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FACTORS CONTRIBUTING TO FREEWAY CRASHES AND COLLISIONS: SOME MEASURES AND FINDINGS ALONG TDM IMPLEMENTATION

Freeway plays an important role in economic and social development, especially for developing countries such as China, which is also an essential issue in TDM strategy. Therefore, proper infrastructure maintenance and management are significantly necessary. Currently, accident related factors and exact effect degree are mostly conducted by human observation. Automated operation would substantially improve the processing speed and accuracy of the key processing tasks, factor detection, classification and degreeing, since the human observation of the large amount of data is tedious, error-prone and time-consuming. 2003~2005 accident data is surveyed from two typical freeways, Jiqing and Dongqing, and then rear-end collision accident is divided into two patterns, namely rear-collision and stationary object collision. PCA (Principal Component Analysis) is induced to identify the effect level of different factors on above mentioned two types of collisions, which reduces the dimension of the image as well as keeping the most important features, and significant effect factors are identified by charting analysis and clustering research. The final investigation result indicates that fatigue driving, over-speeding, environmental factor, unsafe following, truck overload, and trunk driving, over-speeding, overcrowd, fatigue driving illegal overtaking, are main effect factors on rear collisions and stationary vehicle collisions, respectively. Preliminary experimental result presented in the following demonstrates that such a proposed method has potential to solve the identification and classification problem of factors contributing to freeway crashes and collisions.

Keyword: freeway; TDM strategy; rear-end collision; principal component analysis; effect factor

Nowadays, automobiles are pouring into general urban families and becoming a need for enjoying the convenience and short-cut of modern life directly brought by technological development. However, severe social problems, such as heavy traffic congestion, environmental pollution, and traffic accidents, etc, have become one of the central and heated issues, concomitancy with the increase of automobile, among which traffic accident especially attracts the world's attention. In China, for instance, it was officially announced that more than one million people lost lives in traffic accidents in 2003, in which random rear-end and side-wiping collisions, induced by too small vehicle following gap and brake distance, cover about one-third of the total amount.

To cope with this problem, a program on Intelligent Transportation System (ITS) has been proposed to increase road efficiency and decrease the negative effect of accident-related factors and other countermeasures, both administrative and technological, have also been adopted to investigate the rules and probability of traffic accidents [1,2]. During the research, rear-end collision is considered as the main accident pattern on freeway and its occurrence regulation is considered to be a key idea affecting investigation result and result implication, specially rear-end and side-wiping collision [3,4].

Taking the 2003~2005 freeway accident data surveyed from Jiqing Freeway and Dongqing Freeway into consideration, rear-end collision accident is divided into two patterns, including rear-collision and stationary object collision. Principal component analysis (PCA) is induced to identify the effect level of different factors on two types of rear-end collisions. Then, significant effect factors are detected and chosen by charting analysis and clustering research. Such a research would have a significant effect on the occurrence of stationary object collision, which provides a reference to Freeway management departments for TDM strategy.

1. Classification of Rear-end Collision Accidents on Freeway

According to accident pattern [5], freeway rear-end collision accidents are divided into two types, including rear collision, characterized by the collision between the head of following vehicle and the rear of leading vehicle. The other is stationary object collision, which occurs between the head of following vehicle and the rear of stationary vehicle parking around the road.

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Based on above definition, accident surveyed from Jiqing Freeway and Dongqing Freeway ranging from 2003 to 2005 is classified into two types, as listed in Table 1.

Four indicators of rear-end accident pattern distribution Table 1

Freeway	Accident type	Accident Count (Times)	Death (Persons)	Injury (Persons)	Economic loss ($\times 10^4$ Yuan RMB)
Jiqing	Rear-end collision	45	34	43	93.66
	Stationary vehicle collision	7	3	9	5.75
Dongqing	Rear-end collision	53	41	33	142.68
	Stationary vehicle collision	8	2	5	9.39

Equivalent number of accidents is introduced to analyze the seriousness of different patterns of freeway accidents.

$$ER_i = K_1 F_i + K_2 J_i + R_i \quad (1)$$

where ER_i is the equivalent number of the i^{th} rear-end accident. K_1 is the weight of dead persons in the i^{th} rear-end accident. K_2 is the weight of injured persons in the i^{th} rear-end accident. F_i is the statistical number of dead persons in the i^{th} rear-end accident. J_i is the statistical number of injured persons in the i^{th} rear-end accident. R_i is the accident number of the i^{th} rear-end accident.

For the sake of simplicity [6], the weight k_1 of dead person is considered as 2.0 and the corresponding injured k_2 as 1.5. From Table 1, the equivalent numbers of each rear-end accident pattern on Jiqing Freeway are obtained as $ER_1 = 177.5$, $ER_2 = 26.5$ and the same result for Dongqing Freeway is $ER_1 = 184.5$, $ER_2 = 19.5$. Therefore, rear-end collision is the main accident pattern among freeway accidents.

2. Process of Principal Component Analysis Method

To distinguish the effect degree of above-mentioned factors for Freeway rear-end collision [7], principal components analysis method, which is a kind of statistical analysis method transferring a few of indicators into some main indicators, is used to analyze the effect degree. According to its working theory, the calculation process is divided into the following six steps [8].

(1) Data Preparation

The statistical accident data is recorded as:

$$X = \begin{bmatrix} X_1 \\ X_2 \\ \vdots \\ X_n \end{bmatrix} = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1p} \\ x_{21} & x_{22} & \cdots & x_{2p} \\ \vdots & \vdots & & \vdots \\ x_{n1} & x_{n2} & \cdots & x_{np} \end{bmatrix} \quad (2)$$

(2) Data standardization

Accident data is standardized by Z - score as:

$$x_{ij}^* = (x_{ij} - \bar{x}_j) / \sigma_j \quad (i = 1, 2, \dots \text{ and } j \Rightarrow 1, 2, \dots, p) \quad (3)$$

where:

$$\bar{x}_j = \sum_{i=1}^n x_{ij} / n \quad (t = 1, 2, \dots, n) \quad (4)$$

$$\sigma_j^2 = \frac{1}{n-1} \sum_{i=1}^n (x_{ij} - \bar{x}_j)^2 \quad (t = 1, 2, \dots, n) \quad (5)$$

(3) Correlation coefficient matrix R determination

$$R = (r_{ij})_{p \times p} \quad (6)$$

where

$$r_{ij} = \frac{1}{n-1} \sum_{i=1}^n x_{ii}^* \square x_{ij}^* \quad (i = 1, 2, \dots, \text{ and } j \Rightarrow 1, 2, \dots, p) \quad (7)$$

(4) Eigenvalues and eigenvectors of R

If eigenvalues comply with $\lambda_1 \geq \lambda_2 \geq \dots \geq \lambda_p \geq 0$, a_1, a_2, \dots, p is the corresponding Orthogonal unit eigenvector, then the i^{th} PCA of vector X is defined as:

$$Z_i = a_i^T X \quad (i = 1, 2, \dots, n) \quad (8)$$

where Z_1 is named as the first principal component of investigated vector.

(5) Contribution rate of PCA

$$G(m) = \sum_{i=1}^m \lambda_i / \sum_{i=1}^p \lambda_i \quad (i = 1, 2, \dots, n) \quad (9)$$

(6) Result analysis

According to the analysis result, accident causes could be investigated.

3. Principal Components Analysis of Accident Effect Factor

The purpose of analyzing the effect factors is to make the quantitative analysis of the relation between each factor and the occurrence probability of rear-end collision and detect the main factors, which will provide a research basis [9].

3.1 Rear-end accidents

Four indicators of rear-end collision on Jiqing Freeway and Dongqing Freeway are surveyed over the time of 2003-2005, the result is obtained by principal components analysis method as the following.

(1) Eigenvalues and eigenvectors

$$\lambda_1 = 3.6232, \lambda_2 = 0.1837, \lambda_3 = 0.0627, \lambda_4 = 0.0329$$

The eigenvector of λ_1 is $Z_1 = (0.5121 \square 0.5246 \square 0.4678 \square 0.4905)$.

(2) Contribution rate of PCA

Suppose $m = 1$, then the contribution rate of PCA can be calculated by Eq (9):

$$G(1) = \sum_{i=1}^m \lambda_i / \sum_{i=1}^p \lambda_i = 0.9189 > 80\% \quad (10)$$

The result is more than 80 percent and indicates the feasibility of characterizing the four indicators with a comprehensive one.

(3) Analysis result

The effect force of each factor can be judged by Eq (8):

$$Z_1 = 0.5121X_1 + 0.5246X_2 + 0.4678X_3 + 0.4905X_4 \quad (11)$$

where X_i is the standardized accident data as listed in Table 2.

Four standardized indicators and evaluation data of effect factors

Table 2

ID	Effect factor	Accident count (X_1)	Dead toll (X_2)	Injuries (X_3)	Losses (X_4)	Evaluation (Z_1)
1	Over-speeding	1.9544	1.5643	2.0604	0.8278	3.2088
2	Drunk	-0.5113	-0.6187	-0.6953	-0.5824	-1.2033
3	Fatigue	1.7399	2.2537	1.8399	2.6069	4.2116
4	Truck overload	-0.1897	-0.0442	0.2968	0.7024	0.3725
5	Overcrowd	-0.5113	-0.5038	-0.5873	-0.6766	-1.1365
6	Illegal overtaking	-0.6185	-0.6187	-0.5851	-0.5711	-1.1938
7	Illegal parking	-0.8329	-0.6187	-0.6953	-0.7029	-1.4230
8	Unsafe following	0.5608	0.1856	0.0763	0.3245	0.5730
9	Illegal lane-change	-0.61848	-0.6187	-0.5851	-0.6615	-1.2415
10	Brake misconduct	-0.2969	-0.5038	-0.3646	0.0091	-0.5826
11	Vehicle effect	0.7752	0.7601	0.5172	-0.0116	1.0314
12	Pavement	-0.8329	-0.6187	-0.6953	-0.7029	-1.4229
13	Environmental factor	-0.6185	-0.6187	-0.5851	-0.5617	-1.1938

3.2 Effect factors of stationary vehicle collision

Four indicators of stationary vehicle collision on Jiqing Freeway and Dongqing Freeway are surveyed over the time of 2003–2005, and the result is obtained by principal components analysis method as

(1) Eigenvalues and eigenvectors

$\lambda_1 = 3.6050, \lambda_2 = 0.3904, \lambda_3 = 0.0045, \lambda_4 = 0.0002$

The eigenvector of λ_1 is $Z_1 = (0.5265 \square 0.4505 \square 0.4965 \square 0.5228)$

(2) Contribution rate of PCA

Supposing $m = 1$, then the contribution rate of PCA can be calculated by Eq (9)

$$G(1) = \sum_{i=1}^m \lambda_i / \sum_{i=1}^p \lambda_i = 0.9012 > 80\% \quad (12)$$

The result is more than 80% and indicates the feasibility of characterizing the four indicators with a comprehensive one.

(3) Analysis result

The effect force of each factor can be judged by Eq (8) as

$$Z_1 = 0.5265X_1 + 0.4505X_2 + 0.4965X_3 + 0.5228X_4 \quad (13)$$

where X_i is the standardized accident data as listed in Table 3.

Four standardized indicators and evaluation data of effect factors

Table 3

ID	Effect factor	Accident count (X_1)	Dead toll (X_2)	Injuries (X_3)	Losses (X_4)	Evaluation (Z_1)
1	Over-speeding	2.6524	1.3293	3.0077	2.8108	4.9582
2	Drunk	-0.4443	-0.4921	-0.3454	-0.4229	-0.8483
3	Fatigue	1.3262	2.2387	0.7734	1.0829	2.6570
4	Truck overload	-0.4412	-0.4887	-0.3431	-0.4201	-0.8424
5	Overcrowd	-0.4372	-0.4843	-0.3399	-0.4163	-0.8348
6	Illegal overtaking	-0.4474	-0.4956	-0.3478	-0.4259	-0.8542
7	Illegal parking	0.4315	1.2973	-0.3354	0.3074	0.8058
8	Unsafe following	-0.3974	-0.4402	-0.3090	-0.3783	-0.7588
9	Illegal lane-change	-0.4461	-0.4941	-0.3468	-0.42468	-0.8517
10	Brake misconduct	-0.4279	-0.4741	-0.3327	-0.4074	-0.8171
11	Vehicle effect	-0.4292	-0.4755	-0.3337	-0.4087	-0.8196
12	Pavement	-0.4871	-0.5395	-0.3787	-0.4637	-0.9301
13	Environmental factor	-0.4142	-0.4588	-0.3221	-0.3944	-0.7909

4 Effect Factor Choice

The purpose of analyzing the effect factors is to make the quantitative analysis of effect factors on rear-end collisions with the calculation result of evaluation indicators, which will provide the

basis for the relation judgment between each factor and the occurrence probability of rear-end collision.

4.1 Effect factor of rear-end accidents

Using charts and cluster analysis methods to choose the effect factors behind the accident, then the main effect factors can be selected.

(1) Chart method

The chart is a more commonly used method with the simple, direct, easy to understand features. Effect factors acquired by principal component analysis are sorted according to size, then the evaluation index chart is drawn, as shown in Fig. 1.

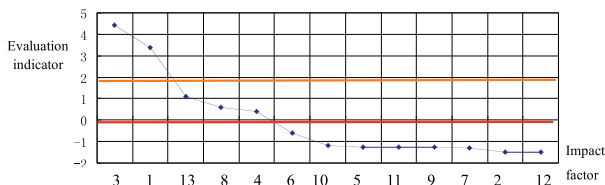


Fig. 1 Effect factor evaluation on rear-end collision on freeway

From Fig. 1, design elements are divided into three types according to the curve trend, then 0 and 2 are chosen as thresholds.

(2) Clustering analysis

The basic idea of clustering analysis is to classify each research object in a category and combine the two that are most similar with each other, then calculate the distance and similarity between a new category and other categories. This process continues until all objects are classified as a category.

With SPSS, Fig. 3 shows the result of clustering analysis.

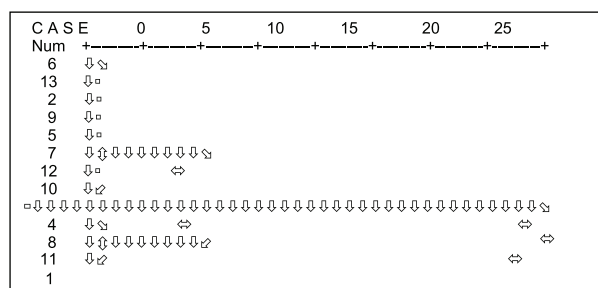


Fig. 2 Hierarchical clustering result

Supposing the linking level is 5, then effect factors on rear-end accidents are classified into three types by Fig. 2.

(3) Result analysis

By chart analysis in Fig. 1, three types are acquired. The first is fatigue driving and over-speeding and the second includes environmental factor, unsafe following, and truck overload.

With clustering analysis, three types are also acquired. The first is fatigue driving and over-speeding and the second is vehicle factors, unsafe following distance, and truck overload. Then the third includes improper brake, passenger overloading, illegal overtaking, environmental factors, drunk driving, illegal lane-change and pavement conditions.

The analysis result indicates their consistency. To the comprehensive analysis, the outstanding five effect factors are chosen as fatigue driving, over-speeding, vehicle factors, unsafe following distance and vehicle overload.

4.2 Effect factor of stationary vehicle collision

Using charts and cluster analysis methods to choose the effect factors behind the accident, then the main effect factors can be selected.

(1) Chart method

Effect factors acquired by principal component analysis are sorted according to size, then the evaluation index chart is drawn, as shown in Fig. 3.

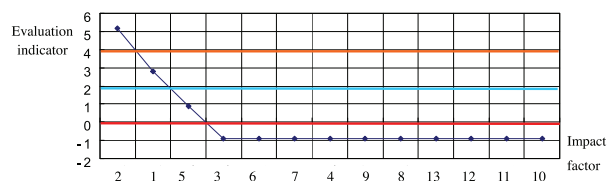


Fig. 3 Effect factor evaluation on stationary vehicle collision on freeway

From Fig. 1, design elements are divided into four types according to the curve trend, then 4, 2 and 0 are chosen as thresholds.

(2) Clustering analysis

With SPSS, Fig. 4 shows the result of clustering analysis.

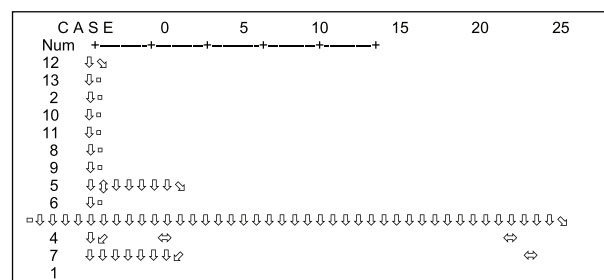


Fig. 4 Hierarchical clustering result

Supposing the linking level is 5, then effect factors on rear-end accidents are classified into four types by Fig. 4.

(3) Analysis result

By chart analysis in Fig. 3, four levels are acquired. The first is trunk driving, the second is over-speeding, the third is overcrowd, and the forth includes fatigue driving, illegal overtaking, illegal parking, truck overload, illegal lane-change, unsafe following, environmental factors, pavement, vehicle effect, and brake misconduct.

With clustering analysis, four types are also acquired. The first is over-speeding driving, the second is fatigue driving, the third is illegal parking and the forth includes improper brake, passenger overloading, illegal overtaking, environmental factors, drunk driving, illegal lane-change and pavement conditions, vehicle factors, unsafe following distance and truck overload. The analysis result indicates their consistency. To the comprehensive analysis, the outstanding three effect factors are chosen as over-speeding, fatigue driving and illegal parking.

5. Conclusion

Evaluation indicators are investigated to analyze the effect factors on rear-end accident and stationary vehicle collision by the principal component analysis method. Our preliminary data shows that based on the methodology integrated with PCA algorithm, the accident features could be effectively extracted and the effect factors can be classified with a promising accuracy. By chart comparison and clustering analysis, the main effect factors on rear-end accident on freeway are identified as fatigue driving, over-speeding, environmental factor, unsafe following, and truck overload. However, trunk driving, over-speeding, overcrowd, fatigue driving and illegal overtaking are detected as the main effect factors on stationary vehicle collision on freeway. Further work will consider other feature extraction techniques combined with SVM model.

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