THE ANALYSIS OF HUMAN AND VEHICLE FACTORS FOR TAIWAN FREEWAY TRAFFIC ACCIDENTS

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Abstract：The increasing freeway traffic accidents in Taiwan have forced Taiwan Area National Freeway Bureau to find out what are the major factors to lead to these accidents. Although some factors, such as traffic regulation enforcement, vehicle and road conditions, the traffic composition and drivers behaviors, have been qualitatively or quantitatively discussed in the past, it is not easy to obtain a clear and whole picture due to the incomplete information and the interaction among these factors. According to the current freeway accident data, most of them are number of accidents, injuries and deaths, and some of them are related to the causes of accidents. Because of this, the purpose of this paper aims to analyze the human and vehicle factors for Taiwan freeway traffic accidents under the condition of incomplete information. As the grey system theory could deal with the problems with incomplete or unknown information and also the small samples, this paper uses the grey relation method to analyze the main factors and uses GM (1,N) model to predict the trend in the case study of Taiwan freeway accidents. The results of the empirical analysis show that speeding is the key factor of traffic accidents, followed by failing to keep a safe distance and driving with alcohol. These findings could help traffic regulation enforcement with limited resources.

Key words: freeway accidents, grey relation analysis, grey prediction, factors.

1.INTRODUCTION

The freeway system in Taiwan has been playing an important role in stimulating regional economic development since the first Sun Yet-Sen freeway has transport service in 1978. However, with an average traffic volume growth rate of 4.75% annually, the accident rate of freeway system in Taiwan has grown and far exceeded that in Western developed countries. This can be attributed to the increase of traffic volume and poor road safety management as well as lax traffic regulations enforcement. It is predictable that the rising car ownership in Taiwan will contribute to the increasing traffic accident rate on freeways. In order to reduce the social cost incurred by such accidents, it is necessary to take a closer look into the major causes.

Since the freeway system is constituted with numerous factors and conditions complicatedly, the occurrences of traffic accidents are often closely related to human factors, vehicle factors and road environment factors. The complicated correlation among these key elements, in particular the randomness of the superficial outcomes or changes, may easily obscure the very nature of these accidents. As a result, accident analysts, while conducting analyses and making decisions, are often denied sufficient information that can help them obtain precise judgment of the accident causes. The current statistical technique on accidents analysis only reveals partial information about the system, e.g., the numbers and casualties of accidents. A problem like this, where partial information is known and the rest unknown, would be treated and termed as a grey system. The traditional methods of analysis like regression analysis or other mathematical statistical approaches that aim to analyze the relationship among and the trend of certain data. All these methods require a tremendous sample size, which proves a daunting task as far as the acquisition of accident samples is concerned. Such a shortcoming on the traditional methods of analysis can be overcome by the grey relation analysis since it could be conducted and explored with a small amount of data.

Considering of the above, this study attempts to analyze the statistics on major causes of accidents on freeways in Taiwan between 1992 and 2001 with both the grey relation analysis and GM(1,N) model. It is hoped that we could more understand the major causes of accidents and provide future references for the authorities to scheme better traffic law enforcement duties with limited enforcing officers.

2. LITERATURE REVIEW

The freeway system in Taiwan is managed and maintained by Taiwan Area National Freeway Bureau. According to the Bureau annual statistics on traffic accidents (Taiwan Area National Freeway Bureau, 2002), all accident causes are reported by highway patrol in a uniform accident investigation form and divided into only ten categories. Such information is not enough to facilitate further analyses of these accidents. It is difficult to use these insufficient data to conduct further research into the causes of accidents on freeways.

In recent years, researchers in Taiwan have started to try looking into what caused accidents on freeways and all relevant factors. Lan and Chi (1996) had discussed on the relationship of accident characteristics and accident severity used by a generalized linear model in one-way and two-way multi-variate analysis of variance analysis. Sun (1998) had used the number of accidents, number of fatality and injury of Sun Yeh-Sen freeway in 1991 to 1996, and analyzed on the case of different situations of weather, time in a day, location, vehicle type and accident causes. Cheng, *et al.* (2002) had used chi-square automatic interaction detection (CHAID) technique to explore the influence of vehicle type, geometric design (curve, grade, etc.), traffic conditions (traffic volume, large vehicle composition, etc.) on accident rate of single vehicle accident of Sun Yeh-Sen freeway. These researches directed some human, environmental and vehicle factors are significant influenced on traffic accident on freeway.

This study applies grey system theory, which has been successfully applied to many academic research projects. Researchers in Taiwan have also begun to adopt this methodology in recent years. Grey relation theory has been widely used to identify the important indicators on transportation academic research. For instance, the identification and selection of evaluation indicators for taxi service quality (Chou and Tseng, 2000; Chou, 2002), the selection of representative indicators for operational and financial performances in air transportation industry (Feng and Wang, 2001), and the selection of assessment criteria for grade-separated railroad (Chang and Cheng, 1997). Besides, it has also been employed to explore the change-order causes in public works (Wu, *et al.*, 2001), the study on backing up a simulated truck (Chang and Lu, 2001), the analysis between the characteristics of car drivers and the accident probability (Yang, 2000), and so on. However, there are still few researches have incorporated grey system theory into road safety analyses, and that is why this study attempts use this methodology to focus on freeway accidents.

3. GREY SYSTEM THEORY

Grey system theory is introduced by Prof. Teng Ju-long of Huazhong University of Science and Technology (Teng, 1992). It combines mathematics with the general system theory, information theory, decision-making and control perspectives so as to solve the problem under insufficient information. Grey relation analysis is used to discover where there is consistency between the changing trends of two factors or not, and to find out the possible mathematical relationship among the factors or in the factors themselves. Grey system theory can be explained as follows.

3.1 Grey Relation Analysis

Grey relation analysis compares geometrical shapes of several curves. The more similar their geometrical shapes are, the more alike the changing trends of the factors are, and the more related they are. Grey relation analysis is therefore a influence measure model characterized by the following features:

(1) There is no strict request for the sample size;
(2) The model built thereof is a non-functional serial model;
(3) The computation method is rather simple;
(4) It does not request the serial data to be normal distribution;
(5) It does not produce conclusions contradictory to those of qualitative analyses.

Grey relation must meet the four rationales and the requests for symmetry and even function, integrity as well as proximity. Mathematically, Grey relation is defined as follow:

Where X is the factor group of the grey relation,

$$X = \{x_i \mid i \in I, I = \{1,2,...,m\}, \ \mathrm{m} \geqq 2, x_i = (x_i(1), x_i(2),..., x_i(n)), \\ x_i(k) \in x_i, k \in K, K = \{1,2,...,n\}, n \geq 3\} \quad (1)$$

In Eq. (1), $x_0 \in X$ is the reference series (reference factor) and $x_i \in X$ is the comparative series (comparative factor). $x_0(k)$ and $x_i(k)$ are respectively the data of x_0 and x_i at the point k. If there is a non-negative real number $r(x_0(k), x_i(k))$ that is the comparative measure of $x_0(k)$ and $x_i(k)$ with X under certain circumstances, and the non-negative real number $r(x_0, x_i)$ turns out to be the average value of $r(x_0(k), x_i(k))$, i.e. Eq. (2), then the following four conditions must be satisfied:

$$r(x_0, x_i) = \frac{1}{n}\sum_{k=1}^{n} r(x_0(k), x_i(k)) \quad (2)$$

(1) Normalization

$$0 < r(x_0, x_i) < 1, \\ r(x_0, x_i) = 1 \Leftrightarrow x_0 = x_i, \\ r(x_0, x_i) = 0 \Leftrightarrow x_0, x_i \in \varnothing \quad (3)$$

Grey relation is between 0 and 1. If it is equal to 1 means these two series are identical. If it is equal to 0 means these two series are independent.

(2) Symmetry

$$x, y \in X, r(x, y) = r(y, x) \Leftrightarrow X = \{x, y\} \quad (4)$$

(3) Integrity

$$x_j, x_i \in X = \{x_\sigma | \sigma = 1,2,\ldots,n\}, n \geq 2 \qquad r(x_i, x_j) \underset{often}{\neq} r(x_j, x_i) \tag{5}$$

(4) Proximity

$|x_0(k) - x_i(k)|$ is more smaller, the grey relation $r(x_0(k), x_i(k))$ is more larger.

In that case, $r(x_0, x_i)$ represents the grey relation of factor x_0 relative to factor x_i, noted as $r_{0,i}$ for short, which represents

$$r_{0,i} = \frac{1}{n}\sum_{k=1}^{n} \xi_i(k) \tag{6}$$

Where,

$$\xi_i(k) = \frac{\min_{i\in N}\min_{k\in K}|x_0(k) - x_i(k)| + \zeta \max_{i\in N}\max_{k\in K}|x_0(k) - x_i(k)|}{|x_0(k) - x_i(k)| + \zeta \max_{i\in N}\max_{k\in K}|x_0(k) - x_i(k)|} \tag{7}$$

$\xi_i(k)$ is the grey relation parameter which $\zeta \in [0,1]$ and so called the distinguished coefficient, is generally set at 0.5. Theis function is to adjust the influence of the comparative environment; that is, to shrink the comparative environment. When $\zeta = 0$, the environment disappears; when $\zeta = 1$, the environment is maintained intact. Figure 1 is the flow chart of the grey relation analysis.

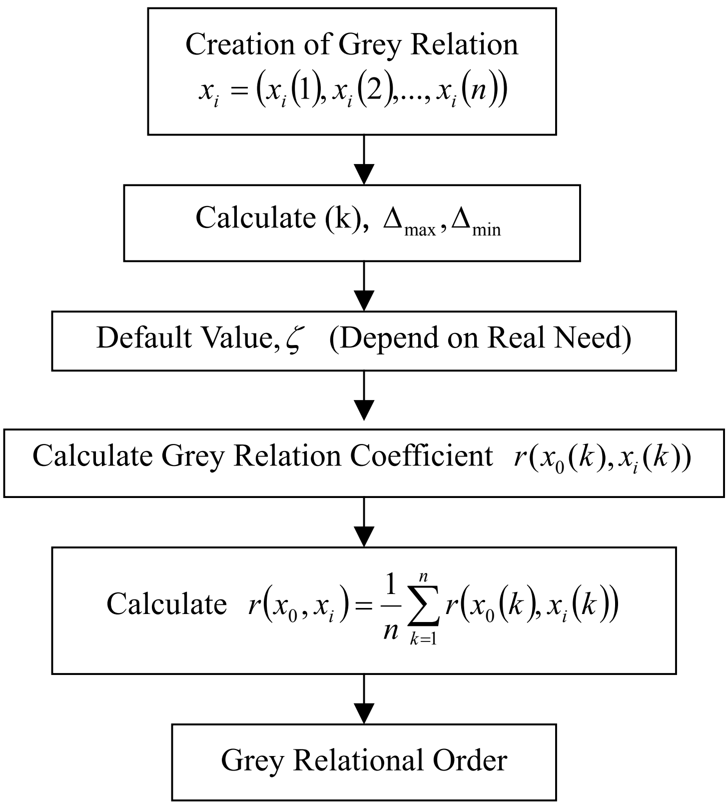

Figure 1. The Flow Chart of the Grey Relation Analysis

3.2 Accumulated Generating Operation

In the grey system theory, accumulated generating operation (AGO) is one important part of the general models. The following description is a brief introduction of AGO.

Where $x^{(0)}$ is an original series, i.e.,

$$x^{(0)} = (x^{(0)}(1), x^{(0)}(2),..., x^{(0)}(n)) = (x^{(0)}(k); k = 1,2,..., n) \tag{8}$$

$x^{(1)}$ is defined as AGO series of order one on $x^{(0)}$, and the mathematical equation could be displayed as follows:

$$\text{AGO}\{\ x^{(0)}(k)\ \} = x^{(1)}(k) = \left[\sum_{k=1}^{1} x^{(0)}(k), \sum_{k=1}^{2} x^{(0)}(k), ..., \sum_{k=1}^{n} x^{(0)}(k)\ \right] \tag{9}$$

Take an example, as Figure 2 illustrates, the curve changes from an up-and-down trend to a strict and monotonous increase by degree due to AGO process.

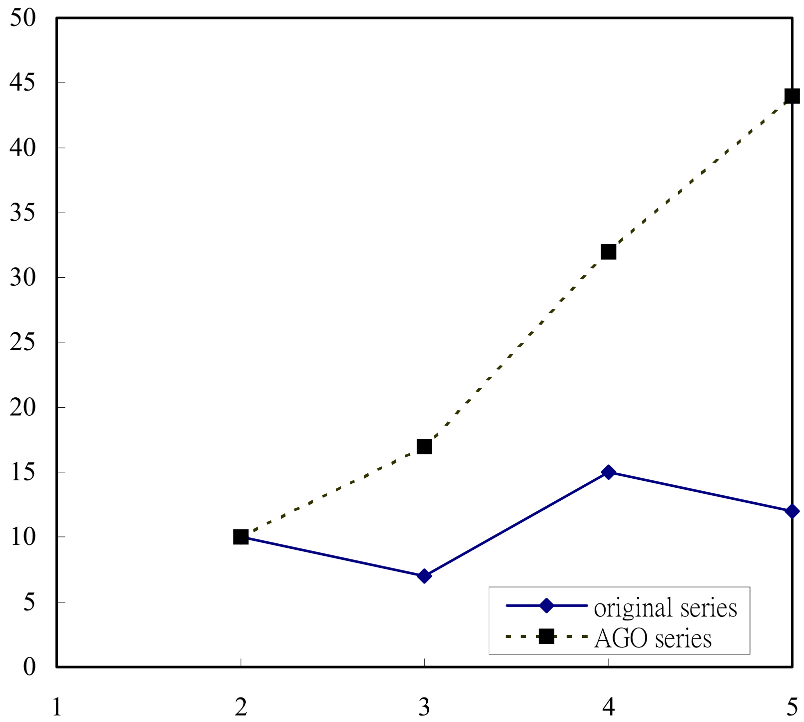

Figure 2. Demonstration of AGO Process

3.3 GM (1, N) Model

The analysis of GM (1, N) model is based on the grey system theory, and might be used for a comprehensive study of the input and output of the system. In addition, it helps to explore the changes of each link of the system. Therefore, the relationship among the factors in the GM (1, N) model might be treated as another grey relation analysis of the system. The analysis involves the following steps.

Step 1: Build the original series

$$x_1^{(0)} = \{\ x_1^{(0)}(1), x_1^{(0)}(2),..., x_1^{(0)}(k)\ \}$$

$$x_2^{(0)} = \{\ x_2^{(0)}(1), x_2^{(0)}(2), ..., x_2^{(0)}(k)\ \}$$

…

$$x_N^{(0)} = \{\ x_N^{(0)}(1), x_N^{(0)}(2), ..., x_N^{(0)}(k)\ \} \tag{10}$$

where, $k = 1,2,...,n$

Step 2: Build the AGO series

$$x_1^{(1)} = \{\ x_1^{(1)}(1), x_1^{(1)}(2), ..., x_1^{(1)}(k)\ \}$$

$$x_2^{(1)} = \{\ x_2^{(1)}(1), x_2^{(1)}(2), ..., x_2^{(1)}(k)\ \}$$

…

$$x_N^{(1)} = \{\ x_N^{(1)}(1), x_N^{(1)}(2), ..., x_N^{(1)}(k)\ \} \tag{11}$$

where, $k = 1,2,...,n$

Step 3: Create the standard equation

In accordance with the GM (1,N) model, the equations behind AGO are combined as:

$$x_1^{(0)}(k) + az_1^{(1)}(k) = \sum b_i x_i^{(1)}(k) \tag{12}$$

where,

$$z_1^{(1)}(k) = 0.5x_1^{(1)}(k) + 0.5x_1^{(1)}(k-1)\ \text{, k} \geqq 2 \tag{13}$$

Step 4: Solution solving

All resultant numerical values are then put into Eq. (12) and the results will be:

$$x_1^{(0)}(2) + az_1^{(1)}(2) = b_2 x_2^{(1)}(2) + b_3 x_3^{(1)}(2) + ... + b_N x_N^{(1)}(2)$$

$$x_1^{(0)}(3) + az_1^{(1)}(3) = b_2 x_2^{(1)}(3) + b_3 x_3^{(1)}(3) + ... + b_N x_N^{(1)}(3)$$

…

$$x_1^{(0)}(n) + az_1^{(1)}(n) = b_2 x_2^{(1)}(n) + b_3 x_3^{(1)}(n) + ... + b_N x_N^{(1)}(n) \tag{14}$$

The above equations are then converted into a matrix form.

$$\begin{bmatrix} x_1^{(0)}(2) \\ x_1^{(0)}(3) \\ ... \\ x_1^{(0)}(n) \end{bmatrix} = \begin{bmatrix} -z_1^{(1)}(2) & x_2^{(1)}(2) & ... & x_N^{(1)}(2) \\ -z_1^{(1)}(3) & x_2^{(1)}(3) & ... & x_N^{(1)}(3) \\ ... & ... & ... & ... \\ -z_1^{(1)}(n) & x_2^{(1)}(n) & ... & x_N^{(1)}(n) \end{bmatrix} \begin{bmatrix} a \\ b_2 \\ ... \\ b_N \end{bmatrix} \tag{15}$$

According to ordinary least square (OLS) process, where

$$y_N = [x_1^{(0)}(2), x_1^{(0)}(2), ... x_1^{(0)}(n)]^T \tag{16}$$

$$B = \begin{bmatrix} -z_1^{(1)}(2) & x_2^{(1)}(2) & \dots & x_N^{(1)}(2) \\ -z_1^{(1)}(3) & x_2^{(1)}(3) & \dots & x_N^{(1)}(3) \\ \dots & \dots & \dots & \dots \\ -z_1^{(1)}(n) & x_2^{(1)}(n) & \dots & x_N^{(1)}(n) \end{bmatrix} \tag{17}$$

$$\hat{a} = [a, b_2, \dots, b_N]^T \tag{18}$$

Solution solving by Eq. (19), the relations between the main affecting factors and the relationships with other factors will be found.

$$\hat{a} = B^T \left(BB^T\right)^{-1} y_N \tag{19}$$

4. AN EMPIRICAL STUDY OF TAIWAN

In order to identify the major factors that contribute to freeway traffic accidents, this study first conducts a descriptive statistical analysis on major causes of traffic accidents on freeways in Taiwan from 1992 to 2001 (Taiwan Area National Freeway Bureau, 2002). According to the statistics, the causes include motorist-related factors such as failing to keep a safe distance, improper loading, speeding, improper driving, driving with alcohol, pedestrian walking on freeway, long time driving, and vehicle-related factors such as vehicle mechanical breakdown, flat tires and others. This study will not look into factors related to road environment for now because of the lack of proper data. Moreover, changes in time and space have resulted in new violations of traffic rules by highway users. So this study takes a step further by building a GM (1,N) model for the above-mentioned ten causes so as to observe any changes or trends inherent in these major factors of traffic accidents. Finally, the two approaches of analysis are synthesized to find out their common main elements in traffic accidents so as to serve as future reference for the authorities to scheme better traffic law enforcement with limited resources.

4.1 The Current Status of Traffic Accidents on Taiwan Freeways

Since freeways are characterized by high driving speed, divided lanes and controlled entry and exit, the types of traffic accidents are different from those on ordinary public roads. Table 1 shows the statistics on traffic accident causes on freeways in Taiwan between 1992 and 2001. The ten causes are represented by variables such as x_1, x_2, ..., and x_{10}. All traffic accidents occurred during the ten years are compiled and listed in Table 2.

Table 1. Traffic Accident Causes of Taiwan Freeways during 1992-2001

Accident causes	Percentage (%)
Failing to keep a safe distance, (x_1)	18
Flat tires, (x_2)	6
Speeding, (x_3)	7
Improper driving, (x_4)	35
Improper loading, (x_5)	0.4
Driving with alcohol, (x_6)	9
Long time driving, (x_7)	3
Vehicle mechanical breakdown, (x_8)	0.6
Pedestrian walking on freeways, (x_9)	2
Others, (x_{10})	18
Total	100

Table 2. Trend of Traffic Accidents of Taiwan Freeways from 1992 to 2001

Year / Accident causes	1992 (k=1)	1993 (k=2)	1994 (k=3)	1995 (k=4)	1996 (k=5)	1997 (k=6)	1998 (k=7)	1999 (k=8)	2000 (k=9)	2001 (k=10)	Total
x_1	44	53	51	31	53	42	52	23	19	14	382
x_2	8	13	20	17	15	13	19	8	5	2	120
x_3	5	3	14	21	30	27	15	16	15	5	151
x_4	133	92	118	103	96	63	57	45	19	19	745
x_5	1	3	1	0	1	3	0	0	0	0	9
x_6	14	12	14	24	27	26	27	25	15	16	200
x_7	7	6	14	7	10	10	2	4	4	0	64
x_8	3	3	3	1	2	1	0	0	0	0	13
x_9	7	10	6	7	5	4	7	3	0	0	49
x_{10}	34	23	37	50	36	37	58	46	30	34	385
Total(x_0)	256	218	278	261	275	226	237	170	107	90	2118

4.2 Grey Relation Analysis

Table 2 lists all original data. Suppose all these factors are given on the same weighting. This study takes the total number of accidents in each year to be the reference series x_o, and all the other factors including failing to keep a safe distance (x_1), flat tires (x_2), speeding (x_3), improper driving (x_4), improper loading (x_5) driving with alcohol (x_6), long time driving (x_7), vehicle mechanical breakdown (x_8), pedestrians walking on freeways (x_9), and others (x_{10}) to be the comparative series. A partial grey relation analysis is then conducted to recognize which are the main causes to freeway traffic accidents. In this process, it helps to find out the degree of correlation between the comparative series and the reference series. The greater of correlation, the more closely related the factor(s) are to the occurrence of traffic accidents. The analytical procedure involves the following steps:

Step 1: Arrange the original series data to process the grey relation analysis.

Step 2: Find the difference series under $\Delta oi(k) = \left| x_0(k) - x_i(k) \right|$, where i, k =1, 2, 3….10.

(a) $\triangle_{01}(1)=212$ $\triangle_{01}(2)=165$ $\triangle_{01}(3)=227$ $\triangle_{01}(4)=230$ $\triangle_{01}(5)=222$

$\triangle_{01}(6)=184$ $\triangle_{01}(7)=185$ $\triangle_{01}(8)=147$ $\triangle_{01}(9)= 88$ $\triangle_{01}(10)= 76$

(b) $\triangle_{02}(1)=248$ $\triangle_{02}(2)=205$ $\triangle_{02}(3)=258$ $\triangle_{02}(4)=244$ $\triangle_{02}(5)=260$

$\triangle_{02}(6)=213$ $\triangle_{02}(7)=218$ $\triangle_{02}(8)=162$ $\triangle_{02}(9)=102$ $\triangle_{02}(10)= 88$

(c) $\triangle_{03}(1)=251$ $\triangle_{03}(2)=215$ $\triangle_{03}(3)=264$ $\triangle_{03}(4)=240$ $\triangle_{03}(5)=245$

$\triangle_{03}(6)=199$ $\triangle_{03}(7)=222$ $\triangle_{03}(8)=154$ $\triangle_{03}(9)= 92$ $\triangle_{03}(10)= 85$

(d) $\triangle_{04}(1)=123$ $\triangle_{04}(2)=126$ $\triangle_{04}(3)=160$ $\triangle_{04}(4)=158$ $\triangle_{04}(5)=182$

$\triangle_{04}(6)=163$ $\triangle_{04}(7)=180$ $\triangle_{04}(8)=125$ $\triangle_{04}(9)= 88$ $\triangle_{04}(10)= 71$

(e) $\triangle_{05}(1)=255$ $\triangle_{05}(2)=215$ $\triangle_{05}(3)=268$ $\triangle_{05}(4)=261$ $\triangle_{05}(5)=248$

$\triangle_{05}(6)=223$ $\triangle_{05}(7)=237$ $\triangle_{05}(8)=170$ $\triangle_{05}(9)=107$ $\triangle_{05}(10)= 90$

(f) $\triangle_{06}(1)=242$ $\triangle_{06}(2)=206$ $\triangle_{06}(3)=264$ $\triangle_{06}(4)=237$ $\triangle_{06}(5)=248$

$\triangle_{06}(6)=200$ $\triangle_{06}(7)=210$ $\triangle_{06}(8)=145$ $\triangle_{06}(9)=92$ $\triangle_{06}(10)=74$

(g) $\triangle_{07}(1)=249$ $\triangle_{07}(2)=212$ $\triangle_{07}(3)=264$ $\triangle_{07}(4)=254$ $\triangle_{07}(5)=265$

$\triangle_{07}(6)=216$ $\triangle_{07}(7)=235$ $\triangle_{07}(8)=166$ $\triangle_{07}(9)=103$ $\triangle_{07}(10)=90$

(h) $\triangle_{08}(1)=253$ $\triangle_{08}(2)=215$ $\triangle_{08}(3)=275$ $\triangle_{08}(4)=260$ $\triangle_{08}(5)=273$

$\triangle_{08}(6)=225$ $\triangle_{08}(7)=237$ $\triangle_{08}(8)=170$ $\triangle_{08}(9)=107$ $\triangle_{08}(10)=90$

(i) $\triangle_{09}(1)=249$ $\triangle_{09}(2)=208$ $\triangle_{09}(3)=272$ $\triangle_{09}(4)=254$ $\triangle_{09}(5)=270$

$\triangle_{09}(6)=222$ $\triangle_{09}(7)=230$ $\triangle_{09}(8)=167$ $\triangle_{09}(9)=107$ $\triangle_{09}(10)=90$

(j) $\triangle_{010}(1)=222$ $\triangle_{010}(2)=195$ $\triangle_{010}(3)=241$ $\triangle_{010}(4)=211$ $\triangle_{010}(5)=239$

$\triangle_{010}(6)=189$ $\triangle_{010}(7)=179$ $\triangle_{010}(8)=124$ $\triangle_{010}(9)=77$ $\triangle_{010}(10)=226$

The followings are shown in vector form obtained above:

$\triangle_{01}=$ (212, 165, 227, 230, 222, 184, 185, 147, 88, 76)

$\triangle_{02}=$ (248, 205, 258, 244, 260, 213, 218, 162, 102, 88)

$\triangle_{03}=$ (251, 215, 264, 240, 245, 199, 222, 154, 92, 85)

$\triangle_{04}=$ (123, 126, 160, 158, 182, 163, 180, 125, 88, 71)

$\triangle_{05}=$ (255, 215, 268, 261, 248, 223, 237, 170, 107, 90)

$\triangle_{06}=$ (242, 206, 264, 237, 248, 200, 210, 145, 92, 74)

$\triangle_{07}=$ (249, 212, 264, 254, 265, 216, 235, 166, 103, 90)

$\triangle_{08}=$ (253, 215, 275, 260, 273, 225, 237, 170, 107, 90)

$\triangle_{09}=$ (249, 208, 272, 254, 270, 222, 230, 167, 107, 90)

$\triangle_{010}=$ (222, 195, 241, 211, 239, 189, 179, 124, 77, 22)

Step 3: Find the maximum difference ($\triangle_{max}$) and the minimum difference ($\triangle_{min}$).

(1) $\max |x_0(k) - x_1(k)| = \triangle_{01}(3) = 227$

(2) $\max |x_0(k) - x_2(k)| = \triangle_{02}(3) = 258$

(3) $\max |x_0(k) - x_3(k)| = \triangle_{03}(3) = 264$

(4) $\max |x_0(k) - x_4(k)| = \triangle_{04}(5) = 182$

(5) $\max |x_0(k) - x_5(k)| = \triangle_{05}(4) = 261$

(6) max｜$x_0(k) - x_6(k)$｜ = $\triangle_{06}(3)$ = 264

(7) max｜$x_0(k) - x_7(k)$｜ = $\triangle_{07}(5)$ = 265

(8) max｜$x_0(k) - x_8(k)$｜ = $\triangle_{08}(3)$ = <u>275</u>

(9) max｜$x_0(k) - x_9(k)$｜ = $\triangle_{09}(3)$ = 272

(10) max｜$x_0(k) - x_{10}(k)$｜= $\triangle_{010}(5)$ = 239

The maximum difference is thus obtained as 275.

(1) min｜$x_0(k) - x_1(k)$｜ = $\triangle_{01}(10)$ = 76

(2) min｜$x_0(k) - x_2(k)$｜ = $\triangle_{02}(10)$ = 88

(3) min｜$x_0(k) - x_3(k)$｜ = $\triangle_{03}(10)$ = 85

(4) min｜$x_0(k) - x_4(k)$｜ = $\triangle_{04}(10)$ = 71

(5) min｜$x_0(k) - x_5(k)$｜ = $\triangle_{05}(10)$ = 90

(6) min｜$x_0(k) - x_6(k)$｜ = $\triangle_{06}(10)$ = 74

(7) min｜$x_0(k) - x_7(k)$｜ = $\triangle_{07}(10)$ = 90

(8) min｜$x_0(k) - x_8(k)$｜ = $\triangle_{08}(10)$ = 90

(9) min｜$x_0(k) - x_9(k)$｜ = $\triangle_{09}(10)$ = 90

(10) min｜$x_0(k) - x_{10}(k)$｜= $\triangle_{010}(10)$= <u>22</u>

The minimum difference is thus obtained as 22.

Step 4: Set ζ as 0.5.

Step 5: Calculate grey relation.

Takes an example of failing to keep a safe distance (x_1), the calculation is as below.

$r(x_0(1), x_1(1))$ = 0.3934
$r(x_0(2), x_1(2))$ = 0.4545
$r(x_0(3), x_1(3))$ = 0.3772
$r(x_0(4), x_1(4))$ = 0.3741
$r(x_0(5), x_1(5))$ = 0.3825*
$r(x_0(6), x_1(6))$ = 0.4277
$r(x_0(7), x_1(7))$ = 0.4264
$r(x_0(8), x_1(8))$ = 0.4833
$r(x_0(9), x_1(9))$ = 0.6098
$r(x_0(10), x_1(10))$= 0.6440

The grey relation of failing to keep a safe distance (x_1) is (0.3934 + 0.4545 + 0.3772 + 0.3741 + 0.3825 + 0.4277 + 0.4264 + 0.4833 + 0.6098 + 0.6440) / 10 = 0.4573

The grey relations of other factors are calculated by this same procedure and the results are listed in Table 3. These human factors and vehicle factors are now put in order according to their grey relations. These are: Improper driving(x_4) > others (x_{10}) > speeding (x_3) > failing to keep a safe distance (x_1)> flat tires (x_2) > driving with alcohol (x_6) > long time driving (x_7) > improper loading (x_5) > pedestrians walking on freeways (x_9) > vehicle mechanical breakdown (x_8).

According to the results of the above grey relation analysis, the major causes of accidents on freeways are improper driving (x_4), followed by others (x_{10}), speeding (x3), failing to keep a safe distance (x1), flat tires (x_2), driving with alcohol (x_6), long time driving (x_7), improper loading (x_5), pedestrians walking on freeways (x_9), and vehicle mechanical breakdown (x_8).

Table 3. Grey Relation of Each Accident Causes

Accident causes	Grey relation
Failing to keep a safe distance, (x_1)	0.4573
Flat tires, (x_2)	0.4563
Speeding, (x_3)	0.4290
Improper driving, (x_4)	0.5091
Improper loading, (x_5)	0.4144
Driving with alcohol, (x_6)	0.4368
Long time driving, (x_7)	0.4153
Vehicle mechanical breakdown, (x_8)	0.4117
Pedestrian walking on freeways, (x_9)	0.4118
Others, (x_{10})	0.4769

4.3 GM (1,N) Model

The study uses the same traffic accidents data to build a GM (1,N) model for analysis with the view of plotting the trend in traffic accident causes. By following the steps listed in section 3, it is found that b_2=125.93, b_3=60.82, b_4=-116.38, b_5=-35.86, b_6=-85.38, b_7=179.49, b_8=442.24, b_9=90.82, b_{10}=321.16, b_{11}=10.07 (see Table 4). Based on the $|b_i|$ concept, all the factors are put in the following order:

Table 4. The Results of GM (1,N) Model

Accident causes	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	Results
x_1	44	53	51	31	53	42	52	23	19	14	b_2=125.93
x_2	8	13	20	17	15	13	19	8	5	2	b_3= 60.82
x_3	5	3	14	21	30	27	15	16	15	5	b_4= -116.38
x_4	133	92	118	103	96	63	57	45	19	19	b_5= -35.86
x_5	1	3	1	0	1	3	0	0	0	0	b_6= -85.38
x_6	14	12	14	24	27	26	27	25	15	16	b_7= 179.49
x_7	7	6	14	7	10	10	2	4	4	0	b_8= 442.24
x_8	3	3	3	1	2	1	0	0	0	0	b_9= 90.82
x_9	7	10	6	7	5	4	7	3	0	0	b_{10}=321.16
x_{10}	34	23	37	50	36	37	58	46	30	34	b_{11}=10.07

Long time driving (x_7)＞pedestrians walking on freeways (x_9)＞driving with alcohol (x_6)＞failing to keep a safe distance (x_1)＞speeding (x_3)＞vehicle mechanical breakdown (x_8)＞improper loading (x_5)＞flat tires (x_2)＞improper driving (x_4)＞others (x_{10}).

The GM (1,N) model that looks into the changes of factors in traffic accident systems, on the other hand, finds out the crucial factors are long time driving (x_7), pedestrians walking on freeways (x_9), driving under the influence (x_6), failing to keep a distance (x_1), speeding (x_3), vehicle mechanical breakdown (x_8), improper loading (x_5), flat tires (x_2), improper driving (x_4) and others (x_{10}).

4.4 Synthesized Analysis of Accident Causes

According to the results of the grey relation analysis, the top five causes of traffic accidents on freeways in Taiwan during the past decade are improper driving, speeding, failing to keep a safe distance, flat tires and driving under the influence. In the GM (1,N) model analysis which probes into the developmental trend of all factors in the traffic accident system, the top five crucial factors that contribute to traffic accidents are long time driving, pedestrians walking on freeways, driving with alcohol, failing to keep a safe distance, and speeding. By synthesizing the results of the grey relation analysis and the trend analysis (GM (1,N) model), the study finds that speeding, failing to keep a safe distance and driving with alcohol are the common causes. Therefore, in view of the limited law-enforcing officers, the authorities may take into account these findings while determining the focus of traffic law enforcement on freeways in the future.

Although some previous researches have been qualitatively or quantitatively discussed what are the main factors lead to these accidents in the past, it is not easy to obtain a clear and whole picture due to the incomplete information and the interaction among factors. Since the grey system theory could deal with the problems with incomplete or unknown information and also the small samples, this paper uses it to analyze the main factors and predict the trend in the case study of Taiwan freeway accidents. The results show that the grey system theory did a good job.

5. CONCLUSIONS

This empirical study has shown that despite the limited available information, the grey system theory applied to explore the causes of traffic accidents on freeways in Taiwan proves that it is an adequate and practical tool. The leading major causes of accidents on Sun Yeh-Sen freeway in Taiwan are ranked as follows: improper driving (x_4), others (x_{10}), speeding (x_3), failing to keep a safe distance (x_1), flat tires (x_2), driving with alcohol (x_6), long time driving (x_7), improper loading (x_5), pedestrians walking on freeways (x_9), and vehicle mechanical breakdown (x_8) through grey relation analysis.

Through the GM (1,N) model exploring changes of human and vehicle factors in traffic accident systems, this study finds out the key factors are long time driving (x_7), pedestrians walking on freeways (x_9), driving with alcohol (x_6), failing to keep a distance (x_1) and speeding (x_3).

By synthesizing the findings of the grey relation analysis and the GM (1,N) model, this study comes to the conclusion that speeding, failing to keep a safe distance, and driving with alcohol are the most important factors related to freeway traffic accidents in Taiwan.

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