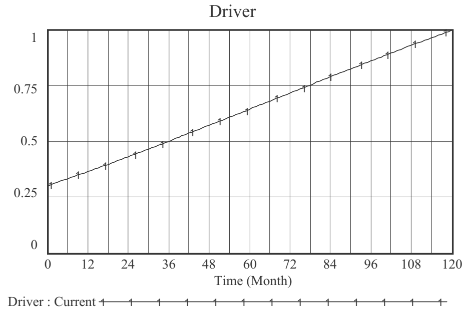

Fig. 4 - The simulate result of the driver rate

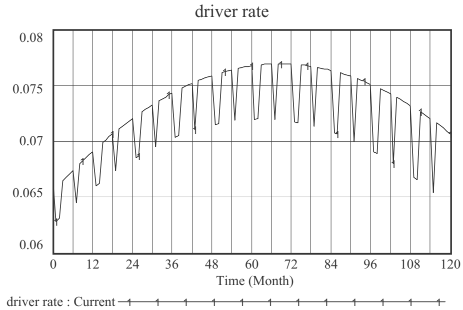

Fig. 5 - The simulate result of the driver

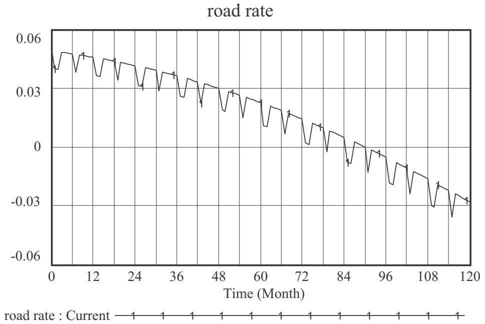

Fig. 6 - The simulate result of the road rate

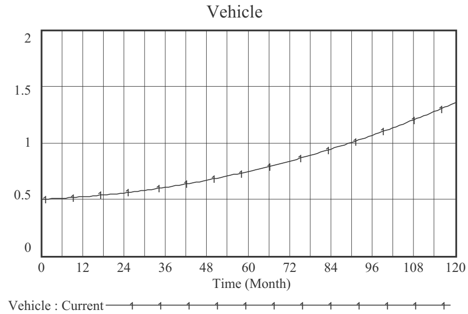

Fig. 7 - The simulate result of the vehicle

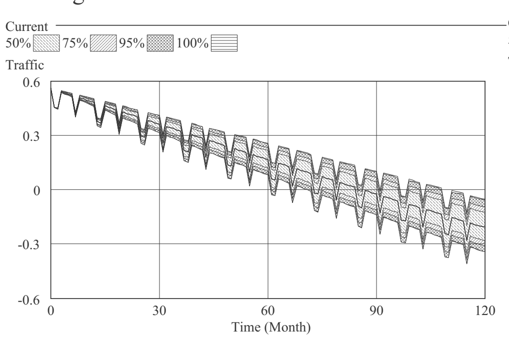

Fig. 8 - The sensitivity of country economy to Traffic

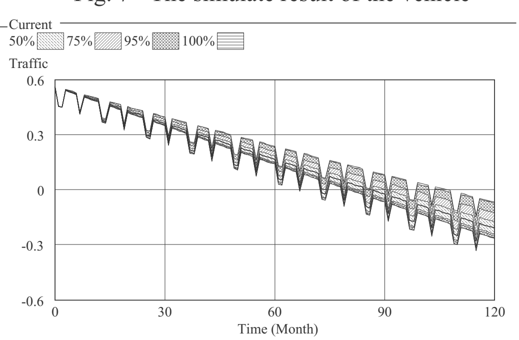

Fig. 9 - The sensitivity of driving time to Traffic

5. Discussions

In this paper, a theoretical model of freeway safety is established. The factors that affect the freeway safety are simulated by the system dynamics model. Through the system dynamics model, we find that:

(1) With the improvement of economic, if the social traffic safety education is improved as well, and the freeway hardware construction will be raised as well, and the accident rate of expressway will decrease gradually.

(2) The influence of weather on freeway safety is periodic, but it does not affect the overall improvement of safety, and freeway traffic safety accidents decrease, which also reflects the periodicity of weather impact on freeway safety.

(3) The effects of long driving and traffic accidents are more sensitive than that of country economy to traffic safety. Therefore, the management and prompting of long driving is more effective than country economy.

(4) Even if the social transportation education is improved continuously, the driver's safety consciousness also gets the promotion unceasingly, but the speed of upgrading, after reaching a certain level, tends to ease off.

In this paper, the system dynamics method is used to establish the freeway safety model, and the sensitivity analysis of the factors affecting the freeway safety can be made to determine which factors have a more obvious impact on the freeway safety under certain circumstances.

Compared with the previous work of the researchers, although the researchers clearly pointed out the main factors affecting the safety of freeway, but the importance of the factors is difficult to sort, in different environments, the importance of the factors will also change. Previous studies have rarely seen a method of ranking influencing factors. The study of freeway traffic safety based on decision theory lacks the influence and prediction of the direction of freeway traffic safety work on long term freeway traffic safety. The method provided in this paper can solve this problem.

A theoretical model established in this paper uses AHP method to assign variables values and equations, so the practicability of assignment needs to be strengthened. Because it is a theoretical model, it does not assign value according to a freeway in reality, so it does not compare the actual data. The model is relatively simple and has abundant expansibility. The variable formula can be modified according to the secondary factor analysis of the influencing factors to improve the practicability.

6. Conclusions

Based on the previous research results, this paper establishes a system dynamics model of freeway safety, analyzes the factors affecting freeway safety, and analyzes the sensitivity of some variables, and predicts the future 10 years. The influence of economic development and other factors on freeway safety.

Through the simulation of system dynamics model, this paper summarizes four discoveries. These findings have made an analysis and a summary of the factors that affect freeway safety, and some revelations have been given to the direction of expressway safety work.

Reference

1. L. Yan and L. H. Peng.(2003).Study on Safety Management of Freeway, China Safety Science Journal,13(2),47-49
2. V. Shankar, F. Mannering and W. Barfield.(1995).Effect of roadway geometrics and environmental factors on rural freeway accident frequencies, Accid Anal Prev,27(3),371-389

3. L. Y. Chang and W. C. Chen.(2005).Data mining of tree-based models to analyze freeway accident frequency, Journal of Safety Research,36(4),365-375
4. L. Lin, Q. Wang and A. W. Sadek.(2016).A combined M5P tree and hazard-based duration model for predicting urban freeway traffic accident durations, Accident Analysis & Prevention,91,114-126
5. J. Wang, W. Xie, B. Liu, S. E. Fang and D. R. Ragland.(2016).Identification of freeway secondary accidents with traffic shock wave detected by loop detectors, Safety Science,87,195-201
6. Y. Chung.(2010).Development of an accident duration prediction model on the Korean Freeway Systems, Accident Analysis & Prevention,42(1),282
7. Milenković, M., & Glavić, D. (2017, May). Analysis of Relations Between Freeway Geometry and Traffic Characteristics on Traffic Accidents. In International Symposium on Innovative and Interdisciplinary Applications of Advanced Technologies (pp. 539-548). Springer, Cham.
8. Z. Wang and L. Zhang.(2016).Evaluation of Severe Traffic Accidents' Emergency Management Effectiveness on Freeway Based on Grey Clustering and AHP, Transportation Science & Technology,
9. Z. Cheng, J. Lu and Y. Li.(2018).Freeway crash risks evaluation by variable speed limit strategy using real-world traffic flow data, Accident; analysis and prevention,119,176
10. C. Liu and M. Tomizuka.(2016). Enabling Safe Freeway Driving for Automated Vehicles. American Control Conference. IEEE.
11. D. Ding, Z. Yin, L. I. Xun, Q. Zhang, D. Zhang and Z. Xie.(2011).Relationship between Traffic Accidents of Beijing-Tianjin-Tangshan Expressway and Meteorological Condition, Journal of Highway & Transportation Research & Development,
12. Z. Yong, M. Fan and Y. Wang.(2000).Causes and Prevention Measures of Expressway Accidents, Journal of Highway & Transportation Research And k Development, 17(6).
13. Y. Wu, Z. B. Qian, J. J. Wang, Y. J. Deng and Y. Lu.(2014).Traffic safety risk assessment and sensitivity analysis on expressway, Journal of Changan University, 34(4). 134-141
14. Y. G. Wang and Y. Wang.(2008).Multidimensional analysis model of accident causes resulted from human factors, Journal of Traffic & Transportation Engineering, 8(2) ,96-100.
15. Cichocki, K., & Wekezer, J. W. (2003). Vehicle trajectories resulting from traversing fdot street curb: numerical analysis and experimental verification. Advances in Transportation Studies, 1.
16. C. Hackley.(2015).Development and applications of models of average speed in the combination area of urban expressway ramps, Advances in Transportation Studies, 35(7) ,19-42.
17. Z. Guo, J. Gao and L. Kong.(2003).The road safety situation investigation and characteristic analysis of black spots of arterial highways, Advances in Transportation Studies,1.
18. Y. Bai, M. He, J. Liu and H. Qi.(2015).Study on the Relationship Between Highway Traffic Accidents and Meteorological Conditions, Meteorological & Environmental Sciences

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Maintenance decision-making model for highway construction project

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Abstract

The investment in highway construction not only promotes the development of China's transportation industry, but also achieves a far-reaching significance to China's economy and society. In this paper, we present a highway-maintenance evaluation system (HMES) during the project lifecycle in highway construction, and the decision-making model for the highway maintenance. The HMES contains three parts including the acceptance list of highway safeguard, the selection and evaluation of highway security scheme, and the analyses and evaluation of safeguard project, which based on the Analytic Hierarchy Process (AHP) method. Also two kinds of grades decision-making models of maintenance management were established, which are the project-grade and the network-level respectively, through the estimation and benefit analysis of different management schemes. The results of case analysis show that the decision-making model can improve highway maintenance effectively.

Keywords – highway construction project, maintenance, decision-making model

1. Introduction

With the rapid increase of mileage in highway construction project, the much heavier maintenance tasks are following within the project cycle. The laws (or regulations) from national level (or regional level) have made specific provision in these aspects respectively: the planning and construction, management, financing and management, highway management, legal responsibility of highway construction projects. However, according to laws (regulations, policies, or standards), how to build a scientific and reasonable evaluation system of maintenance of highway construction project to evaluate the maintenance level objectively and address various problems existing in the current evaluation, has been paid more attention by financial investment management department to solve the problems.

2. Literature review

In the process of evaluation of maintenance project, all those that meet the conditions of maintenance projects can be used as alternative projects in the database. Nevertheless, actually, in the decision-making process, the determination of maintenance project options also might finally be affected by the constraints of budget and implementation time of the project. So the purpose of road maintenance projects is to choose an optimal scheme from a variety of alternatives, to make the best use of the budget to maximize benefits. For the choice of highway investment projects and highway maintenance projects, the domestic and external highway management sectors and scholars have conducted extensive research and practice, especially in the United States.

At present, the methods selectable for road maintenance items mainly include Ranking method and Model method.

2.1. Ranking method

Ranking method is used more often by the federal highway administration (FHWA). It consists of two steps: the first step is to identify alternative type of highway maintenance project, calculating separately for each type of maintenance projects its maintenance cost, in which to select each of the maintenance projects of the lowest-cost project alternative [1]; the second step is to select the optimal project in these options according to some criteria.In step 2, the selection criteria can be a single standard, such as initial cost, construction period, return on investment, or comprehensive consideration of highway type, traffic condition, security situation, etc. [2].

2.2. Model method

The Model method mainly includes a decision-making model and a probability model, which solves problems through constructing the corresponding mathematical model and design the algorithm to conclude that the choice of the optimal scheme. The model method is widely used to address the selection issues of highway maintenance project. Ouyang [3] used mixed integer nonlinear programming to study the choice of highway maintenance projects. Geoff Roy [4] adopted the target compromise plan to select the maintenance project of the New York highway network. Teng [5] and Li [6] adopt the multi-objective decision-making method to select the traffic investment projects. DE la Garza [7] and Salem [8] et al. modeled through simulation of the safety, performance, traffic volume and project cost of highway investment projects, so as to make a rational selection of highway investment projects. Jha [9] used Markov model to predict project benefit from the perspective of project life cycle, and it is used as the basis for selecting highway investment projects. Li [10] adopted random multi-dimensional knapsack model to solve the problem of highway project selection in the uncertain budget. Touran [11] constructed the decision support system including 24 indicators as the tool of choice of road transportation projects. Bosurgi [12] adopted artificial neural network method to construct road surface maintenance project selection model. Shanteau [13] adopted hybrid genetic simulation model to make a rational selection of highway road maintenance projects. Based on constructing the multi-objective decision evaluation index of highway investment projects, Zimmerman [14] has adopted AHP method to determine the project decision plan.

3. Maintenance model of highway construction project

Usually limited by the capital in the maintenance and management, it is unlikely to meet all the maintenance of requirements. Under the situation, it demands the decision makers to confirm the order of every line maintenance management in the road network according to certain standard, and the sorting results can reflect the degree of urgency and comprehensive importance in the road maintenance.

We considered the sort of influence factors, including road condition value (PCI), PCI rate of change (kPCI), 2 (AADT) traffic, daily maintenance, and management level and the role of the road in the network, etc. The factors affecting the decision-making are shown in Table 1.

The year of decision-making is a particular year for making the plan of maintenance. On one hand, in terms of determining the future PCI, it is necessary to predict the PCI value in this particular year, which is called the *future year*. On the other hand, in order to accurate influence of PCI, it is generally considered the year that three years after decision-making year as a future year, which determines PCI through predicting the future year's PCI.

Tab.1 - Factors affecting decision alternatives

Factors	Ranking weight	Order rules
PCI	ω_1	Sort by the value of PCI and the smaller one is at the front
kPCI	ω_2	Sort by the value of k PCI and the bigger one is at the front
AADT	ω_3	Sort by the average daily traffic flow size and the bigger at the front
RCSP	ω_4	Sort by the daily management level score and the bigger one at the front
LWDW	ω_5	The one with higher segment technical level or administrative level or traffic growth is at the front

When determining the position of a section of a highway in the road network, it is useful to adopt experts' experience method and comprehensive scoring method.

The algorithm that represents the change of PCI between the decision-making year and the future year is:

$$k_{PCI} = \frac{PCI_0 - PCI_j}{j} \times 100\% \tag{1}$$

In the formula (1), PCI_0 is the value for the decision-making year; PCI_j is the value for the future year; J is the time difference between the future year and decision-making year. The 0~1 linear programming method was applied to the 0~1decision-making model of maintenance finance distribution in network-level decision-making. Its main idea is whether it is in line with the intention of the policy-makers through discussing several goals, to choose or not each of the decision variables according to the calculation results, the decision variable values only 1 or0,which can be expressed as:

$$x_i = \begin{cases} 1 & Priority\ to\ maintenance \\ 0 & Non-preferential\ curing \end{cases} \tag{2}$$

For rural highway network decision-making, the article selects the strategies with minimized opportunity cost and optimized overall technical conditions of the road network as decision-making target, which subjected to the daily workload of maintenance and the area needed maintenance, the decision-making objective model is established as follow:

$$\begin{cases} \min z_1 = x_1 y_1 + x_2 y_2 + \cdots + x_n y_n \\ \max z_2 = x_1 s_1 + x_2 s_2 + \cdots x_n y_n \end{cases} \tag{3}$$

St.

$$\begin{cases} x_1 d_1 + x_2 d_2 + \cdots x_n d_n \le D \\ x_1 m_1 + x_2 m_2 + \cdots x_n m_n \le M \\ x_1 r_1 + x_2 r_2 + \cdots x_n r_n \le R \end{cases} \tag{4}$$

In the formula, x_i is a section of the highway needs to be maintained; y_i is the opportunity cost of section i; s_i is the performance score of the road i after being maintained; M is the total amount of maintenance funds; R is the total number of maintenance personnel; D is the total maintenance area.

Based on the equation 7-3, using the method of the weighted coefficient of multi-objective programming problem can be converted to the single objective programming problem, through the weights to reflect the objectives for the importance of the decision makers, and using the weighted summation method combined multiple objective functions to be a single objective function. The details are as follows:

Suppose that there are n targets $Z_j(x)$ (j = 1,2,...,n) in the original problem, multiplied by a set of weight coefficients λ_j (j = 1,2,...,n) represented the importance of each target, and then the summation serves as the general objective function, which is to construct the following single-objective problem:

$$\min z'(x) = \sum_{j=1}^{n} \lambda_j z_j(x) = \lambda^T z(x) \tag{5}$$

And the objective function is to solve the non-inferior solution in the constraint set of the original multi-objective function, which is the non-inferior solution of the single objective.

4. Case study

Take Tengzhou for example, a small city in Shandong province in China, supposed that in 2008 the city was planning to maintain six highway asphalt road within the scope of their jurisdiction, they are Hanzhuang–Xiqiaotou, Zhang kongzhuang - Qianlidian, Wanglin - Lizhuang, Tanzhuang - Nanlilou, Dongtian - Daguan and Qianfoge–Baziya.

Take the year 2008 as the decision-making year, the year 2010 as the future year, according to the preliminary survey, evaluation and forecast results, the sorting index of each section is shown in the Table 2. The steps of sorting are:

(a) For PCI, according to six sections of the highway of the value of in the decision-making year to sort.Namely, the worse the road conditions and the smaller the value, which is shown as table 6-5, the PCI of Hanzhuang–Xiqiaotouis minimum, so we assigned its value as 1; the PCI of Dongtian–Daguan is the largest, its maximum value assignment is 6;

(b) For k_{PCI}, sorting with the size of each section within the next two years, in the table 6-5,we can see the k_{PCI} of Dongn-Daguan is the largest, so its minimum value assignment is 1, Hanzhuang - Xiqiaotouis minimum, thereby its maximum value assignment 6;

(c) For AADT, order by the average volume in decision-making year according to values supplied by sorting seen as table 6-5, Qianfoge–Baziya, is the largest volume, so its minimum value assignment 1, Hanzhuang - Xiqiaotou is the least traffic volume, so its maximum value assignment 6;

(d) For RCSP, which is to sort according to the score of evaluation in decision-making year's daily management level.The higher score, the better daily management level,the former the order of sorting.Vice versa. Hanzhuang–Xiqiaotou evaluates the highest management level, so its value assignment is 1, Dongtian-Daguan is the lowest score of management level, the assignment sets 6;

(e) For LWDW, the status of road network mainly considered the technical level, the administrative ranks of the route and the volume of traffic, the more important the former. According to the on-the-spot investigation and experts' experience. Hanzhuang - Xiqiaotou is the most important, so its minimum value assignment 1, Wanglin - Lizhuangis the least important, the assignment sets 6;

(f) To calculate the weight of five factors (ω_1, ω_2, ω_3, ω_4, ω_5) = (0.4,0.2,0.15,0.15,0.10) respectively, the result is μ_i (i=1,2,3,4,5,6) = (2.75,2.85,4.35,4.05,3.9,3.1. That is, under the condition of without considering other factors, only to meet the needs of maintenance, the ranked order from the highest to lowest is:Hanzhuang - Xiqiaotou, Zhang Kongzhuang–Wianlidian, Qianfoge-Baziya, Wang Lin-Lizhuang, Tanzhuang - Nanlilou, Dongtian-Daguan.

Tab. 2 - Ranking index scores of each section

No.	1	2	3	4	5	6
Route	Hanzhuang-Xiqiaotou	Zhangkongzhuang-Qianlidian	Dongtian-Daguan	Tanzhuang-Nanlilou	Wanglin-Lizhuang	Qianfoge-Baziya
PCI in 2008	80.04	80.35	89.46	86.68	86.18	83.97
PCI in 2010	77.39	77.69	86.5	83.81	83.32	81.12
K_{PCI}	1.325	1.33	1.48	1.435	1.43	1.425
AADT	1188	1288	1244	1256	1356	1577
RCSP	95	89	81	85	86	83
LWDW	1	3	2	4	6	5

Tab. 3 - Sorting results

NO.	1	2	3	4	5	6
Route	Hanzhuang-Xiqiaotou	Zhangkongzhuang-Qianlidian	Dongtian-Daguan	Tanzhuang-Nanlilou	Wanglin-Lizhuang	Qianfoge-Baziya
PCI	1	2	6	5	4	3
K_{PCI}	6	5	1	2	3	4
AADT	6	3	5	4	2	1
RCSP	1	2	4	3	6	5
LWDW	1	3	4	6	5	2
μ_i	2.75	2.85	4.35	4.05	3.9	3.1
Results	1	2	6	5	4	3

Tab .4 - Decision instance

Route	Maintenance order	Investment Benefit (¥10000)	Opportunity cost (¥10000)	Daily workload	Area (m^2)	maintenance costs (¥10000)	Highway technical condition index
Zhangkongzhuang-Qianlidian	2	20	23	112	44000	150	86
Qianfoge-Baziya	3	15	23	124	48000	115	81
Wanglin-Lizhuang	4	23	21	100	46000	155	85
Dongtian-Daguan	6	19	23	110	42000	145	82
Tanzhuang-Nanlilou	5	18	23	130	40000	140	83
Hanzhuang-Xiqiaotou	1	21	23	160	48000	150	82

The specific results are shown in Table 3.

Assuming the funds for rural roads maintenance is 6 million in Tengzhou city in 2008, due to the limited maintenance ability, it is possible to maintain 200,000m^2 at most, and meanwhile, it demands the daily maintenance workload with 500 person-days requirements after curing.

The specific conditions, such as opportunity cost, sort, workload, and so on, are shown in Table 4.

The objective function is:

$$\begin{cases} \min z_1 = 23x_1 + 23x_2 + 21x_3 + 23x_4 + 23x_5 + 23x_6 \\ \max z_2 = 86x_1 + 81x_2 + 85x_3 + 82x_4 + 83x_5 + 82x_6 \end{cases} \tag{5}$$

s.t

$$\begin{cases} 150x_1 + 115x_2 + 155x_3 + 145x_4 + 140x_5 + 150x_6 \le 600 \\ 44000x_1 + 48000x_2 + 46000x_3 + 42000x_4 + 40000x_5 + 48000x_6 \le 200000 \\ 112x_1 + 124x_2 + 100x_3 + 110x_4 + 130x_5 + 160x_6 \le 500 \end{cases} \tag{6}$$

In order to simplify the calculation process, the multi-objective 0~1 linear decision above can be converted into a single-objective 0~1 linear decision-making model.

The weight of the importance of the two objective functions is obtained from the exchange of views with the maintenance administrative department as follows:

$$\lambda_1 = 0.45, \ \lambda_2 = 0.55, \ \lambda_1 + \lambda_2 = 1 \tag{7}$$

The single objective plan after transformation is:

$$\max Z = 36.95x_1 + 34.2x_2 + 37.3x_3 + 34.75x_4 + 35.3x_5 + 34.75x_6 \tag{8}$$

Using the genetic algorithm to solve, the results are $x_1 = x_3 = x_4 = x_5 = 1$, $x_2 = x_6 = 0$, namely under the three constraints, four lines of Zhangkongzhuang-Qianlidian, Wanglin-Lizhuang, Dongtian-Daguan, and Tanzhuang–Nanlilou should be repaired, For this, on the basis of sorting, we can meet and satisfy the constraints to achieving the optimal decision strategy.

The required maintenance funds are $6 million, the opportunity cost is 900,000 yuan, and the overall technical status of the road network is 336.

According to the result of network level with decision-making and PCI, from the maintenance in the decision tree to select the corresponding maintenance countermeasures, the four lines, Zhangkongzhuang-Qianlidian, wanglin-Lizhuang, Dongtian-Daguan, Tanzhuang-Nanlilou, the maintenance strategy should be given the priority to daily maintenance.

5. Conclusion

This paper introduces the maintenance decision-making models of highway construction project under financial support, which include project maintenance management decision-making model and network maintenance management decision-making model. Take Tengzhou city for example to verify the fitness of different models, which can be given the maintenance strategy suited for project characteristics according to the model results.

Reference

1. Sun, S., Liu, C. (2016).Application of improved storage technology in Intelligent Transportation System. Advances in Transportation Studies,3,51–60
2. Cui wenbo. Research on the timing of preventive maintenance based on the decay of road performance]. Xi 'an: chang 'an university, 2011.
3. Ouyang Y, Madanat S. Optimal scheduling of rehabilitation activities for multiple road facilities: exact and approximate solutions. Transportation Research Part A: Policy and Practice, 2004, 38(5): 347-365.
4. Geoffroy D N, Shufon J J. Network-Level Road Management in New York State: A Goal-Oriented Approach. Transportation Research Record, 1992 (1344).
5. Teng J Y, Tzeng G H. A multi-objective programming approach for selecting non-independent transportation investment alternatives. Transportation Research Part B: Methodological, 1996, 30(4): 291-307.
6. Li Z, Sinha K. Methodology for multi-criteria decision making in highway asset management. Transportation Research Record: Journal of the Transportation Research Board, 2004 (1885): 79-87.
7. De la Garza J M, Drew D R, Chasey A D. PEER-REVIEWED PAPER Simulating Highway Infrastructure Management Policies. Journal of Management in Engineering, 1998, 14(5): 64-72.
8. Salem O, AbouRizk S, Ariaratnam S. Risk-based life-cycle costing of infrastructure rehabilitation and construction alternatives. Journal of Infrastructure Systems, 2003, 9(1): 6-15.
9. Jha M K, Abdullah J. A Markovian approach for optimizing highway life-cycle with genetic algorithms by considering maintenance of roadside appurtenances. Journal of the Franklin Institute, 2006, 343(4): 404-419.
10. Li Z. Stochastic optimization model and O (N 2) solution algorithm for highway investment decision making under budget uncertainty. Journal of Transportation Engineering, 2009, 135(6): 371-379.
11. Touran A, Gransberg D D, Molenaar K R, et al. Selection of project delivery method in transit: Drivers and objectives. Journal of Management in Engineering, 2010, 27(1): 21-27.
12. Bosurgi G, Trifirò F. A model based on artificial neural networks and genetic algorithms for road maintenance management. International Journal of Road Engineering, 2005, 6(3): 201-209.
13. Shanteau R M. Road management system: U.S. Patent Application 12/141,874[P]. 2008-6-18.
14. Zimmerman K A. Road management methodologies to select projects and recommend preservation treatments. Transportation Research Board, 1995.