A SPATIAL CORRELATION BETWEEN ACCIDENTS AND HIGHWAY GEOMETRIC ELEMENTS

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abstract: This paper presents the findings of a spatial analysis of accidents with the assistance of statistical analysis and the geographic information system (GIS). The investigation of the spatial correlation of accidents is to determine if the occurrence of accidents are spatially interrelated. Accident data from January 1980 to December 1994 of the National Sun Yat-Sen freeway (373.2 kilometers in length) were collected and analyzed to form the main theme of this paper.

1. INTRODUCTION

Traffic accident analysis is a major topic in the field of Traffic Engineering or Highway Engineering. Many highway or traffic control improvements are based on the findings of safety analysis or safety concerns suggested by the general public. Safety analysis is an important tool as traffic fatalities form the largest portion of accident fatalities in many countries.

Traditionally, accidents are analyzed by statistical techniques, such as regression analysis, analysis of variance (ANOVA), or multivariates analysis(Kihberg 1968, Ahmed et al 1980, Neuman et al 1984, Scott 1986, Khansnabis et al 1989). Those methodologies are used to correlate the dependent variable such as accident number or accident rate with those suspected factors such as grade, curvature, number of lanes, etc(Gupta et al 1975, Neuman et al 1983, Zeer 1988, Miaou et al 1993,). Normally, there are three different tasks to be faced in safety analysis. They are 1. to identify the components of a specific safety problem, 2. to evaluate an accident-reducing countermeasure program or device, and 3. to study the interrelationship among a number of variables thought to be relevant to accidents(FHWA,1980). Among them, spatial relationship of accidents was rarely investigated in the past. Although the relationship between accidents and highway geometry has long been studied, the joint impact of highway geometry and spatial distribution has seldom been researched. It is probably because of the failure to quantify the spatial attributes and their correlation among themselves. Such failure is considered by most researchers to be caused by the absence of proper visual displays and high speed geographic correlation computation (Goh 1993). Without the proper tools and the capability to code such kinds of spatial interaction, it is almost impossible to conduct a statistical spatial correlation test.

Recently, the advancement of computer technology and the development of geographic information system (GIS) offers an opportunity to present accident distribution visually and spatially on electronic maps(Peled et al 1993). The capability of GIS to overlay each individual accident on highway line graphs or raster images thus offers a good chance to look into this untouched issue of accident spatial relationship with highway geometric elements.

In this study, an accident GIS was first developed. Accidents were presented graphically by the developed GIS. The GIS then helped to identify those hypotheses of questioned spatial relationship between accidents. Accident records, elements of freeway geometric design, and traffic control devices of the interested area were then studied by times series analysis and other statistical techniques. For the reason of hypotheses development, the accident GIS is a vital component. It is necessary to retrieve relevant data for further statistical analysis. This study employed the GIS software MAPINFO(MapInfo 1992-1995) as the tool for system development. The attributes data bases and the map base were integrated through the MAPINFO's geocoding procedure. With such an integrated GIS capable of showing accident distribution and their data base available, accident data can be properly maintained and further updated for analysis in the future.

2. SCOPE OF STUDY AND APPROACH

In this study, the National Sun Yat-Sen freeway of Taiwan was chosen as the subject of study. It extends from Keelung City in the north to Kaoshiung City in the south and has a length of 373.2 kilometers (KM). The complete freeway has been open for public to use since January 1979. Since opening, its traffic volume has been increasing at an average yearly rate of 9.89%(National Taiwan Freeway Bureau, 1980-1995) and its high design standard and convenience has made the freeway the most important North/South artery for land transportation in Taiwan.

2.1 Data Bases

In order to test the spatial correlation between accidents and freeway geometric elements, both accident data and freeway geometric data have to be collected.

For this study, a total of 15 years' accident records, from January 1980 to December 1994 were collected. The accident data were initially stored with the spreadsheet software EXCEL(EXCEL 1993-1995). The A-1 class accident with a sample of 4377 records were chosen as the population for analysis. A-1 stands for fatal or serious injury accidents. In contrast, a class A-2 accident stands for a minor injury accident and a class A-3 accident stands for a property damage only accident. Both A-2 and A-3 accidents were not included in the study data base for their relative information had not been computerized into digital format. They were stored in draft papers and not cost-effective to convert them into useful form. The information of each computerized accident includes date, location, type of crash, number of fatalities or injuries, weather condition, pavement condition, traffic control, type and number of vehicles involved, etc(National Taiwan Freeway Bureau, 1980-1995).

In the freeway attributes data base, the 373.2 kilometers length of freeway is divided into hundreds of small sections. Normally, each section is 1 kilometer long except at the sites of interchange, toll plaza, or other special featured locations, where the section may deviate somewhat from 1 kilometer. Each section is assigned an identification number (ID) which indicates its traveling direction and location of its KM post on the freeway. The max./min. grade and max./min. turning radius, number of lanes, and special features are some basic attributes of each section. For example, an ID S18K stands for a southbound direction section, from KM post 18 to KM post 19. The freeway attributes data base is presented in Table 1. Because the turning radius of a straight line is difficult to measure, any section with turning radius equivalent to or greater than 20 KM is considered as a straight line and assigned a 20 KM turning radius.

Each accident record was also attached to an ID of KM post which is the same as the freeway section division. This is designed to ensure both data bases can be geocoded with the map features of the map base. The basic information of each accident selected to be used in the study includes details of the crash, location, date, and weather condition. It is presented in Table 2.
To develop the draft data bases, the spreadsheet software EXCEL was used for data entry. Later, the draft EXCEL data bases were geocoded and transferred into MAPINFO's location correlated data bases with longitude and latitude values attached to freeway features and accident records.

2.2 Map Base

To develop the maps for the Sun Yat-Sen freeway and its surrounding areas, the 1:25,000 aerial photos and their digitized digital line graph(DLG) data were acquired from the Ministry of Interior for the main line freeway sections. A total of 35 map sheets were acquired and attached to form a continuous freeway. Because the 1:25,000 aerial photos were not sufficient for detailed analysis, some 1:5,000 aerial photos and their digitized DLG data were also acquired. There are some special interesting sections, such as freeway interchanges, toll plazas, emergency aircraft landing strips (EALS), etc. Vector data such as freeway mainline, provincial highways, rivers, railroads, etc. are stored in the individual layer of the acquired files and stored with the data exchange format of DXF.

After the freeway geometry data base and the accident data base were established, they were transferred into the developed GIS as two relational data bases. Later they were geocoded with the map base. The geocoding process was done by MAPINFO's built in procedure and the key for geocoding is the ID in all three relevant data bases. The geocoding process and the system development process is illustrated in Figure 1.

Table 1 Basic Freeway Geometry Data Base

ID	Maximum Grade (%)	Minimum Grade (%)	Maximum Turning Radius (m)	Minimum Turning Radius (m)	NO. of Lanes	Function	Maintenance District
S14K	1	-1	20000	850	2	-	Northern
S15K	1	-1	20000	2000	2	-	Northern
S16K	3	-1	2000	2000	2	-	Northern
S17K	3	-1	3500	2000	2	-	Northern

Table 2 Freeway Accident Data Base

ID	Location	Date	Number	Fatality	Injury	Severity	Direction	Time	Day	Weather
S18K	18650	1993 0421	1	2	2	27	S	0800	SAT.	RAIN
S19K			0	0	0	0	S			
S20K			0	0	0	0	S			
S21K			0	0	0	0	S			
S22K	22800	1993 0830	1	0	2	8	S	0647	TUE.	CLOUDY

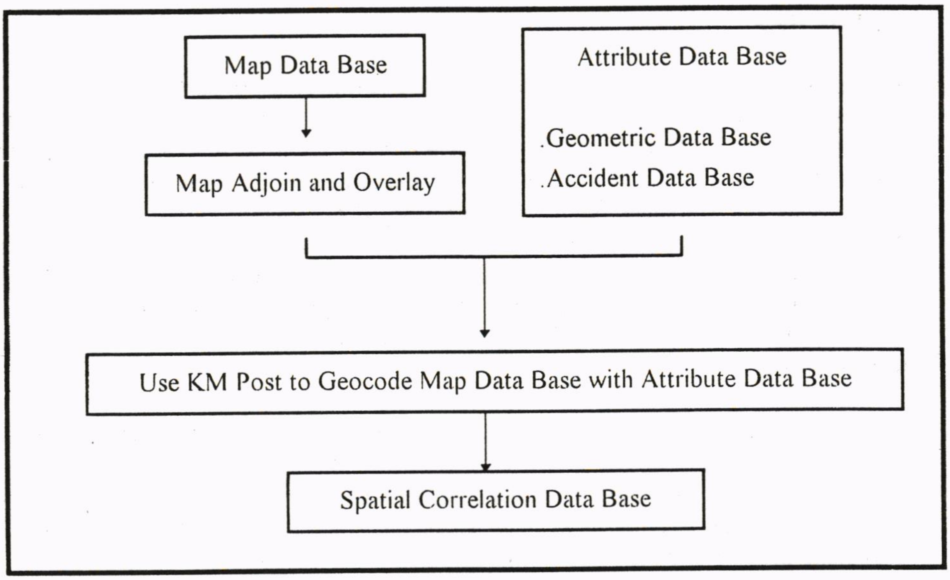


Figure 1 System Components and Development Process

3. SPATIAL ATTRIBUTES ANALYSIS

3.1 Variation of Grade and Its Length

After the establishment of the freeway geometry data base, the change of geometry along the freeway can be previewed before accident spatial correlation analysis is completed. Figure 2 illustrates the grade variation along the southbound freeway within the Northern Maintenance District (KM post 0-95) and several findings can be made.

1. It is seen at KM post 40-45, the grade has a tremendous change. The max. grade (solid line) changes from upgrade 6% to downgrade -5%. A total of 11% max. grade change over a distance of 6 (=45-40+1) kilometers. The change of min. grade (dot line) is not as significant as the max. grade. It changes from 2% to -6% within 2 kilometers at KM post 38-39.
2. At KM post 39, the largest variation between max. grade (6%) and min. grade (-6%) has occurred. It implies a sharp crest existing within that area.
3. At KM post 42-47, there exists a continuous 6 kilometer long downgrade. Within this distance, both max. and min. grades have negative "-" values.

After reviewing the above 3 findings, a hypothesis surfaced, "Is the area from KM post 37 to KM post 47 an accident prone area?"

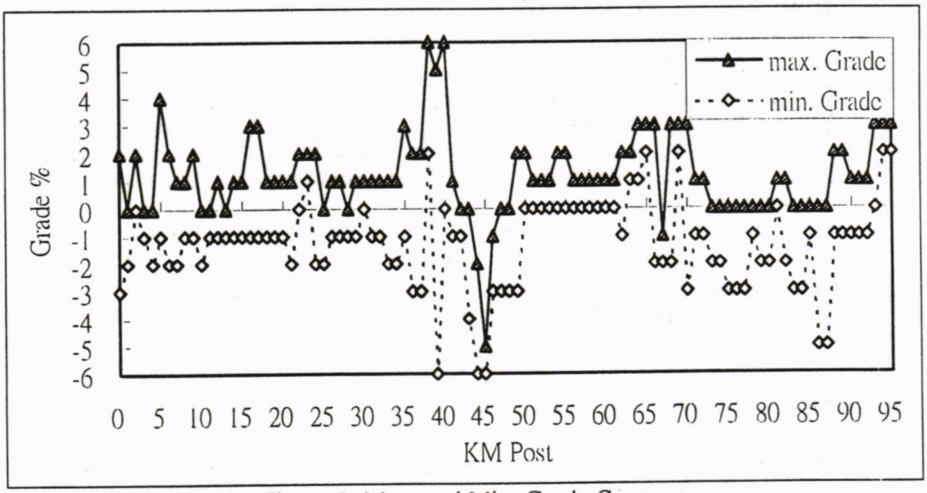


Figure 2 Max. and Min. Grade Curves

3.2 Variation of Horizontal Curvature and Its Length

Curvature is the degree of curve. It is defined to be the central angle subtended by a chord of 30.48-meter (100-ft) length. Because the allowable curvature for freeway is relatively small, this study defines a term "curvature index" which is 20,000/turning radius (meter/meter) to better represent their variation. The larger the curvature index, the smaller is the turning radius. According to the definition aforementioned, the curvature index for a straight line equals one. Figure 3 illustrates the variation of curvature index along the southbound freeway within the northern maintenance district and several findings can be unveiled.

1. It is seen near the northern end of the freeway, at KM post 1-5, the southern bound freeway has very sharp curves. Both max. and min. curvature indices are in the high range area. Nonetheless, at KM post 2, there is a straight line. This implies the area's horizontal alignment changes from sharp curve to straight line then back to sharp curve.
2. At KM post 32-40, there exists a relatively large difference between max. curvature index and min. curvature index. This also implies that the change of horizontal alignment is very significant.
3. It is learned from both Figure 2 and Figure 3 that the area at KM post 39 is not only a crest but also a curve.

After reviewing the above 3 findings, two hypotheses are postulated. There are 1. "Is the area from KM post 1 to KM post 5 an accident prone area?" and 2. "Is the area at KM post 39 an extreme accident prone area?".

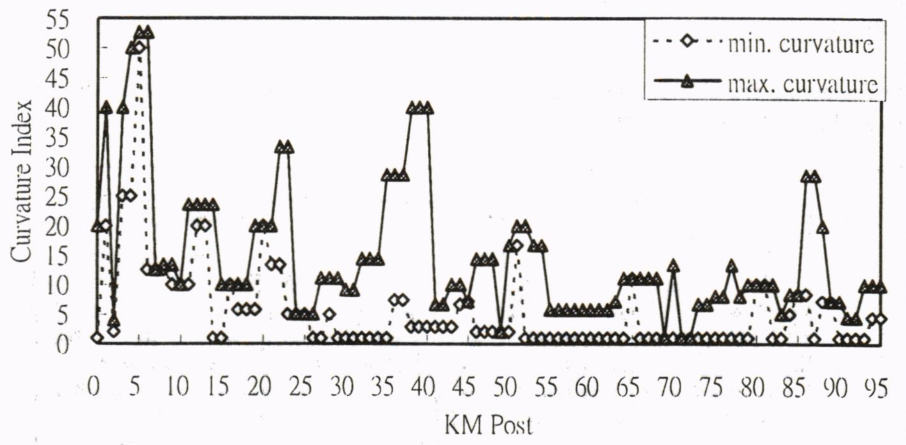


Figure 3 Max. and Min. Curvature Indices

3.3 Special Featured Area and Its Location

Along the National Sun Yat-Sen freeway, there are areas with special features and suspected to have higher accident experience. They are 1. interchanges, 2. toll plazas, and 3. emergency aircraft landing strip (EALS). Figure 4 illustrates their locations in the northern maintenance district and a detailed description is as follows.

1. Interchanges: There are 41 interchanges on the National Sun Yat-Sen freeway. The distance from the starting point of the deceleration lane to the end point of the acceleration lane is considered as the interchange length. In this study, a length of 1.5 kilometers is purposely used as the interchange length for easy data handling and safety analysis, though each interchange of the freeway has slightly different length.
2. Toll Plaza: The Sun Yat-Sen freeway was designed to collect toll on freeway mainline instead of on ramps. There are ten toll plazas on the freeway. The length of a toll plaza is considered starting from the point where passage lanes increase to

the point where the extra passage lanes terminate. There exist three kinds of length, namely, 0.7, 0.8, and 1.4 kilometers. For the reason of simplicity, one kilometer is used to define toll plaza length in the study except the Taishan toll plaza which is the only one using the 1.4 kilometers design.

3. Emergency Aircraft Landing Strip: There are five emergency aircraft landing strips on the Sun Yat-Sen freeway. They are designed to accommodate aircraft landing and taking off when emergency situations occur. They are located at 58K+010 ~ 60K+310 (2.3 KMs), 204K+513 ~ 206K+867 (2.3 KMs), 257K+023 ~ 259K+507 (2.5 KMs), 295K+597 ~ 297K+927 (2.3 KMs), 331K+403 ~ 333K+887 (2.5 KMs).

Figure 4 illustrates the distribution of those three kinds of special feature areas within the Northern Maintenance District. There are 13 interchanges, 3 toll plazas, and 1 EALS. Checking with Figures 2 and 3, it is seen that the only EALS (58K+010 ~ 60K+310), has 1% max. grade and 0% min. grade, max. curvature index 6, and min. curvature index 1.

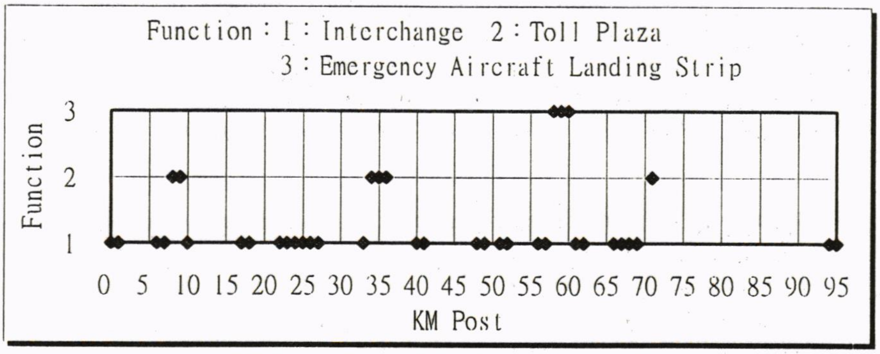


Figure 4 Distribution of the Special Featured Areas

4. ACCIDENT ANALYSIS

In addition to the study of accident numbers, traffic volume was also used to calculate vehicle travel distance as the exposure value for accident rate analysis. The yearly traffic counts and mixture ratios along those ten toll plazas were used to estimate yearly traffic counts between each two neighboring interchanges. Multiplying traffic counts by distance between two interchanges, the traffic exposure with the unit of million vehicle kilometer (MVK) can be obtained.

4.1 Accident Severity

Because the same accident number or accident rate does not mean the same accident severity, this study employs the concept of equivalent total accident number (ETAN) as the index for severity analysis. The severity formula is presented in F-1. The factors 9.5 and 3.5 are values obtained through research for use in Taiwan(Lin 1987). The calculated ETAN of each freeway section is then adjusted by traffic exposure (MVK) to obtain its severity rate for statistical testing.

$$ETAN=9.5*F+3.5*J+TAN \quad \text{F-1}$$

ETAN : Equivalent Total Accident Number
F : Fatality
J : Injury
TAN : Total Accident Number

4.2 Accident Trend and Comparison

Figure 5 uses Season as the dependent variable to plot the changes of accident rates according to times. The accident rates of general freeway sections, interchanges, toll plazas, and EALSs are listed for comparison. Figure 6 presents the plots of severity for the three special feature areas. It is seen from both Figure 5 and Figure 6 that toll plazas had high accident rates since the period from opening of the freeway in year 1979 to the end of 1985. After 1985, accident rates at toll plazas have gradually decreased and even have reached a level lower than general freeway sections. This implies freeway users are getting used to the existence of the toll plaza and expect to encounter a traffic disturbance around toll plazas. To the contrary, the EALSs have been suffering both high accident rate and severity. The values have been decreasing but are still higher than others.

Table 3 lists the 2 by 2 difference test for the four kinds of freeway sections. It is seen that one of the hypotheses has been proved. The EALSs have both accident rate (0.0602 accident/MVK) and accident severity (1.0724 ETAN/MVK) higher than those of general freeway sections (0.0469 and 0.5558 respectively). However, the differences between general freeway sections and interchanges or toll plazas are insignificant.

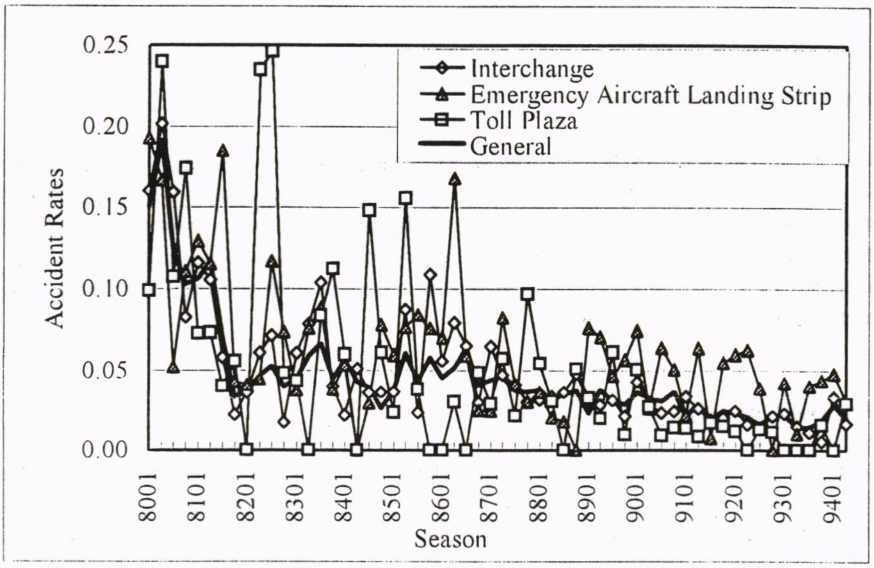


Figure 5 Accident Rates Comparison

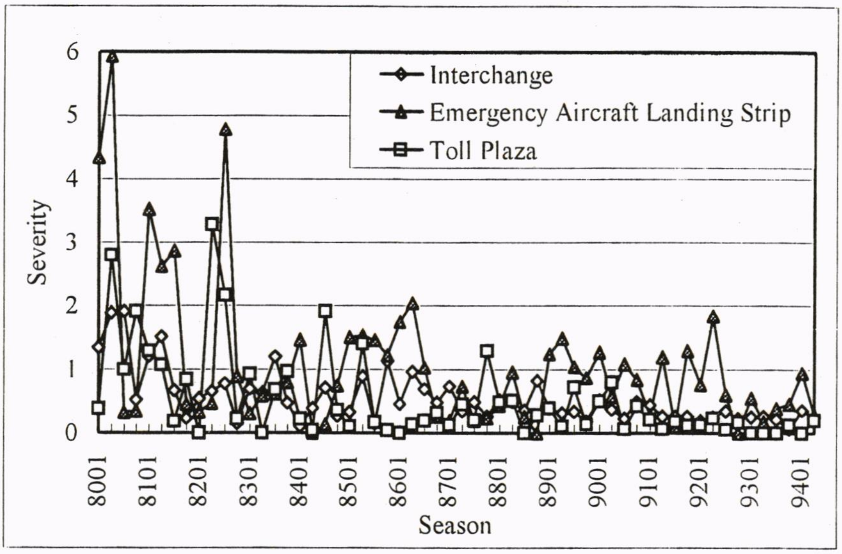


Figure 6 Special Featured Areas Accident Severity Comparison

Table 3 Accident Statistical Tests for Special Feature Areas

T-test						
Accident Rate	**Interchange**	**General**	**Toll Plaza**	**General**	**EALS**	**General**
Average	0.0494	0.0469	0.0504	0.0469	0.0602	0.0469
Variance	0.0022	0.0013	0.0066	0.0013	0.0049	0.0013
Degree of Freedom	328		241		261	
t	0.5507		0.5195		**2.2325**	
P(T<=t): Single Tail	0.2911		0.3019		0.0132	
Critical Value: Single Tail	1.6495		1.6512		1.6507	
Accident Severity	**Interchange**	**General**	**Toll Plaza**	**General**	**EALS**	**General**
Average	0.5442	0.5558	0.5224		1.0724	
Variance	0.2786	0.1548	0.8138		4.0296	
Degree of Freedom	324		239		188	
t	-0.2350		-0.4254		**3.3499**	
P(T<=t): Single Tail	0.4072		0.3358		0.0005	
Critical Value: Single Tail	1.6496		1.6513		1.6530	

5. CORRELATION ANALYSIS

After completing spatial attributes analysis and accident analysis, the correlation between them can be further studied.

5.1 ACCIDENTS IN NORTHERN MAINTENANCE DISTRICT

In section 3, the freeway within the Northern Maintenance District has been used as an example for spatial attributes analysis. Accident Experience of the same district will thus be used for correlation analysis. Figure 7 and Figure 8 present the accident number and accident severity occurring in the southbound direction within the Northern Maintenance District.

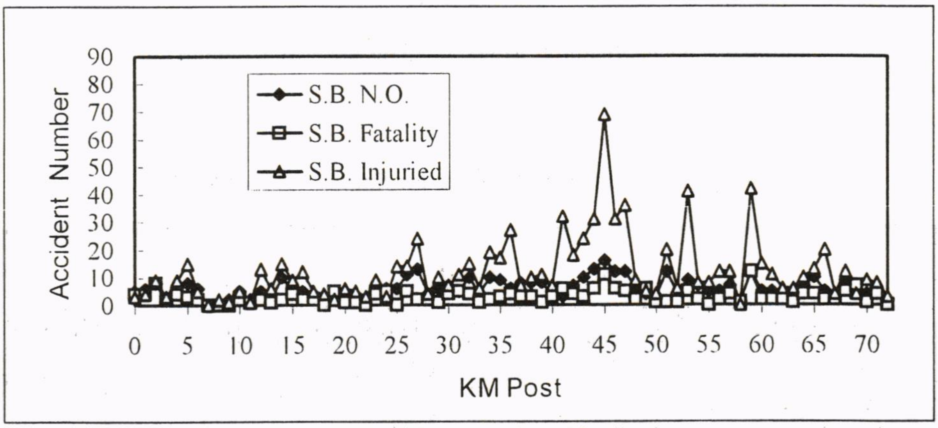


Figure 7 Accident Number Distribution

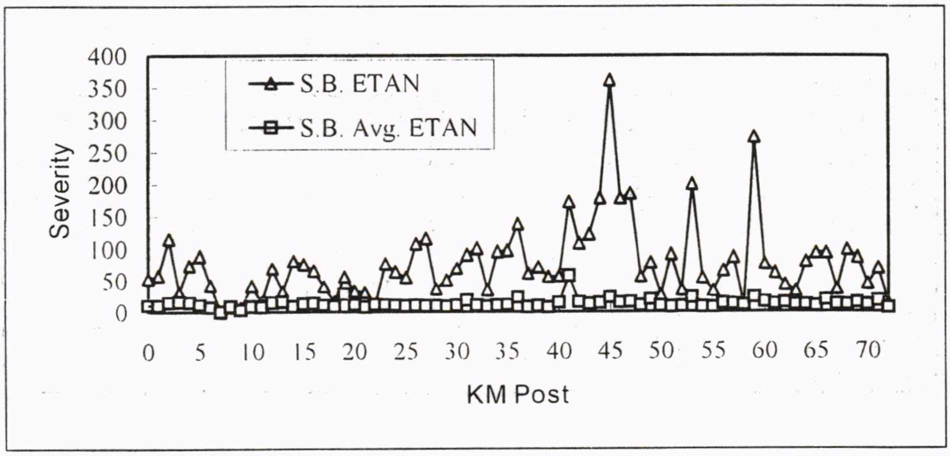


Figure 8 Accident Severity Distribution

5.2 HYPOTHESES EXAMINATION

About the few questions raised in the previous sections, they can be examined as follows.

1. Is the area from KM post 37 to KM post 47 an accident prone area?
2. Is the area from KM post 1 to KM post 5 an accident prone area?
3. Is KM post 39 an extreme accident prone area?

These three hypotheses can be examined with the assistance of Figures 7 and 8. First, the section from KM post 37 to KM post 47 is indeed an accident prone area. The frequency of accidents shapes a continuous peaking form at this section, especially from the pattern of injuries. Second, the section from KM post 1 to KM post 5 does not have a significantly higher accident frequency than other sections in the area. Third, the southbound KM post 39 had 8 accidents, 1 fatality, and 11 injuries. Its accident frequency is higher than the area's mean of 6.03 accidents, but is less than the value of 9.41 which is one standard deviation (3.38) above mean. Therefore, it is not an extremely accident prone area.

The examination of these three hypotheses indicates that the spatial presentation of the freeway geometry may help to identify some questionable correlation between accidents and geometric elements. However, those suspicions require further analysis to prove their correctness.

5.3 GIS Spatial Correlation Presentation

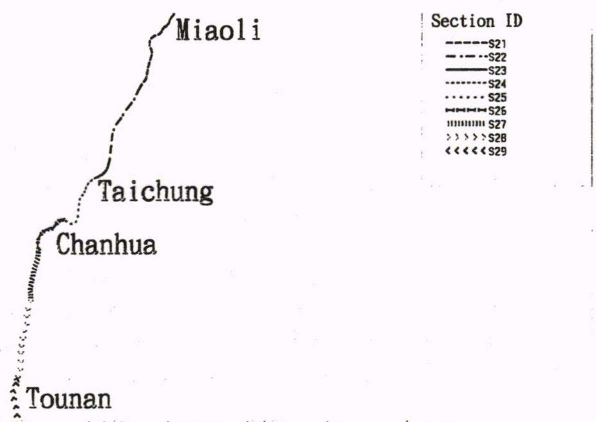
From other study findings of the research, it is found that the freeway within the central maintenance district has significantly higher accident numbers than both northern and southern maintenance districts. Some reasons are listed as follows.

1. Transitional Geographic Change: The Northern Maintenance District is in a rolling mountainous terrain and the southern maintenance district is in level terrain. Freeway users have to use this section of freeway to adjust themselves to the two kinds of travel environments. Such a transition may cause higher accident frequency.
2. Spatial Attribute Change: In addition to the geographic transition change, there are also spatial attribute changes including both vertical and horizontal alignments.
3. Fog Prone Area: Environmentally, the central maintenance district has many fog prone areas within its district.

This section employs the developed accident GIS to present graphically the accident phenomena within the central maintenance district. Figure 9 presents the summation of accidents per section of southbound freeway in the year of 1993. The horizontal alignment of the area can also be seen in conjunction with the presentation of the accident data base. For example, the modified section S21 (KM post 132.814-150.225) from Miaoli interchange (I. No. 21) to Sanyi interchange (I. No.22) had the most: 8 accidents, 5 deaths, 14 injuries, 95 ETAN. It is also seen from Figure 9 that section S21 has very sharp turning curves. Checking the geometric attributes data base, it also indicates the area is very rolling. It has a 5.0% steep upgrade as well as some minor up and down hills.

Figure 10 presents the groups of accident rates by pattern for each section of southbound freeway. The histogram of the accident rate by KM post can also be seen in this thematic figure. Checking the data base for the highest accident rate, it is learned that this occurs at section S23 (0.03119 accidents/MVK). S23 is from Fengyuan interchange (I. No. 23) to Taya interchange (I. No. 24). Section S21 between Miaoli interchange (I. No. 21) to Sanyi interchange (I. No.22) (0.02898 accidents/MVK) and the section S26 between Wangtien interchange (I. No. 26) and Changhua interchange (No. 27) (0.03026 accidents/MVK) have the third and second highest level of accident rate respectively. The possible causes for S21 to have a high accident rate are explained above. The causes for section S23 and S26 have to be further analyzed.

The illustrations of Figure 9 and Figure 10 basically present the capability of functional mapping of the developed accident GIS. Several detailed safety analysis can further be obtained through such a spatial correlation analysis. For example, the distribution of accident severity can also be plotted on the functional map.



ID	Year	O_D	KM_Post	Length	Accident	Fatality	Injury	severity
S21	1,993	Miaoli-Sanyi	132.814 – 150.225	17.411	8	4	14	95
S22	1,993	Sanyi-Fengyuan	150.225 – 167.617	17.392	6	3	9	66
S23	1,993	Fengyuan – Taya	167.617 – 174.235	6.618	4	4	3	52.5
S24	1,993	Taya-Taichung	174.235 – 178.622	4.387	1	1	0	10.5
S25	1,993	Taichung-Wangtien	178.622 – 188.959	10.337	3	3	3	42
S26	1,993	Wangtien-Chanhua	188.959 – 198.497	9.538	6	6	7	87.5
S27	1,993	Chanhua-Yuanlin	198.497 – 210.985	12.488	4	3	10	67.5
S28	1,993	Yuanlin-Hsilo	210.985 – 230.470	19.485	2	1	2	18.5
S29	1,993	hsilo-Tounan	230.470 – 240.569	10.099	2	2	2	28

Figure 9 Yearly Accident Phenomena within the Central Maintenance District

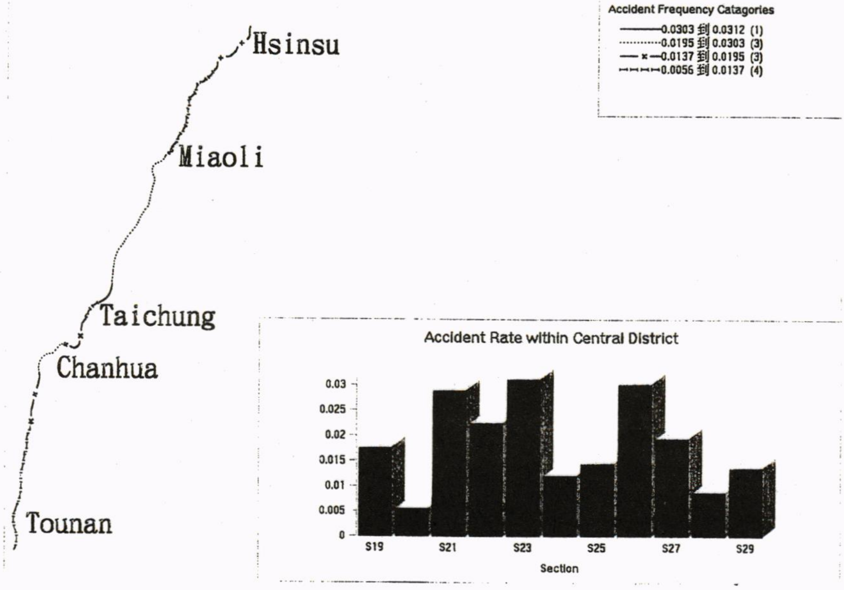


Figure 10 Yearly Accident Rate within the Central Maintenance District

6. CONCLUSION AND RECOMMENDATION

From this study, several findings can be reached. Findings of the study include:

1. The development and application of GIS is a possible methodology in conducting accident spatial correlation with freeway geometric elements. The thematic mapping function of GIS can help to identify the possible cause/result factors among the variables of time, location, and accident.
2. The A-1 accidents, accident rate, and total accident severity with the conversion unit of ETAN illustrate a decreasing trend over the years. With yearly 9.89% traffic increase, this is quite an achievement. It implies that the users of National Sun Yat-Sen freeway are more familiar with driving correctly on a freeway.
3. Installation of a toll plaza often causes an increase of accidents in the first few years after its opening. However, its impact decreases gradually with time.
4. The emergency aircraft landing strips have both accident rates and accident severity higher than those of general freeway sections.
5. The area of interchanges on the freeway shows no significant impact on the occurrence of accidents; even though there are a great deal of lane changes and weavings near the interchange area.
6. In the central maintenance district, the S21 section had the highest accident number and severity. Its accident rate was in the second highest level. It is believed that geometric elements have a critical impact on it.

There are also some recommendations described as follows.

1. The grade of a slope (either ascending or descending slope) has a significant impact on accident occurrence. The combination of grade, curvature, and its length also forms an interesting spatial relationship between accidents and freeway alignment in the rolling or mountainous areas. Such a topic needs better technique to quantify those features and their correlation before a statistical test can be carried out.
2. Because only the A-1 class accident records were used in the study, it may be necessary to use the complete data for spatial analysis. However, those accidents have to be computerized first.

REFERENCES

Ahmed, S.A., & Cook, A.R. (1980). Time series models for freeway incident detection. **ASCE Journal of Transportation Engineering**, 731-766.

Excel (1993-1995). **Microsoft Excel User Guide**, Microsoft Corporation, U.S.A.

Federal Highway Administration (1980). **Accident Research Manual**, Report No. FHWA/RD-80/016, 9.

Goh, P.C. (1993). Traffic accident analysis using geoprocessing techniques. **Road and Transport Research**, V.2, 76-85.

Gupta, R.C., & Jain, R.P. (1975). Effect of certain roadway characteristics on accident rates for two-way roads in Connecticut. **Transportation Research Record**, No. 541, 25.

Khansnabis, S., & Lyoo, S.H. (1989). Use of time series analysis to forecast truck accident. **Transportation Research Record**, No. 1249, 30-36.

Kihberg, J.K. (1968). Accident rate as related to design elements of rural highways. **Highway Research Board,** NCHRP Report No. 47, 1.

Lin, D.L., (1987). The establishment of a computerized accident information system for Taiwan area roads. **Transportation Quarterly**, V. 16, No. 2, 199-232.

MapInfo (1992-1995). **MapInfo Professional Reference**, MapInfo Corporation, Troy, New York.

Miaou, S.P., & Lum, H. (1993). Modeling vehicle accident and highway geometric design relationships. **Accident Analysis and Prevention**, V. 25, 689-709.

National Taiwan Freeway Bureau (1980-1994). **Annual Report**.

Neuman, G., & Saag M. (1983). Accident analysis for highway curves. **Transportation Research Record**, No. 923, 65.

Neuman, G., & Evanston, L. (1984). Discriminant analysis as a tool for investigation highway safety relationships. **ITE Journal**, Vol. 54, No. 10.

Peled, A., & Hakkert, A.S. (1993). PC-oriented GIS application for road safety analysis and management. **Traffic Engineering & Control**, V.34, 355-361.

Scott, P.P. (1986). Modeling time series of British road accident data. **Accident Analysis and Prevention**, V. 18, 109-117.

Zeer, C.V. (1988). accident effects of sideslope and other roadside features on two-lane roads. **Transportation Research Record**, No. 1195.