Quantitative Evaluation of Accidents Due to a Complex Traffic Environment

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ABSTRACT

It is very important to understand roadway safety performance for effective safety management and road improvement. In this study, we quantitatively evaluated the following: how a driver recognizes and judges a road environment; how the driver reacts; and how the context causes the driver to error. We assume that traffic accidents are caused by a combination of various factors: geometric design, road signs/symbols, traffic control, and traffic flow. A particular context generated by two or more factors causes a certain type of accident. We evaluated accident factors caused by complex traffic environments by using historical accident data, accident spot survey, and multivariate statistics.

Accident analysis sheets document time-series driving behaviors, human errors, and the road environment. The relationship between accidents and the road environment was classified into three stages: low (1), normal (3), and high (5). We performed factor analysis on the accident analysis sheet and extracted factors from the road environment. Five common factors were extracted from the head-on and rear-end collisions. This paper introduces a new concept for estimating safety performance before and after intersections.

INTRODUCTION

In 2004, 65% of the traffic accidents that occurred in Tokyo were intersection-related crashes. Of these accidents, 82% involved serious injuries, and death occurred in 73% of crashes at or near an intersection, as shown Table 1. Furthermore, 34% of the deaths involved a pedestrian or bicycle riders who were crossing the pedestrian lane (Tokyo Metropolitan Police Department; MPD, 2005). Intersection accidents have similar characteristics in the United States (National Highway Traffic Safety Administration; NHTSA, 2005). Given the high proportion of intersection crashes and high severity, MPD identified 137 sites in Tokyo where the rate of accident is highest and introduced measures to reduce 30% of accidents within five years (2005-2010).

Treat (1977) found that human error was the sole cause in 57% of all accidents and was a contributing factor in over 90%. However, human error characterizes the outcome of an action rather than the cause of a traffic accident. That is, the safety of a traffic system is determined by the outcomes of interactions between the vehicle, human (driver), and the road.

Table 1 Intersection-related accident statistics

Tokyo, 2004

		Total	Total intersection-related accidents	Signalized	Unsignalized
Crashes	Number	86,118	55,911	26,034	29,877
	Percent Total (%)		65%	30%	35%
Total injured persons	Number	98,262	62,883	30,105	32,778
	Percent Total (%)		64%	31%	33%
Deaths	Number	320	232	114	118
	Percent Total (%)		73%	36%	37%
	Pedestrian/bicycle		78		
Seriously injured persons	Number	1,365	1,118	553	565
	Percent Total (%)		82%	41%	41%
	Pedestrian/bicycle		284		
Slightly injured persons	Number	41,648	23,403	16,549	6,854
	Percent Total (%)		56%	40%	16%
	Pedestrian/bicycle		4,993		

Note : Urban street crashes (Experessway crashes are excluded)

Driving involves a series of perception, cognition, decision, and motor responses. The driver's task is highly cognitive in nature and is dependent on mental processes. Human error is a result of an inappropriate or undesirable mental process. Rasmussen (1983) suggested that human error should be replaced with man-machine misfits. He makes a provocative point that an action might become an error only because the action is performed in an unkind environment that does not permit detection and reversal of the behavior before an unacceptable consequence occurs. Rasmussen (1982) identifies 13 types of error and three levels of behavior involved: skill-based, rule-based, and knowledge-based behavior. This model is known as the Step-Ladder Model (SLM) or S-R-K model. Skill-based behavior is controlled by subconscious routines and stored patterns of behavior and is appropriate for skilled operations in routine situations. Rule-based behavior is also a type of behavior that becomes activated in familiar work situations, but it is distinguished from skill-based behavior by requiring some degree of conscious involvement. Knowledge-based behavior occurs in unique, unfamiliar situations for which actions must be planned in relation to a goal. However, the Step-Ladder Model (SLM) has a disadvantage in that it is not always easy to distinguish between the different levels of cognitive control (Dougherty E. M., 1990).

Hollnagel (1990) proposed the term *erroneous action* to characterize a certain type of action without implying anything about the cause. An erroneous action is an action that fails to produce the expected result and, therefore, leads to an unwanted consequence. Hollnagel identifies four types of erroneous action and four characteristic control modes as follows: scrambled, opportunistic, tactical, and strategic control modes. A scrambled control mode means that the choice of the succeeding action is apparently irrational or random. An opportunistic control mode means that the choice of the succeeding action is determined by the salient features of the situation with limited planning or anticipation. The tactical control mode is characteristic of situations where performance more or less follows a known procedure or rule. The strategic control mode is used when a person uses a wider time horizon and looks ahead at higher level goals. This model is known as the contextual control model (COCOM). Table 2 shows error mode and phenotype.

Table 2 Taxonomy of phenotype of erroneous action

Error Mode	Phenotype	Definition
Action in wrong place	Repetition	An action has been carried out twice
	Omission	An action has been omitted from consequence
	Jumping	An action jump forward/backward in the consequence
Action at wrong time	Delay	An action does not occur when it is required
	Premature action	An action occurs when no action was expected
Action of wrong type	Replacement	An action in a sequence is substituted by an equivalent action
Action not included in current plan	Intrusion	It occurs if the action does not belong to the action sequence, and if it disrupts it.
	Insertion	The action does not belong to the action sequence and if it does not disrupt

Note :

1) Action in wrong place: the action belongs to the current sequence but is placed incorrectly.

2) Action at wrong time: the action was not carried out when it was required.

3) Action of wrong type: the action was incorrect although not so wrong that it disrupted the current plan.

4) Action not included in current plan: the action does not belong to the current action sequence.

AASHTO's design policy (American Association of State Highway and Transportation Officials, 1990) is based on the following driver performance characteristics: detection-recognition time, perception-reaction time, brake-accelerator movement time, and time to shift gears. The driver's characteristics are central in defining the operational state of the traffic system. In the Highway Capacity Manual (Transportation Research Board, 1985), the basic tenets of the calculations for level of service (LOS) for uninterrupted and interrupted flow are set forth.

FHWA (Loren Staplin et al., 1997) investigated the relationship between human error based on accident data and four highway elements: road geometry, road operation, traffic control devices, and traffic lighting. The investigation was conducted by focusing on the effects of specific highway elements and design criteria of the driver's cognitive capability. The geometric aspects of intersections affect its level of safety and level of service. These features are visible to the driver and affect the driver's performance. Intersection models in the IHSDM (Interactive Highway Safety Design Module) are a set of statistical models for predicting crashes at two- and four-lane intersections. The crash prediction module is based on historical accident data. It has an accident prediction algorithm for the five types of rural at-grade intersections. For each of the five intersection types, there are three different sets of models. The first type is the annual average daily traffic (AADT) model, which includes base models for predicting crashes as a function of major and minor road AADT. The second type includes full models. These models are meant to provide a fuller understanding of the geometric, roadside, and operational features of intersections that influence crashes. These statistical models forecast crashes as a function of a relatively large set of independent variables. The third type of model is an accident modification factor (AMF). This model represents the estimated effects of various geometric, roadside, and operational features (Andrew Vogt, 1999).

Historical accident data are important indicators of the safety performance of a roadway. In particular, a high-accident location is a roadway section or intersection that is identified because it experienced more than a specified threshold number of accidents during a recent period. An improvement project may be programmed and constructed locations where a particular accident pattern is clearly evident and an appropriate countermeasure is feasible. Many statistical models that predict the accidents on roadways and at intersections have been proposed. Such models are developed by historical accident data and roadway characteristics: traffic flow, road geometric features, and traffic control features. Most of them were developed with multiple regression analysis to estimate the values of the coefficients or parameters in that model. Regression models are very accurate tools for predicting the expected total accident experience for a location or a class of locations (K.M. Bauer and D.W. Harwood, 2000). Regression models are based on statistical correlations between roadway characteristics and accidents that do not necessarily represent cause and effect relationships. If the independent variables in the model are strongly correlated to one another, it is difficult to separate their individual effects. Furthermore, traffic accidents are very rare events and many locations experience no accidents, or at most one accident, over a period of several years.

This study focuses on understanding and quantitatively evaluating the following: how a driver recognizes and judges a road environment; how the driver reacts; and the context that causes driver error. We assume in this study that traffic accidents are caused by a combination of various factors. The main factors contributing to traffic accidents are classified as follows: road geometry, signal control, roadside conditions, traffic flow, lighting, and obstacles. These factors are not mutually exclusive. The context generated by the causal relationship of two or more factors causes a certain type of accident. In order to make an effective accident prevention plan, it is important to understand a driver's cognitive process with these factors and context without giving the driver too great of a cognitive workload. A result of this study can be applied as a new concept for estimating safety performance before and after an intersection.

METHOD

GEOMETRICAL AREA

For practical reasons, this study was limited to the Seta intersection, where one of the heaviest traffic volumes in Tokyo and traffic congestion occurs frequently. As shown in Fig.1, the Seta intersection is a channelized five legs intersection. There are two arterial roads with three lands each and two Metro local road: National highway N466, N246 (Tamagawa-Dori) and Metropolitan highway N311 (Kanpachi-Dori), N427 (Seta Nukui line). N246, N311, and N466 have six traffic lanes (width: 3.5m/lane) and a median strip. Four lanes of the N246 are passing under the N466. The intersection approach is divided into four lanes: two through lanes, an exclusive right-turn lane, and an exclusive left-turn lane (width: 3.3m/lane). Except for the approach from Takaido (from west to east), pedestrian bridges are provided. However, a bicycle cannot pass because it does not have a move-lane for bicycles. Thus, bicycle accidents occur frequently. The annual average traffic accident frequency in this area is 60 or more. It was specified as a hazardous road section by Tokyo MPD in 2004. West bound of N466 is also connected to the Tomei Expressway, Metropolitan Expressway, and carries many heavy trucks.

The total traffic volume was an average of 8,000 vehicles per hour (vph). The peak hour volume is more than 9,000 vph. Table 3 shows traffic flow and signal control features, which were measured by the authors in 2004. The traffic signal cycle time is about 160 seconds.

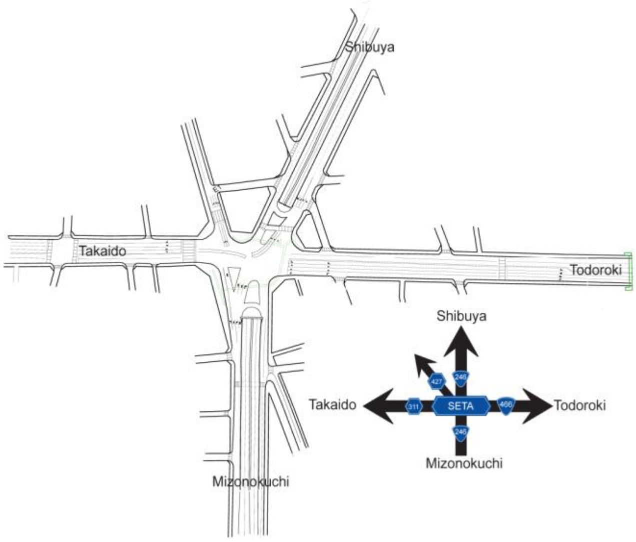

Fig.1 Features of Seta Intersection

Table 3 Features of traffic flow and signal control (Seta intersection)

[August, 2004]

Root name	Metroporitan highway 311				National highway 466				National highway 246						Metroporitan highway 427		
Direction	East bound (Todoroki)				West bound (Takaido)				North bound (Sibuya)			South bound (Mizonokuchi)			South-bound		
	LT	TH1	TH2	RT	LT	TH1	TH2	RT	LT	TH	RT	LT	TH	RT	LT	TH	RT
Traffic Volume(Veh/h)	358	634	611	199	346	878	713	439	436	48	312	250	50	339	64	78	38
Heavy Vehicle(Veh/h)	52	96	167	23	32	119	189	143	126	3	35	7	6	55	0	10	6
% Heavy Vehicle	15%	15%	27%	12%	9%	14%	27%	33%	29%	6%	11%	3%	12%	16%	0%	13%	16%
Pedestrian*bicycle/h		121*251				*				*			*			*	
Signal Phasing		φ1		φ2		φ1		φ2		φ5	φ4		φ5	φ4		φ3	
Green Time(s)		78		22		65		15		13	12		13	12		15	
Yellow Time(s)		4		4		4		4		4	4		4	4		4	
Notes		19sec (φ3)				Pedestrian bridge				Pedestrian bridge			Pedestrian bridge			Pedestrian bridge	

Note:
1) LT: Left turn lane, TH: Through lane, RT: Right turn lane
2) Heavy Vehicle: The truck or bus exceeding net gross 10 ton

DATA COLLECTION

The following parameters are observed and investigated in a traffic environment in the field: intersection legs, road alignment, spacing between intersections, lane width, right and left turn lanes, number of lanes, channelization, signal control, traffic flow, vehicle behavior, behavior of pedestrians and bicycles, traffic signs, road markings, and roadside condition.

Traffic accident analysis is the basis for formulating appropriate traffic measures that are applicable to the real world. In this study, we used traffic accident records taken from the Tamagawa Police Station, Tokyo MPD. The essential issues in analyzing traffic accidents at the SETA intersection are the following: (a) to investigate the relationship between human errors based on accident data and four highway elements that include road geometry, road operation, traffic control device, and traffic lighting; (b) to evaluate traffic environments at accident spots according to the accident analysis sheet and virtual reality simulation (VR-simulation); (c) to analyze and determine the primary accident factors due to the traffic environment using multivariate statistics.

VR simulation

The VR model is based on the road plan (design), aerial photograph, road map, and a field investigation. The UC/WIN Road virtual simulation tool is used (Furum8 Ltd.) to reproduce the following: surrounding vehicles, traffic signals, the climate, sight distance, and the movement of a viewpoint (pedestrian, bicycle, and cockpit). Surrounding vehicles were generated by micro-traffic simulation models. The traffic generation model has three main parameters: a random number generator with a Poisson distribution, a vehicle dynamics model based on the vehicle type, and traffic models (car-following, gap-acceptance, and lane-changing models). It was used mainly to evaluate sight distance, traffic sign visibility, road markings, and accident spots where a safe approach is difficult. Fig. 2 shows a sample screenshot taken from the simulation.

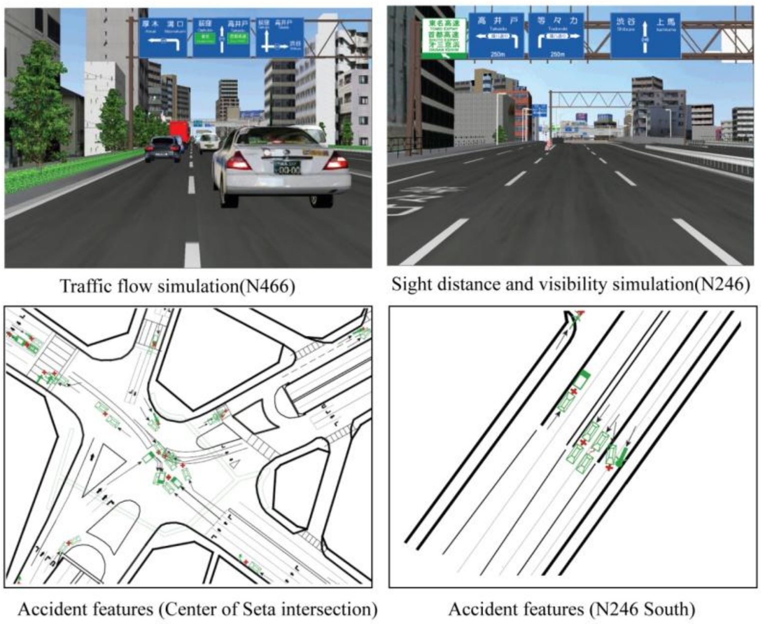

Fig. 2 Sample screenshot taken from simulation

Field survey

In the accident record analysis, we used traffic accident analysis and a management system (KOA/TBS) from the Tamagawa Police Station, MPD, within a 50-meter radius from the center of SETA Intersection, for the past two years (2004 to 2005). Traffic accidents due to a criminal offense (e.g., drunk driving or drugs) were not considered because the purpose of this study is to evaluate human error due to the traffic environment.

The accident analysis sheet was classified into road geometry, pedestrian crossing or obstacle, traffic restriction or traffic control, and traffic flow characteristics. Table 4 and Table 5 show details of the evaluation criteria. A total of 91 injury accidents were investigated, and in order to carry out a quantitative evaluation of the road environment, accident relevance was classified into three stages: low (1), normal (3), and high (5).

These factors are used to form uncorrelated linear combinations of the observed variables. The first component has maximum variance. Successive components explain progressively smaller portions of the variance and are all uncorrelated with each other.

DATA ANALYSIS

To analyze and determine the primary accident factors, we performed factor analysis from the accident analysis sheet and extracted factors from the traffic environment. Factor analysis is a type of multivariate analysis that attempts to identify underlying variables or factors that explain the pattern of correlations within a set of observed variables.

Various factor analysis procedures include principal component analysis (PRIN) for factor extraction, *varimax* rotation, and an SSPS computing tool (SPSS Inc.)

Table 4 Evaluation criteria of rear-end collisions

Category Factors	Variable name	Detail component
Road Geometry		
Poor visibility	X1	A car in front cannot be easily seen from a rear vehicle.
	X2	Existence of a crossing is overlooked at a non-signal crossing.
A channelized left-turn lane.	X3	Lane un-installing only for right-turn.
Pedestrian Crossing institution		
Visibility prevention	X4	A car in front cannot be easily seen from a rear vehicle for a place along the route structure
	X5	A scene, a signboard, a pedestrian, light leak, etc. serve as a vision noise, and it is front carelessness.
	X6	A signal light and them does not appear easily.
Obstacles		
Indication of a lapse in judgment	X7	Looking aside while driving by a conspicuous place along the route institution.
The obstacle of a function	X8	The multi-lane road of a division line, a sign, and a display is inadequate.
	X9	Lane stray by unclear road sign, road surface label,and item.
Traffic restriction or traffic control		
Visibility prevention	X10	A car in front cannot be easily seen from a rear vehicle with obstacles, such as parking vehicles.
Signal parameter	X11	Lapse of judgment (clearance intervals) at the dilemma zone.
	X12	Impossible crossing penetration of the rear vehicle resulting from impatience of crossing passage.
Place-along-the-route receipts-and-payments stopping-and-parking action	X13	Visibility complications along the route: route receipts and payments or stopping and parking vehicles.
Traffic flow		
Mismatching of transport demand and crossing control	X14	Traffic cannot pass because it is blocked by the car that was rear-ended.
	X15	Impossible crossing penetration of a rear vehicle resulting from complication with crossing pedestrian demand and its vehicles.
Visibility prevention	X16	It is unclear from a rear vehicle that a car in front is stopping or decelerating.
Unsuitable operation	X17	Stray.
	X18	Sudden interruption, a slam on the brake.
	X19	A succession vehicle running speed instigates a car in front highly.

Table 5 Evaluation criteria of head-on collisions

Category Factors	Variable name	Detail component
Road Geometry		
Poor visibility	X1	It is difficult for the partner vehicles to see one another.
	X2	Intersection geometry feature is unclear at the time of intersection penetration. (e.g., inadequatet sight distance or ambigus road sign/road marking)
	X3	The existence of an intersection is overlooked at a non-signal intersection.
	X4	The speed of the intersection direction partner vehicle is unclear.
	X5	The gap of the intersection direction partner vehicles is unclear.
Indication of a lapse in judgment	X6	The direction of movement of the intersection direction partner vehicles is unclear.
	X7	A sense of distance of the intersection direction vehicles and presencecannot be recognized.
Pedestrian intersection institution		
Visibility prevention	X8	The intersection direction partner vehicles are difficult to see due to the pedestrian pathway or intersection construction.
	X9	Misconception or poor recognition of a signal light.
Obstacles		
The obstacle of a function	X10	The contents of signal control are unclear.
	X11	In a non-signal intersection, the halt sign or label is not clearly visible.
	X12	There are many vehicles which do not stop at a non-signal intersection.
Indication of a lapse in judgment	X13	The drives does not check if the car in front of him is moving.
	X14	The driver is distracted by a pedestrian, signboards, or some other situation.
Traffic restriction or traffic control		
Signal parameter	X15	Lapse of judgement of signal change (clearance intervals)
	X16	Impossible intersection penetration by impatience of intersection passage
	X17	The going-straight direction is blocked, yet there is road beyond the intersection.
	X18	No sign or stop label in a non-signal intersection.
Inducement priority-related is incongruent.	X19	The traffic between non-priority and priority roads is reversed at a non-signal intersection.
	X20	The width between non-priority and priority roads is reversed at a non-signal intersection.
Traffic flow		
Visibility prevention	X21	Vehicles appeared suddenly from the shade of vehicles in queuing.
	X22	Vehicles appeared suddenly from the back of vehicles in queuing.
Inducement of lapse of judgment	X23	Misconception of the direction vehicles speed of a intersection.
	X24	A front car is followed and it collides with the intersection direction vehicles.
	X25	A two-flower vehicle appeared from the width which the intersection direction vehicles stopped.
Mismatching of transport demand and intersection control	X26	The transport demand sold well safely is exceeded at a non-signal intersection.
Inducement of lapse of judgment	X27	Inconsistency which is confirming safe conditions at a non-signal intersection.

RESULT

DRIVER'S ACTION AND PHONETYPES OF ERRONEOUS ACTION

A driver's action type at the time of an accident was classified into the following: slowdown and stop to wait for green signal, left turn, right turn, car following, lane changing, or passing. The phenotype of erroneous action was classified into one of the following: omission, intrusion, delay, replacement, or premature action. Fig.3 shows the relationship between a driver's action type and erroneous action phenotypes.

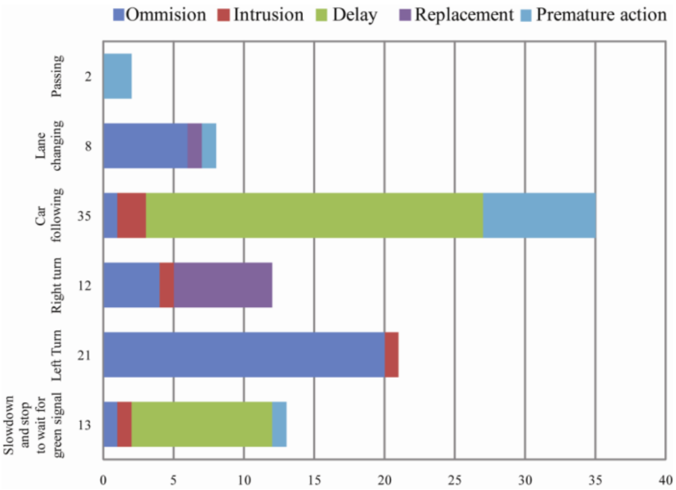

Fig. 3 Driver's action and erroneous action phenotypes

Fig.4. shows the results when a driver's action type is classified into one of four error modes. That is, 48% of the accidents that occurred at the Seta intersection result from 'action at wrong time' and that 35% result from 'action in wrong place'. They are caused by the sudden behavior of a front car (e.g., acceleration, deceleration, and breaking in to the line). It is important to secure sufficient sight distance for a driver to access the likely motion of front vehicles. As a result, most intersection accidents originate not from performing suitable action in a suitable time, but rather driving skill or simple reaction time (RT).

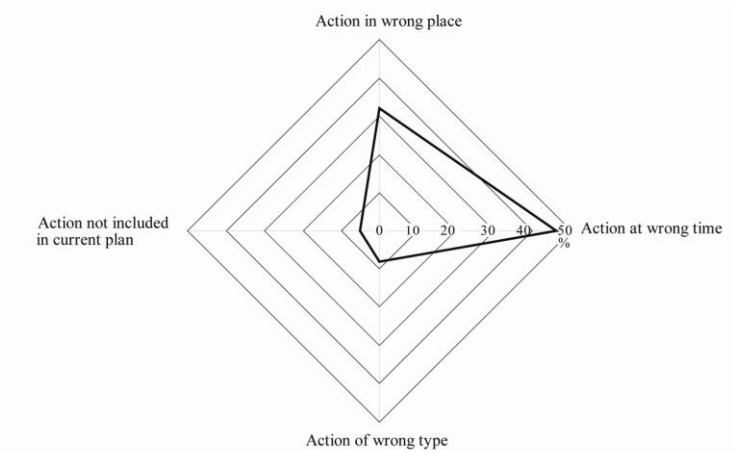

Fig. 4 Erroneous action error mode

ACCIDENT FACTOR DUE TO TRAFFIC ENVIRONMENT

Principal Component Analysis (PRIN) is a multivariate technique for examining relationships among several quantitative variables. The initial accident factor solution was obtained from the accident analysis sheet. Generally, the main factors are those that have large component contribution. Table 6 and Table 7 show the results of the principal component analysis. In rear-end collisions, five common factors were extracted and with a cumulative influence of 79.6. This means that 79.6% of rear-end collisions are related to five common factors. By the same method, 93.7% of head-on collisions are explained by five extracted common factors. Factor rotation is a method for clarifying the relationship between each factor and its evaluation components.

Table 6 Total variance explained (Rear-end collisions)

Component	Initial eigenvalues			Extraction sums of squared loadings			Rotation sums of squared loadings		
	Total	% of variance	Cumulative %	Total	% of variance	Cumulative %	Total	% of variance	Cumulative %
1	4.27	28.48	28.48	4.27	28.48	28.48	3.52	23.49	23.49
2	2.79	18.58	47.06	2.79	18.58	47.06	2.90	19.35	42.83
3	2.01	13.43	60.49	2.01	13.43	60.49	2.18	14.55	57.38
4	1.66	11.05	71.54	1.66	11.05	71.54	1.78	11.88	69.26
5	1.21	8.05	79.60	1.21	8.05	79.60	1.55	10.34	79.60

Extraction Method: Principal Component Analysis.

Table 7 Total variance explained (Head-on collisions)

Component	Initial eigenvalues			Extraction sums of squared loadings			Rotation sums of squared loadings		
	Total	% of variance	Cumulative %	Total	% of variance	Cumulative %	Total	% of variance	Cumulative %
1	6.95	34.74	34.74	6.95	34.74	34.74	6.10	30.50	30.50
2	4.46	22.31	57.05	4.46	22.31	57.05	3.91	19.53	50.02
3	3.34	16.71	73.76	3.34	16.71	73.76	3.34	16.72	66.74
4	2.31	11.55	85.31	2.31	11.55	85.31	2.78	13.92	80.66
5	1.68	8.38	93.69	1.68	8.38	93.69	2.61	13.03	93.69

Extraction Method: Principal Component Analysis.

The *varimax* method is an orthogonal rotation method. It is used when all factors are independent of each other, and it minimizes the number of variables that have high loadings on each factor. This simplifies the factor interpretation. The final cumulative estimates are the proportion of variance of the variables accounted for by the common factors. When the factors are orthogonal, the final communalities are calculated by taking the sum of squares of each row of the factor pattern matrix. A communality (XC_i) of evaluation component X_i is described in equation (1), and the contribution (percentage of variance, FC_j) of common factor F_j is described in equation (2).

$$XC_i = \sum_{j=1}^{m} b^2{}_{(i,j)} \qquad (1)$$

$$FC_j = \sum_{i=1}^{p} b^2{}_{(i,j)} / p \qquad (2)$$

where b_{ij} are the factor weights,
i is the *i*-th evaluation component (1,2,3, …., p) , and
j is the *j*-th common factor (1,2, …m)

We judged that five factors are independent of each other. Table 8 and Table 9 show the results of the varimax rotation of the five extracted factors and the final cumulative estimates of the rotated factors.

Table 8 Rotated component matrix (Rear-end collisions)

Variable name	Component factors					Cummunality
	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	
X1	-0.06	-0.28	0.07	**0.82**	-0.04	0.76
X2	**0.71**	-0.43	0.14	-0.39	-0.09	0.87
X3	-0.18	-0.07	0.05	**0.86**	-0.08	0.78
X4	-0.47	-0.28	0.34	-0.13	**0.59**	0.78
X5	0.33	**0.75**	-0.08	0.09	0.05	0.70
X6	-0.18	**0.81**	-0.17	-0.25	-0.13	0.80
X7	0.08	0.18	-0.26	0.04	**0.85**	0.83
X8	0.28	**0.88**	-0.08	-0.09	0.01	0.86
X9	**0.93**	0.05	0.12	-0.04	0.05	0.89
X10	-0.22	-0.23	0.35	-0.19	**0.62**	0.65
X11	**0.94**	0.11	-0.09	-0.05	-0.05	0.91
X12	**0.85**	0.12	-0.25	-0.12	-0.21	0.85
X13	-0.17	**0.66**	0.13	-0.22	-0.04	0.53
X14	-0.06	-0.04	**0.91**	-0.02	0.06	0.83
X15	0.00	-0.04	**0.94**	0.15	-0.04	0.91
Sums of squared factor loadings	3.52	2.90	2.18	1.78	1.55	11.94
Contribution (%)	**23.49**	**19.35**	**14.55**	**11.88**	**10.34**	**79.60**

Rotation method: Varimax rotation

Table 9 Rotated component matrix (Head-on collisions)

Variable name	Component factors					Cummunality
	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	
X1	**0.86**	0.18	-0.17	0.03	0.44	0.99
X4	-0.13	0.25	0.56	0.05	**0.76**	0.97
X5	-0.23	0.09	-0.22	0.20	**0.92**	1.00
X7	0.36	0.07	**0.84**	0.28	0.23	0.98
X8	0.15	-0.18	**-0.73**	0.00	0.03	0.60
X9	-0.41	0.14	-0.05	**-0.64**	-0.53	0.89
X11	**0.94**	-0.33	-0.03	0.08	-0.08	1.00
X12	**0.94**	-0.33	-0.03	0.08	-0.08	1.00
X14	-0.10	-0.19	**-0.92**	0.16	0.14	0.94
X15	**-0.75**	0.38	0.38	-0.30	-0.06	0.95
X16	-0.33	**0.92**	0.12	-0.11	-0.12	0.99
X17	-0.14	**0.90**	0.15	0.21	0.14	0.92
X18	**0.87**	-0.18	0.33	-0.16	-0.19	0.97
X21	**0.87**	-0.18	0.33	-0.16	-0.19	0.97
X22	0.56	0.00	0.11	-0.59	0.56	0.99
X23	-0.16	0.33	0.11	**0.91**	0.15	0.99
X24	-0.14	**0.65**	0.23	0.52	0.25	0.82
X25	**-0.58**	-0.47	0.48	-0.01	0.30	0.87
X26	-0.14	**0.90**	0.15	0.21	0.14	0.92
X27	0.53	0.24	-0.36	**0.72**	-0.04	1.00
Sums of squared factor loadings	6.10	3.91	3.34	2.78	2.61	18.74
Contribution (%)	**30.50**	**19.53**	**16.72**	**13.92**	**13.03**	**93.69**

It shows the proportion of variance explained by each factor and the final cumulative estimates, including the total cumulative estimate. The final cumulative estimates are the proportion of variance of the variables accounted for by the common factors. After the factors are estimated, it is necessary to interpret them. Interpretation usually means assigning a name to each common factor that reflects the salient points of the factor in predicting each of the observed variables, that is, the coefficients in the pattern matrix that correspond to the factor. In order to indicate a salient variable-factor relationship, factor loadings are usually required to have a value greater than |0.4|. In this table, we type the bold-faced values larger than |0.6| (rounded off to one decimal place).

This represents the relationship between five common factors and the evaluation details from the accident analysis sheet. For example, common factor 4 of rear-end collision accident is strongly explained by variable X1 (0.82) and X3 (0.86).

Rear-end collisions

For rear-end collisions, the contribution ($FC_{j)}$ common factors j(1-5) are 23.49%, 19.35%, 14.65%, 11.88%, and 10.34%. Each common factor name stands for the characteristic of each variable. The bold-faced values in Table 8 are larger than |0.6|, and the following are the common factor names:

- Factor 1: X2, X9, X11, X12 > |0.6|, FC_1=23.49%, error caused by forced intersection approach.
- Factor 2: X5, X6, X8, X13 > |0.6|, FC_2=19.35%, misjudged gap and speed of the front or rear vehicle.
- Factor 3: X14, X15 > |0.6|, FC_3=14.65%, sudden interruption ahead and a front vehicle slams on the brake.
- Factor 4: X1, X3 > |0.6|, FC_4=11.88%, poor visibility of the front vehicle or traffic display due to geometric alignment and obstacles.
- Factor 5: X4, X7, X10 > |0.6|, FC_5=10.34%, Sudden parked vehicles or vehicles that go on and off the roadside.

Head-on collisions

For head-on collisions, the contributions (FC_j) common factors j(1-5) are 30.50%, 19.53%, 16.72%, 13.92%, and 13.03%. Each common factor name stands for the characteristic of each variable. The bold-faced values in Table 9 are larger than |0.6|, and the following are common factor names.

- Factor 1: X1, X11, X12, X15, X18, X21, X25 > |0.6|, FC_1=30.50%, poor visibility because of shade, a road obstacle, and the oncoming car by geometric succession.
- Factor 2: X16, X17, X24, X26 > |0.6|, FC_2=19.53%, crossing impossible because of impatience waiting for a signal or traffic congestion.
- Factor 3: X7, X8, X14 > |0.6|, FC_3=16.72%, delay of circumstantial judgment because of a complicated road display or road marking.

- Factor 4: X9, X23, X27 > |0.6|, FC_4=13.92%, speed judgment error of the oncoming car by the increase in the amount of intersections.
- Factor 5: X4, X5 > |0.6|, FC_5=13.03%, direction or vehicle interval judgment error of the oncoming car because of the road geometry structure.

CONCLUSIONS AND FUTURE STUDY

This study tries to evaluate quantitatively the factors that may cause a human error due to the traffic and road environment in an accident. From the result of this study, the correlation between road environment and human error (at a signalized intersection) can be explained as follows:

- The extracted common factor is a context that was generated by correlation, such as road geometry, traffic control, and traffic flow. For the SETA intersection, which was the subject of this study, 80% or more of the causes of accidents were due to the context, which was made by two or more independent traffic environment parameters. Before implementing a plan to lower the number of accidents, it is necessary to understand the context.
- Rear-end collisions were almost unrelated to road geometry. The extracted common factors shows that rear-end collisions were caused by the driver's cognitive error (speed judgment, response delay) to events which are not expected in the traffic flow (e.g., a sudden interruption ahead or an obstacle).
- Head-on collisions were related to road geometry, traffic flow, and road-side condition. The extracted common factors show that head-on collisions were caused by poor visibility due to shade, and traffic congestion.

For a future study, which is based on the results of this study, we are investigating safety performance before and after intersections. A 3D model for VR-simulation is utilized to drive a simulator experiment to determine the relationship between the traffic environment and driving behavior characteristics (I. Hong, T. Kurihara, and M. Iwasaki, 2008).

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REFERENCES

(1) AASHTO (American Association of State Highway and Transportation Officials), "A Policy on Geometric Design of Highways and Streets", Washington, D.C., 1984

(2) AASHTO (American Association of State Highway and Transportation Officials), "A Policy on Geometric Design of Highways and Streets", Washington, D.C., 2001

(3) Andrew Vogt, "Crash Models for Rural Intersections: Four-Lane by Two-Lane Stop-Controlled and Two-Lane by Two-Lane Signalized", FHWA-RD-99-128, FHWA (Federal Highway Administration), 1999

(4) Dougherty E. M., "Human reliability analysis-Where should thou turn?, Reliability Engineering & System Safety", Vol. 29, Issue 3, 1990 pp.283-299

(5) Loren Staplin, Karlene Ball, Denise Park, Lawrence E. Decina, Kathy H. Lococo, Kenneth W. Gish, and Bari Kotwal, "Synthesis of human factors research on older drivers and highway safety", FHWA-RD-97-094, FHWA (Federal Highway Administration), 1997

(6) Erik Hollnagel, "Human Reliability Analysis Context and Control, Academic Press, London" , 1990, pp.145-300

(7) K.M. Bauer and D.W. Harwood, "Statistical Models of At-Grade Intersection Accidents-Addendum", FHWA-RD-99-094, FHWA (Federal Highway Administration), 2000

(8) I. Hong, T. Kurihara, and M. Iwasaki, "Old driver' driving behaviors during complex traffic conditions at a signalized intersection", Proceedings of the Institution of Mechanical Engineers, Part D, Journal of Automobile Engineering, Vol. 222, No. 11, 2008, pp1879-1892

(9) Rasmussen J., "Human errors process control", Contribution to NATO Workshop on Origin of Human Error, September, Bellagio, Italy, 1983

(10) Rasmussen J., "A taxonomy for describing human malfunction in industrial installations", Journal of Occupational Accidents (4), 1982, pp311-333

(11)Transportation Research Board (TRB), "HCM 1985", Chapter 1, Transportation Research Board, National Research Council, Washington, D.C., 1985

(12)Transportation Research Board (TRB), "HCM 2000", Chapter 16, Transportation Research Board, National Research Council, Washington, D.C., 2000

(13)Treat J. R., Tumbas N. S., McDonald S. T., Shinar D., Hume R. D., Mayer R. E., Stanisfer, R. L. and Castellan, N. J, "Tri-level study of the causes of traffic accidents", DOT-HS-034-3-535 -77, 1977

(14)Tokyo Metropolitan Police Department (MPD), "Traffic accident statistics. (Japanese)" , 2005

(15)National Highway Traffic Safety Administration (NHTSA), "Traffic Safety Facts 2005", NHTSA's National Center for Statistic and Analysis (NCSA), Washington, D.C. , 2005