LOS and Safety Analysis By A GIS-Based FTIMS

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Abstract:

The Sun Yat-Sen Freeway (373 kilometres in length) in Taiwan has endured an average of 11.62 $ annual traffic growth since its inauguration in October 1978, with a surprising 20.18% for 1987(NFB, 1992). Its number of accidents had also increased 94% from 209 accidents in 1982 to 405 accidents in 1990; and average of 1.11 accidents with 0.98 person killed and 1.76 persons injured per day. Heavy traffic combined with those alarming accident experience force the freeway administration office - Taiwan Area National Freeway Bureau (NFB) to face the problem seriously. The NFB views managing the freeway to provide general public a smooth and safe travel a top priority.

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1. INTRODUCTION

Background of the Problem

The Sun Yat-Sen Freeway (373 kilometers in length) in Taiwan has endured an average of 11.62% annual traffic growth since its inauguration in October 1978, with a surprising 20.18% for 1987[NFB, 1992]. Its number of accidents had also increased 94% from 209 accidents in 1982 to 405 accidents in 1990; an average of 1.11 accidents with 0.98 person killed and 1.76 persons injured per day. Heavy traffic combined with those alarming accident experience force the freeway administration office - Taiwan Area National Freeway Bureau (NFB) to face the problem seriously. The NFB views managing the freeway to provide general public a smooth and safe travel a top priority.

The Need to Have a GIS-Based FTIMS

In the past, many information systems had been developed to assist works of the NFB and its counterpart - National Expressway Engineering Bureau (NEEB). However, those systems are often incompatible in their operation environments or data formats. They also are not able to display analysis result on a map with relative locations and spatial attributes. GIS, equipped with its powerful database management and graphic display capabilities, was considered a possible solution to integrate those independent systems. The idea was proposed to the National Science Council (NSC) of Taiwan and two grants in two consecutive years were awarded since 1991. This paper presents some results of the NSC projects and their working procedures.

2. INFORMATION PRIORITIZATION

Because budget and time are limited, a two-stage analytical hierarchy process (AHP) was used to rank priorities of information needs instead of by the business system planning (BSP) procedure. The steps to unveil the priorities are as follows:

1. use questionnaire to reveal extent of computer usage in the working environment of transportation professionals,

2. interview officials of the NFB and NEEB to learn their information needs and priorities,

3. apply the analytical hierarchy process (AHP) to compute the relative priority vector for each information item,

4. conduct statistical analysis to learn how working environment affect the priority vectors, and

5 recommend a priority order of modules development for the GIS-based freeway traffic information management system.

Tables 1 to 3 show survey results of the first questionnaire classified by organizations. It is learned that[Ho, 1992]

1. The primary job contents of NFB is freeway expansion including road widening and maintenance (91.30%). For NEEB and CECI, their primary work loads are highway planning, design, and construction, 71.43% and 50% respectively.

2. The degree of work computerization for NFB primarily focuses on maintenance/management(56.52%). For NEEB, it focuses on cost estimation and billing (38.10%). For CECI, both transportation planning/corridor analysis and preliminary engineering/design have the same responses (77.78%). The function of an organization seems to dominate the direction of office computerization.

3 The NFB expects FTIMS to provide information primarily on roadway maintenance (86.96%). For NEEB, 57.14% of the answers expect to have data for road planning and design. For CECI, both road planning and design data and traffic conditions have an equal highest interest of 77.78%. Land use data along freeway were also ranked with a similar highest interest.

Figure 1 defines the hierarchy of the information needs. Level zero is the focus of the problem which is the core reason to develop a FTIMS. Level one classifies types of benefit. Level two asks the channel to receive benefit. Level three lists the diversities of information and a total of six items are included. They are

C1. area topology and roadway geometry,
C2. road/bridge maintenance records,
C3. accident records,
C4. traffic volume and roadway capacity,
C5. traffic control devices, and
C6. interchange locations and freeway adjoining roads.

The AHP analysis of the information needs found that the benefits to have a FTIMS were ranked to achieve 1. prompt information retrieval, 2. efficient data filing and updating, and 3. effective capability to communicate information between departments or bureaus. The reason to benefit from a FTIMS was the capability to share information through application of a computer network 1. within bureau, and 2. between bureaus.

Analysis of the level 3 - priorities of the 6 information items is presented in Table 4. It was concluded that C4- traffic volume and roadway capacity were valued the most needed information and C2- road/bridge maintenance records were the least needed[Hwang, 1992]. The consistency ratio for each level of the hierarchy is less than 0.1 and the overall hierarchy consistency ratio 0.002 is also less than 0.1 which is an acceptable level Saaty[Saaty, 1980] recommended.

Table 1 Analysis of the Work Contents

Organization / Duty	NFB	NEEB	Other Grmt. orgn.	University	CECI	Other Company
Planning, design Construction	34.78%	71.43%	50.00%	0.00%	77.78%	42.86%
Toll charging, traffic management	17.39%	14.28%	33.33%	0.00%	22.22%	14.28%
Freeway expansion and maintenance	91.30%	14.28%	0.00%	0.00%	11.11%	14.28%
Research and development	17.39%	14.28%	16.67%	100.00%	22.22%	71.43%

Note : NFB ie. National Freeway Bureau NEEB ie. National Expressway Engineering Bureau CECI ie China Engineering Consultants Inc

Table 2 Work Load Computerization Analysis

Organization / Computerized Affairs	NFB	NEEB	Other Grmt. orgn.	University	CECI	Other Co.
Transportation planning/corridor analysis	17.39%	33.33%	33.33%	58.33%	77.78%	66.67%
Prelimiary/detailed Design	13.04%	33.33%	16.67%	33.33%	77.78%	66.67%
Cost estimation billing	52.17%	38.10%	16.67%	0.00%	66.67%	11.67%
Schedule controling	34.78%	33.33%	0.00%	0.00%	44.44%	33.33%
Traffic Condition Monitoring	13.04%	21.43%	50.00%	41.67%	44.44%	11.67%
Maintenance / Management	56.52%	0.00%	16.67%	0.00%	0.00%	16.67%

Table 3 Information Expect to Provide

Expected Information \ Organization	NFB	NEEB	Other Grmt. orgn.	University	CECI	Other Co
Road planning and design	30.43%	57.14%	33.33%	66.67%	77.78%	57.14%
Tunnel monitoring/ traffic control	39.13%	42.86%	0.00%	0.00%	22.22%	42.86%
Traffic conditions	34.78%	50.00%	33.33%	75.00%	77.78%	57.14%
Roadway maintenance Record	86.96%	35.71%	16.67%	0.00%	44.44%	57.14%
Land Use	39.13%	50.00%	16.67%	50.00%	77.77%	57.14%
Construction Management	8.70%	14.28%	0.00%	0.00%	0.00%	0.00%

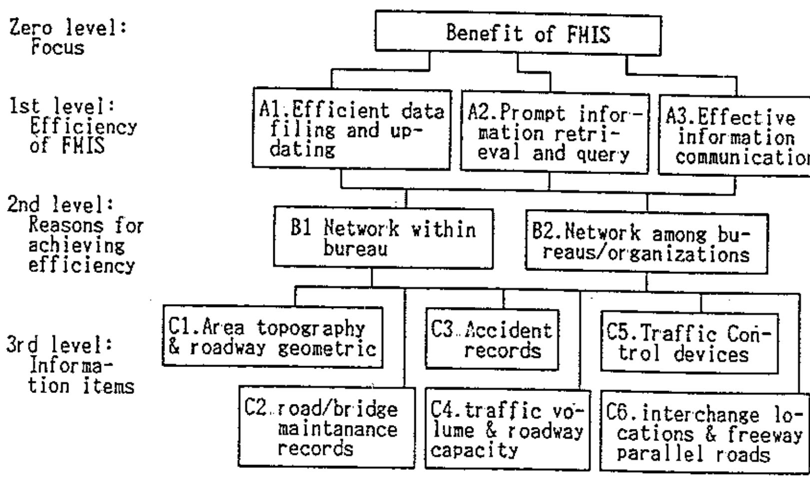

Figure 1 AHP Hierarchy Structure

Table 4 Priority Vectors for Information Items

	C1	C2	C3	C4	C5	C6
Eigenvalue	0.159	0.132	0.189	0.209	0.163	0.148
Priority Order	4	6	2	1	3	5

3. SYSTEM STRUCTURE

After information priorities were ranked, the proposed system was ready for development. The freeway section from Keelung to Yangmei plus the spur to Chiang Kai Shek airport (a total of 80 kilometers in length) was selected to build a prototype system. Figure 2 illustrates the procedure to establish the system.

The system comprises three modules. They are 1. cartographic maps module, 2. attribute database module, and 3. application models module. A short description of these modules follows:

Cartographic Maps Module

One hundred 1:5,000 scaled Taiwan aerial photo maps were used for digitization of the Transverse Mercator coordinates of the studied area. The digitized area covers about 63 x 33 square kilometers. Table 5 illustrates the length of highway digitized and the frequency of feature tag used. A total distance of 1,554.4 kilometers is digitized which equals to 310.9 meters on 1:5,000 maps.

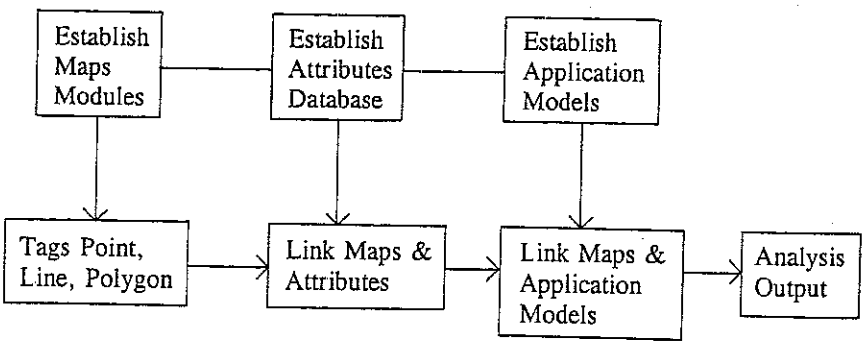

Figure 2 System Development Procedure

Table 5 Map Highway Length Input

Attribute	Length (Meter)	Percent	Frequency
Freeway	146,711.55	9.44%	79
Airport Spur	17,582.16	1.13%	6
Ramp	39,754.52	2.56%	144
Rest Area	2,626.62	0.17%	31
State Highway	157,435.26	10.13%	496
County Highway	168,449.02	10.84%	420
City Street	1,021,832.03	65.74%	6,640
SUMMARY	**1,554,391.17**	**100.00%**	**7,816**

Attribute Database Module

Three kinds of data base were established. They are data bases of 1. basic roadway geometries, 2. traffic volume, and 3. accident records. Data base of the basic roadway geometries includes attributes as follows:

1. starting and ending mileposts of each coded freeway segment

2. function type of freeway segment: in symbol
   T - toll station U - tunnel
   I - interchange L - aircraft landing strip
   R - rest area G - general section
3. construction district
4. maintenance resident division
5. minimum and maximum turning radius
6. minimum and maximum ascending/descending grade

Table 6 illustrates attributes of a freeway segment (42 segments in total) input in the roadway geometry data base.

The traffic volume data base includes a huge amount of data. They are hourly volumes tagged to each freeway segment or to an entrance/exit for a consecutive of 24 hours. Vehicles are classified in six types: 1. passenger car, 2. light truck, 3. bus, 4. heavy truck, 5. trailer truck, and 6. others. The hourly traffic input in the traffic volume data base were based on the 1989 freeway traffic survey[NFB, 1989].

Table 6 Basic Roadway Geometry

No	Mile Post	Name	Lanes	Radius (M)	S.B. %	N.B. %
1	0.0-0.6	Tunnel	4	infinite	0.65	-0.65
2	0.6-1.6	Keelung Interchange	4(6)	1000	-2.4/-0.35	0.35/2.4
3	1.6-4.0	Keelung	4	500-800	-1.6/1.6	-1.6/1.6

The accident data base includes 1,114 accident records from January 1879 to March 1991. They are data of point feature and are grouped together for further analysis in an unit of accident per kilometer. The description of an accident in the data base includes: 1. travel direction, 2. weather, 3. illumination, 4. location, 5. vehicle, 6. collision type, 7. death, 8. injury, etc. In order to indicate the relative hazardousness of a location, an index of equivalent total accident number (ETAN) is calculated and added to the data base which has the form as follows:

$$ETAN = 9.5 \times F + 3.5 \times J + TAN$$

F = fatality number
J = injury number
TAN = total accident number

Application Models Module

This part of the system was primarily designed for analysis of the traffic level of service (LOS), accident severity, and information inquiry.

In traffic LOS analysis, the module uses the Taiwan Highway Capacity Manual[IOT, 1990] as an evaluation tool supplemented with the 1985 U.S. HCM[TRB, 1985]. A capacity value of 2,400 pcu/hour/lane was used for basic freeway section and those passenger car equivalents listed in Table 7 are used.

Table 7 Passenger Car Equivalents

Vehicle Type	Passenger Car	Light Truck	Bus	Truck	Trailer Truck	Others
PCE	1.0	1.0	1.5	1.5	2.5	2.0

In safety analysis, GENAMAP supports statistical analysis for accident data such as fatality, injury, and ETAN. Table 8 lists those statistics.

Table 8 Statistical Analysis

Items	FATALITY	INJURY	ETAN
Minimum Value	0	0	1
Maximum Value	8	50	223.5
Mean	0.430	1.898	11.727
Variance	0.574	12.189	238.753

unit: number/kilometer

4. SYSTEM CAPABILITIES

The capabilities of FTIMS are established through a group of macro commands written in GENAMAP language to link data bases with application models. A macro command executes a batch file to do an analysis or a query. It then displays the result on a screen to form a thematic map. Because development of the proposed FTIMS is an on-going process, its capabilities have been added gradually. Table 9 lists the abilities currently supported by the FTIMS

Table 9 System Capabilities

MACRO COMMANDS	Command Function
PLOTIND	display freeway and adjoining roads
PLACE	display roadway type
PLOTSEC	display interchanges and toll stations
PLOTRAD	query turning radius for a road section
PLOTGRA	query ascending or descending grade %
PLOTGRADM	query both grade and turning radius
PLOTVOLM	query/display traffic volume for a specific vehicle type on a road section during a specific hour
PLOTLOS	display LOS for a specific road section
PLOTACC	display accident locations
PLOTETAN	display ETAN class for road sections

5. SYSTEM APPLICATION

Level of Service Analysis

For application of the system, this study evaluated traffic volume to identify when and where the freeway has the lowest level of service. A six-points weight scale assigned to LOS A-F was used. Evaluation of the freeway (18 sections from Keelung to Yangmei) shows that the northbound traffic is the most congested from 5-6 p.m. with a freeway total weight of 50 points. An average weight of 2.78 points per section indicates a B to C LOS. For southbound traffic, it is most serious from 4-5 p.m. with a total weight of 47 points. An average weight of 2.61 points indicates that the LOS of southbound traffic is also ranked between B and C.

This study also took the average freeway volume/capacity ratio as another evaluation tool. Figure 3 and 4 illustrate the results which conclude the average V/C ratio is the highest from 5-6 p.m. (0.700) with C LOS for northbound traffic. For southbound traffic, the average V/C ratio is the highest from 10-11 a.m. (0.625) with C LOS. The aforementioned analysis give a comparison of the two evaluation methods used, weight scale v.s. V/C, and shows that they are not fully consistent.

For an individual freeway section, the FTIMS was also employed to review LOS for the freeway section between Yuanshan and Taipei. It is found the section has the highest V/C ratio 0.874 (LOS D) from 4-5 p.m. for northbound traffic and the highest V/C ratio 0.831 (LOS D) from 11-12 a.m. for southbound traffic.

Accident Analysis

In accident analysis, Figures 5 and 6 display distribution of the 1,114 accidents along the freeway. Figures 7 and 8 show ETAN distribution respectively. It is seen from the figures that northbound travel has both the highest accident number (42) and ETAN (671.5) at 35-36km. Southbound travel has both the highest accident number (16) and ETAN (362) at 45-46km. Such an identification process for travel hazardous locations can then be used for improvement.

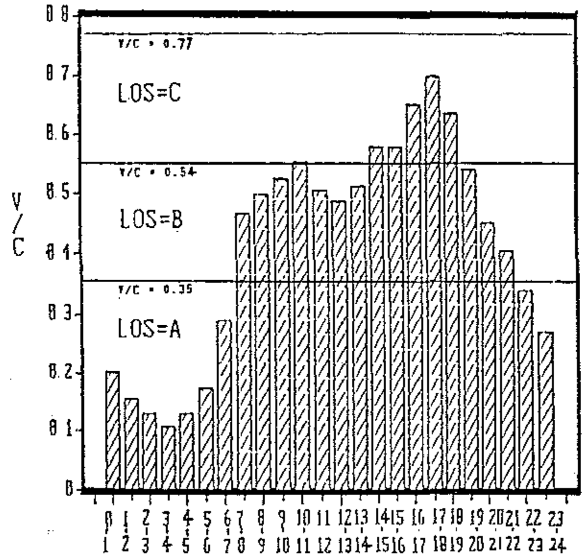

Figure 3 Average V/C Ratio, N.B.

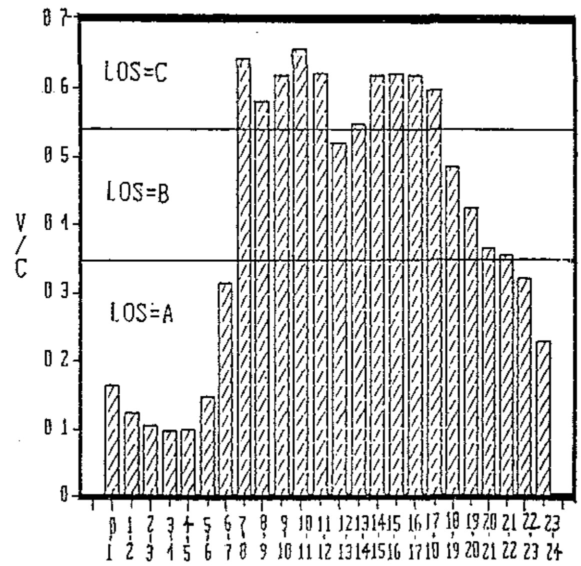

Figure 4 Average V/C Ratio, S.B.

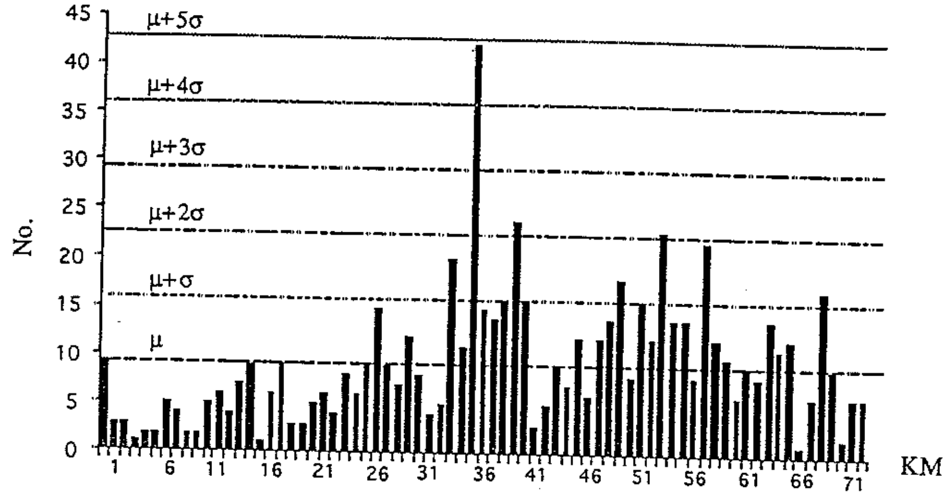

Figure 5 Accident Distribution, N.B

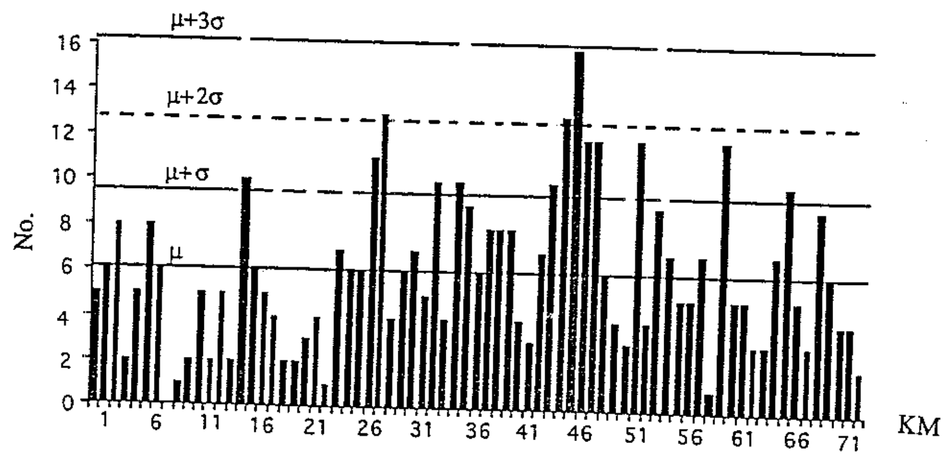

Figure 6 Accident Distribution, S.B

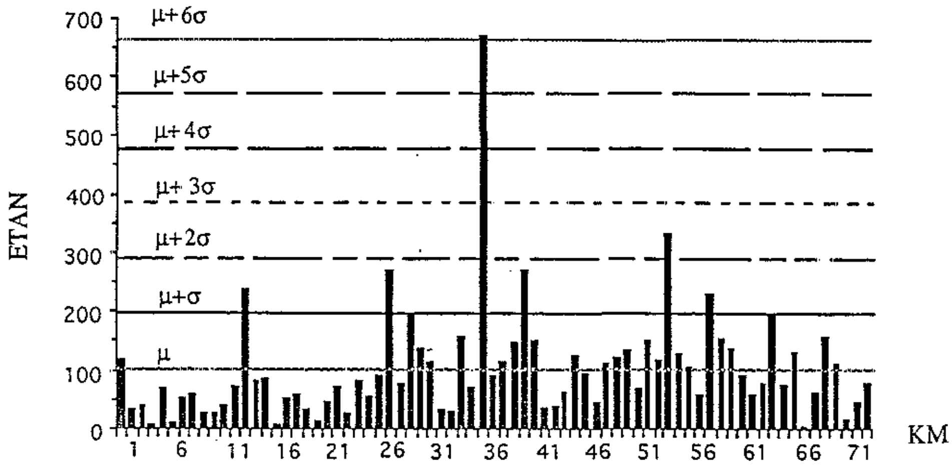

Figure 7 ETAN Distribution, N.B.

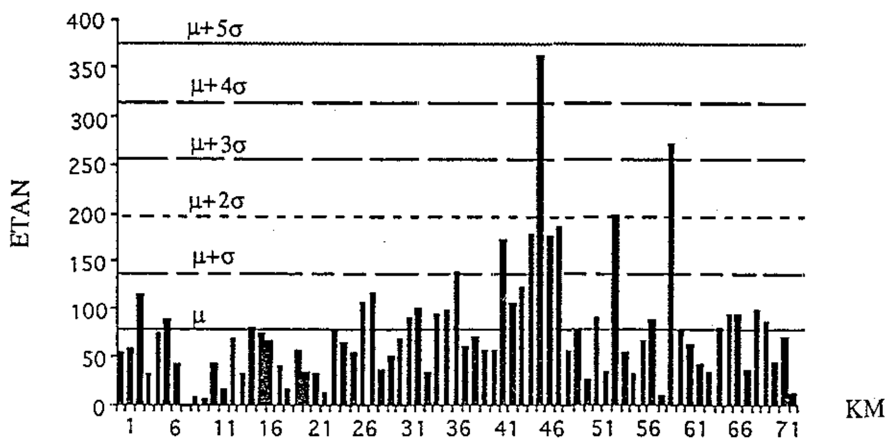

Figure 8 ETAN Distribution, S.B.

6. CONCLUSION

From the AHP analysis and development experience of the FTIMS, this study has the following conclusions about freeway management information needs, accident analysis, and those possible applications of FTIMS.

1. The most needed information to develop a FTIMS were ranked 1. traffic volume and roadway capacity, 2. accident records, 3. traffic control devices, 4. area topology and roadway geometry, 5. interchange locations and freeway adjoining roads, and 6. road/bridge maintenance records.

2. The developed prototype system includes a. cartographic maps module, b. attribute database module, and c. application models module. Both traffic volume/roadway capacity and accident records are two major components of the attribute database module.

3. The developed prototype system can assist an user to query both freeway geometries and traffic characteristics to display them on a screen.

4. From the application of the prototype system, it is learned that the studied freeway had an average B to C level of service during peak hour. For an individual freeway section, level of service maybe as bad as D and its V/C ratio could be as high as 0.874.

5. In general, on the studied section of Sun Yat-sen Freeway, traveling northbound is more dangerous than traveling southbound. Northbound has both higher fatality rate and injury rate, 3.6 versus 3.0 persons and 16.9 versus 12.0 persons.

6. The 35 kilometer northbound milepost at Taishan toll station is ranked the most dangerous to travel in the study area. Forty two accident had occurred at this milepost for the past 12 years and its equivalent total accident number is as high as 671.5 The site needs immediate improvement.

REFERENCES

Ho, Y.L., "A Study of the Freeway Traffic Management GIS," Master Thesis, pp.4.8-4.9, National Cheng-Kung University, 1992.

Hwang, K.P. and Y.L. Ho, "Ranking Information Needs for Freeway Management by a Two-Stage Analytical Hierarchy Process," Proceedings of the 10th International Conference on Multiple Criteria Decision Making, pp.229-240, July 19-24, 1992, Taipei.

IOT, "The Highway Capacity Manual in Taiwan," pp.II.1-101, Ministry of Transportation and Communications, 1980.

NFB, "The 1989 Sun Yat-Sen Freeway Traffic Survey," pp.25-45, Taiwan Area National Freeway Bureau, 1989.

NFB, "The 1990/1991 Sun Yat-Sen Freeway Annual Report," pp.2-3, Taiwan Area National Freeway Bureau, 1992.

Saaty, T.L., "The Analytical Hierarchy Process," McGraw-Hill Company, 1980.

TRB, "Highway Capacity Manual," Special Report 209, pp.3.1-3.34, National Research Council, Washington, D.C., 1985.