

DEVELOPMENT OF A RISK EVALUATION MODEL FOR REAR END COLLISIONS CONSIDERING THE VARIABILITY OF REACTION TIME AND SENSITIVITY

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Abstract: A model and a measure that can evaluate the risk of rear end collision are developed considering actual driver's behaviors. These behaviors are analyzed on the basis of three concepts - risk, responded risk, and accident - related to accidents. An index that can represent the risk was also developed based on the methods used in evaluating noise level. For risk comparison among various situations, the equivalent risk level with respect to the intensity and duration time is developed. The model was validated with field surveys of the expressway of Seoul using a test vehicle capable of collecting the traffic flow data. Based on these data, the risk by section, lane, and traffic flow conditions was evaluated and compared with the accident data and traffic conditions. The results showed that evaluated risk level corresponds closely to the patterns of actual traffic conditions and number of accident.

Key Words: The risk of traffic flow, rear end collision, behaviors of a driver, risk index

1. INTRODUCTION

Many countries have constructed expressways to solve their serious traffic problems, but they have not benefited from these projects because of frequent accidents as well as inefficient management and operation of the roads. For the expressways to be operated and managed properly, quantifying both safe transportation and smooth transportation are a must, which can be achieved by safely and efficiently operating and managing the traffic flow.

Most traffic accidents seldom results from a single cause, but usually several influences such as the human element, the vehicle element, and the highway element affect accidents at any given time (*I*). Thus these factors should be considered at the same time when analyzing the risk of an accident and when developing safety models. Although most risky situations and accidents on the roads result from the poor response of the driver to various stimuli, many researchers have modeled the risk or accident by analyzing only the stimuli without considering the response of the driver; which leads to low reliability of models. In addition, every dangerous situation does not always turn into accidents because drivers try to respond properly to the dangerous situations. Moreover, many accidents in continuous traffic flow conditions are caused by the failure of lane-changing or car-following, which happens when the driver behaves or decides improperly.

This study focused on the risk caused by car-following. Many earlier models for evaluating this risk assume maximum deceleration rate and fixed reaction time, but these assumptions do not represent real conditions. To overcome the limitations and problems of the previous researches, a model was developed by considering the factors related to the driver's behaviors when a car follows lead vehicle. To consider the driver's behavior the factors such as reaction time and deceleration rate were included in the proposed model. In addition, the risk index was also developed to compare the risk of each section, each lane, and each traffic flow condition with other things.

2. LITERATURE REVIEW

This study is focused on developing a model that can evaluate the risk of rear end collision not from the theoretical viewpoint but from the practical. In this chapter, earlier studies on analyzing the quality of traffic flow and on stability analysis that investigates rear end collision theoretically are reviewed.

2.1 Acceleration Noise

Herman, et al (1959) suggested that the standard deviation of acceleration, so called acceleration noise, which is affected by the geometry and traffic conditions of a road, can reflect the smoothness of flows; thus, it can be a qualitative measurement for the potential risk of traffic flow (2).

Drew (1968) suggested acceleration noise as a qualitative measurement traffic flow conditions and safety, which depends on drivers, roads, and traffic conditions as shown in equation (1) (3).

$$\sigma = \left[\frac{1.465^2 (\Delta v)^2}{T} \sum_{i=0}^T \frac{1}{\Delta t_i} \right]^{1/2} \quad (1)$$

where, σ = acceleration noise

T = travel time of a vehicle (sec)

Δv = change in speed during unit time (mph)

Δt_i = unit time (sec)

According to their studies, the smoothness of traffic flow, which is an essential part in evaluating the safety of traffic flow, could be shown as a distribution of accelerations for the average acceleration, which can be measured by its standard deviation. However, the acceleration noise only indicates the variation of the speed of an individual vehicle and it does not explain why and how this variation affects the smoothness of traffic flow.

2.2 Stability Analysis

Stability analysis has been performed to understand microscopic traffic flow conditions related to the car-following by considering parameters included in the 'car-following' theory such as reaction time and sensitivity.

The basic concept of stability analysis was introduced by Herman, Montroll, Potts, and Rothery (1959) and they classified stability into two groups; local stability and asymptotic stability (2). They showed that the car-following theory, which is based on a simple linear differential equation and the assumption of uniform reaction time and sensitivity, could not explain complicated traffic situations such as passing and vehicle interferences.

Chandler (1958), arguing that instability was caused by reaction time, tried to analyze the stability of traffic flows by using Fourier Series Expansion for the speed function of the lead vehicle (5). He suggested that the product of the reaction time and sensitivity is the most important value in evaluating stability.

Köhler (1974) suggested that unstable movement of vehicles in a group could result in rear end collisions (6). He proved that, if vehicles in a group move in an unstable state, the amplitude of the variation of the spacing between vehicles would increase depending on the movement of the lead vehicle, which could result in rear end collisions.

Ferrari (1994) showed that the deterministic values of parameters that make traffic flow unstable did not exist, but only the probability of instability according to the parameters could be known for a certain time period (7). In his study, the probability of instability is determined by two dominant parameters, the reaction time and sensitivity.

Zhang, et al. (1997) analyzed the characteristics of stability mathematically by linear approximation of a nonlinear model (8). They also improved the earlier theories on the linearity of the characteristic equation and classified the equation into four equations according to the parameters of sensitivity term in the car-following model.

According to the previous researches, the parameters that affect the stability of traffic flows are the reaction time and sensitivity, and these parameters do not have deterministic but stochastic characteristics depending on both drivers and environments of traffic flow. So far, few studies have considered the stochastic characteristics of parameters because of the complexity of the equations. However developing linear models into nonlinear model in this technique is a remarkable improvement. Despite the improvement, studies on stability analysis are still at a theoretical level.

3. MODEL DEVELOPMENT

Because rear end collisions result from unstable traffic flows, as mentioned above, two parameters such as reaction time and sensitivity were considered in modeling the risk. In developing the model, safe stopping distance and accident probability were used for better understanding and for more reliable modeling of the risk. The risk index was developed to compare the risks and validate the model with real data collected on an expressway in Seoul.

3.1 When the Risk Begins?

To model risk, the situations that cause the risk, that is, when and how the risk begins should be defined. For the risk of rear end collision, these situations can be linked to the point when the lead vehicle starts to affect the following vehicle. However, because this point is difficult to identify, we assumed that risk begins at the time when a driver passes the point where he/she can respond safely to any stimuli from the lead vehicle. The spacing between the two vehicles at that time was defined as the Safe Stopping Distance; that is, if the following vehicle follows the lead vehicle out of this distance, the driver of the following always can decelerate and stop safely with adequate reaction time and moderate deceleration rate. The moderate deceleration rate means that, at which all the drivers feel comfortable and can decelerate their vehicles without concerns of rear end collision, and this value was a function of a vehicle's speed (10). The maximum deceleration rate, which depends on both the performance and the traveling speed of vehicle, was used according to reference (10) in developing the model. Consequently, based on these values, the safe stopping distances for the different speed groups were calculated from the acceleration equation and it was assumed that the risk of rear end collision between two vehicles begins when the following vehicle travels within the safe stopping distance.

3.2 Does a Risk Cause an Accident Directly?

A closer look into the relationships between risk and accidents reveals that they are linked to each other by driver's behaviors and depending on the drivers, the risk, as it is on the road-vehicle system, may be ignored or call drivers' attention. Therefore, an accident depends on how the driver handles risk, that is, the risk which affects to an accident is not the risk itself but the risk responded by a driver.

Thus, driver's behaviors are considered in developing model and to reflect these behaviors, three concepts related to accidents are introduced as follows; Potential risk, Responded risk, and Accident. Based on these concepts, a new factor (R_{prob}) denoting accident probability is introduced to model the risk of rear end collision. Considering the relationships between the risk itself and the wrongly-responded risk, accident probability can be modeled as the ratio of the risk which is ignored or wrongly-responded to by the driver (R_d) to the risk which exists potentially in the road-vehicle system (R_{sys}), as is shown in the following formula.

$$R_{prob} = \frac{R_d}{R_{sys}} \quad (2)$$

3.3 How can we Derive these R_s Conceptually?

Rear end collisions are usually caused by improper responses to the stimuli given by the lead vehicle, namely deceleration in this study. To develop the model, the factors influencing on R_{sys} and R_d must be found. Considering the R_d and R_{sys} in terms of rear end collision, R_{sys} represent all the possible dangerous situations of the risk of rear end collision, which arise when a vehicle follows the lead vehicle within the safe stopping distance. R_d represents the risk which is ignored or wrongly-responded to by the driver and depends on how close a vehicle is to the lead vehicle. The driver's behaviors such as the reaction time and deceleration rate, which he/she exerts on the basis of his/her driving experiences, usually determine the closeness to the lead vehicle.

Consequently, to model the R_{prob} , the factors that can describe car following situations, such as the speed of vehicles, deceleration rate, spacing, and reaction time, should be considered. As mentioned above, the R_{prob} is determined by the driver's behaviors because the R_{sys} is constant for a given 'car following' situation. Hence, the R_{prob} , for a given driving situation, can be determined by the reaction time and deceleration rate.

The conditional equation for stopping without collision can be formulated as follows;

$$S_a + h \geq S_b \quad (S_a = v_a t_a + \frac{1}{2} a_a t_a^2, \quad S_b = v_b t_b + \frac{1}{2} a_b t_b^2) \quad (3)$$

In equation (3) h , s_a , s_b , v_i , a_i , t_a , t_b , t_r denotes spacing between two vehicles (m), stopping distance of the lead vehicle (m), stopping distance of the following vehicle (m), speed of vehicle i (m/s), deceleration rate of vehicle i (m/s^2), the duration time of deceleration of vehicle a (sec), the duration time of deceleration of vehicle b (sec) and reaction time of the driver in vehicle i (sec) respectively.

At 'car-following' situations, the driving condition of the two vehicles is determined by the speed of each vehicle and the spacing between the two vehicles. After the driving condition of the two vehicles is given, the factors which can determine the level of risk of rear end collision are the deceleration rate and the reaction time of the following vehicle. The deceleration rate chosen by the driver of the lead vehicle is one point on the axis of a_a as shown in Figure 1 (a). And then, the risk is determined on the coordinate plane with the axes of the deceleration rate and the reaction time. Namely, by plotting the point of (a_b, t_r) which satisfies equation (3) on this plane, this plane is divided into two areas, the area of safe response and the area of dangerous response, and then the risk of rear end collision between the two vehicles is determined as the ratio of the area of danger to the entire area as shown in Figure 1 (b).

Because the driver can respond differently to a stimulus, his reaction time and the car's deceleration rate may show some statistical distributions. However, finding these distributions of each driver is rarely possible so that it is assumed that the probabilities of choosing reaction time and deceleration rate at a situation be same.

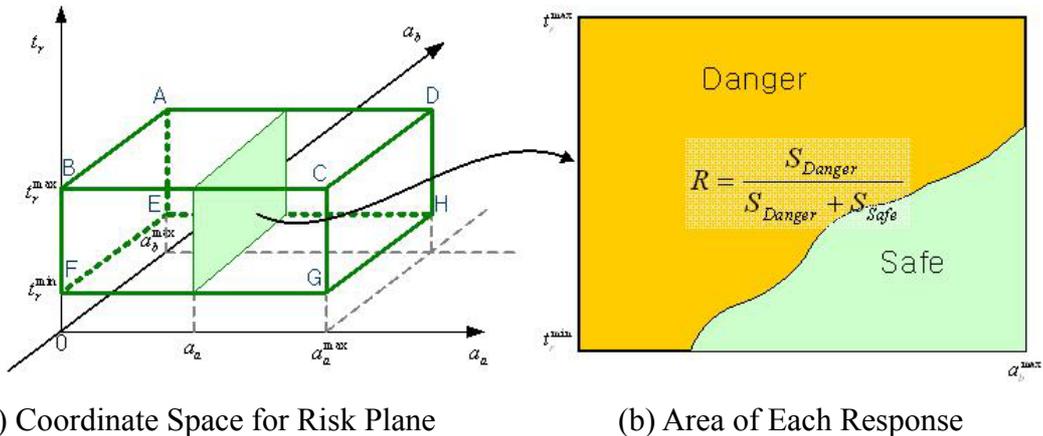


Figure 1. Danger and Safe Response Area

Because the driver of a following vehicle cannot predict the deceleration rate of the lead vehicle, all possible deceleration rates of the lead vehicle at a given situation should be considered to evaluate the risk of rear end collision. Therefore, by considering all the possible a_a , the risk of rear end collision between two vehicles can be determined, as shown in Figure 2.

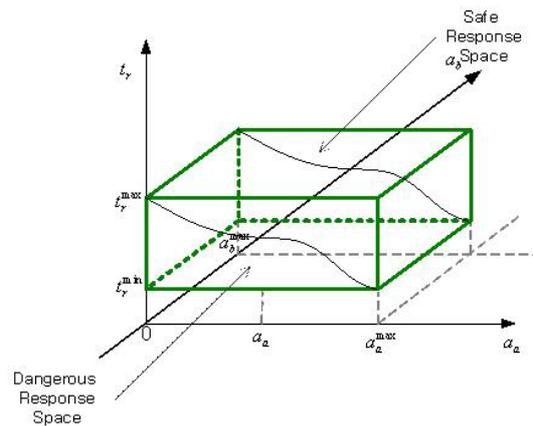


Figure 2. Danger and Safe Space for Risk Calculation

3.4 How can we Derive the Risk Mathematically?

Based on the concepts developed in the previous section, a mathematical model for each risk was developed. Let the stopping distances of the two vehicles at the constant deceleration rates of a_a and a_b be S_a and S_b , respectively.

$$s_a = v_a t_a + \frac{1}{2} a_a t_a^2 = -\frac{v_a^2}{2a_a} \tag{4}$$

$$s_b = v_b t_r + v_b t_b + \frac{1}{2} a_b t_b^2 = v_b t_r - \frac{v_b^2}{2a_b} \tag{5}$$

where, $a_i = f_i \cdot g$ (m/s^2)
 g = Acceleration of gravity (m/s^2)

f_i = Friction coefficient between tire and surface of the road

From equation (3), the boundary condition of rear end collision is as follows:

$$h + S_a = S_b \tag{6}$$

The equation (6) can be rewritten for reaction time t_r as follows:

$$t_r = \frac{h}{v_b} + \frac{v_b}{2a_b} - \frac{v_a^2}{2a_a v_b} \tag{7}$$

Subject to $a_b^{\text{mod}} \leq a_b \leq a_b^{\text{max}}$, $t_r^{\text{min}} \leq t_r \leq t_r^{\text{max}}$

In equation (7), h , v_a , v_b are given at a situation, so that t_r is calculated for all the possible a_a . Thus, equation (7) depends on a_b , which can be rewritten as equation (7).

$$t_r = k_1 + \frac{k_2}{a_b} \quad \left(k_1 = \frac{h}{v_b} - \frac{v_a^2}{2a_a v_b}, \quad k_2 = \frac{v_b}{2} \right) \tag{8}$$

The graph of equation (8) can be classified into 4 types according to the conditions of the coefficients; this means that the curve type is determined by both the driving condition factors and the deceleration rate of the following vehicle. With equation (8) the safe response area and the dangerous response area is calculated by integrating the function for a given a_a .

$$S_d = \int_{a_b}^{a_b^{\text{max}}} \{t_r^{\text{max}} - t_r(a_b)\} da_b \tag{9}$$

$$S_{\text{sys}} = \int_{a_b}^{a_b^{\text{max}}} \{t_r^{\text{max}} - t_r^{\text{min}}\} da_b \tag{10}$$

where, S_d = The area of danger zone

S_{sys} = The total area

Considering all the possible a_a , each area can be calculated by integrating equations (9) and (10) for a_a .

$$R_d = \int_{a_a}^{a_a^{\text{max}}} \int_{a_b}^{a_b^{\text{max}}} \{t_r^{\text{max}} - t_r(a_b)\} da_b da_a \tag{11}$$

$$R_{\text{sys}} = \int_{a_a}^{a_a^{\text{max}}} \int_{a_b}^{a_b^{\text{max}}} \{t_r^{\text{max}} - t_r^{\text{min}}\} da_b da_a \tag{12}$$

Finally, from the definition of the accident probability, the risk of the rear end collision is calculated as follows:

$$R_{prob} = \frac{\int_{a_a}^{a_a^{max}} \int_{a_b}^{a_b^{max}} \{t_r^{max} - t_r(a_b)\} da_b da_a}{\int_{a_a}^{a_a^{max}} \int_{a_b}^{a_b^{max}} \{t_r^{max} - t_r^{min}\} da_b da_a} \quad (13)$$

3.5 How can we Rate the Risk Level?

In this section, an index for evaluating and comparing the risk was established from the methods used in evaluating the noise level because of the similarities of the noise and the risk, such as a variety of sources, non-accumulating property, locality of the effect, subjectivity of the recognition, etc. For instance, the variation of both risk and noise is complex and irregular, and people recognize differently in spite of the same intensity and frequency. And the risk and the noise, if evaluated at their peak intensity, are likely to be overestimated, or underestimated when they are evaluated at their low intensity.

Based on these concepts, the average of the 75th percentile is used to represent the risk level of a data set, because only a risk, like noise, beyond some intensity can make a driver feel danger. Based on this value, to compare the risk objectively, the Equivalent Risk Level (ERL), which reflects the frequency and the intensity of the risk, is developed as follows:

$$R_i^{eq} = \frac{N_i}{\sum_{i=1}^n N_i} \times R_i^{75\%} \quad (14)$$

where, R_i^{eq} = the equivalent risk level of group i which consists of two vehicles
 N = the frequency of group i
 $R_i^{75\%}$ = the average of 75th percentile of group i

For more general situations, considering two vehicle groups which have n vehicles surveyed for m seconds and p vehicles for l seconds, the equivalent risk level of each vehicle group is as follows:

$$R_g^{eq} = \frac{m \times (n-1)^{75\%}}{N_t} \times R_g^{75\%} \quad (15)$$

$$R_{g'}^{eq} = \frac{p \times (l-1)^{75\%}}{N_t} \times R_{g'}^{75\%} \quad (16)$$

where, $N_t = m \times (n-1)^{75\%} + p \times (l-1)^{75\%}$
 R_i^{eq} = the equivalent risk level of vehicle group i
 $(n-1)^{75\%}$, $(l-1)^{75\%}$ = the average of 75th percentile of each vehicle group.

4. WHAT KIND OF DATA IS NEEDED FOR VALIDATION?

The data that should be collected for validating the model consist of 3 groups. The first data group is the accident account number by lane and by time for analyzing the relationships between accident and the risk level calculated by the model. The second data group is the

macroscopic traffic flow data to analyze the relationships between traffic flow conditions and the risk level. The third data group is microscopic data of each vehicle for input data of the model.

4.1 Accident Data

Accident data of rear end collision on 1st and 3rd lane of the survey fields during the period was collected with the help of transportation management center of Seoul. Usually, the accident data used in analyzing a model are 3-year data but in this study, because the accident data were used for comparing the model with the accident accounts, the data used in the validation covered just the period from March to December of the year 2002.

4.2 Traffic Flow Data 1

The data such as speed and traffic volume were collected from a video detector equipped at each road section. Based on these data, the traffic flow conditions were classified into four groups by means of speed-volume curve, as shown in Figure 3.

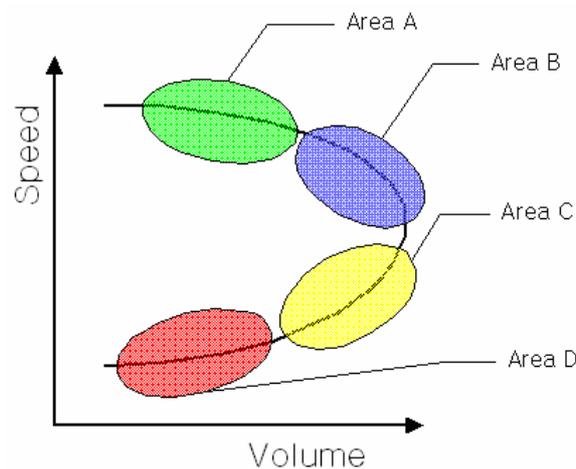


Figure 3. Traffic Flow Conditions

4.3 Traffic Flow Data 2

The eight days of field surveys including 2 days of preliminary survey were done for collecting the data such as speed of test vehicle, spacing, and deceleration rate on the expressway of Seoul. To consider the characteristics of the traffic flow pattern and ramp connection of each lane and section, the subject road was divided into two sections and surveyed for 12 hours, from 7 a.m. to 7 P.M for week.

For this field survey, it was very important to choose proper drivers for objective and proper data collection. Thus, based on the driving career and the driver's sex, test drivers were classified into 4 groups ; Novice Drivers, Practiced Drivers, Experienced Drivers, Routine Drivers. In addition, to collect the microscopic data of each vehicle, the test vehicles equipped with a tachometer analyzer and data login system were used. The collected data from these test vehicles were processed through the code-conversion program in the login system and were calculated and analyzed with EXCEL and MATLAB S/W.

4.4 Data Correction

To filter the noises due to data conversion by the tachometer, namely the non-flatness of the surface and the difference of driving distance, two correction steps were chosen. At first the difference between traveling distance by a vehicle and the distance in the map was corrected the average dividing method. The noise produced by data conversion was filtered by eliminating abnormal data, and then the data was filtered by using the wavelet tool in MATLAB (11, 12).

5. RESULTS

To calculate the risk level it is necessary to consider the reaction time and the possible deceleration rate that the driver can choose at each time lapse. Therefore, the maximum and the moderate deceleration rate (m/s^2), based on the performance and speed of the vehicle, were classified by traveling speed as follows:

- 0 ~ 30 kph : 6.468(Max. Deceleration Rate), 2.08(Moderate deceleration rate)
- 30 ~ 40 kph : 6.272(Max. Deceleration Rate), 1.86(Moderate deceleration rate)
- 40 ~ 50 kph : 6.076(Max. Deceleration Rate), 1.39(Moderate deceleration rate)
- 50 ~ 60 kph : 5.978(Max. Deceleration Rate), 1.39 (Moderate deceleration rate)
- 60 ~ 70 kph : 5.782(Max. Deceleration Rate), 1.39 (Moderate deceleration rate)
- 70 ~ 80 kph : 5.684(Max. Deceleration Rate), 1.39 (Moderate deceleration rate)

According to the previous research (9) and field test, the time range for the reaction time from 0.5 sec to 2.3 sec was applied to the model.

5.1 Results by Section and by Lane

According to the results, the risks of shoulder lane of each section 1 and 2 were 0.882 and 0.795 respectively, so that the risk of section 1 was higher than that of section 2 (See Table 1(a)). However, comparing the risk of each lane of the two sections using the equivalent risk level, the ERL (Equivalent Risk Level) of lane 1 of section 1 was 0.638 and that of lane 1 of section 3 was 0.362 so that the ERL of section 1 was about 2 times higher than that of section 2 (See Table 1(b)).

To examine the relations between the ERL and the number of accidents, ERL was compared with the number of accidents that occurred in each section. According to the data, section 1 had 11 accidents for the period and section 2 had 2 accidents for the same period, which shows that the number of accident agrees with the results. For the 3rd lane of each section, the ERLs of each section were 0.612 and 0.388. Although section 1 had almost twice the ERL of section 2, the number of accidents that occurred in each section was equal, and this discrepancy between the ERL and the number of accident in each section was due to the direct comparison of the results from the model based on non-accident with the accident data (See Table 1(b)).

The ERL of section 1 was higher than that of section 2 because of the different geometries of the two sections and the traffic condition due to the volumes of inflow from ramps and outflow to ramps. Namely, section 1 had two off-ramps and one on-ramp and the section 2 had one on-ramp and two off-ramps. Entering and exiting traffic caused disturbances to traffic on main roads and affected the safety as well as the capacity and level of service. From the traffic data of ramps and the ERL of each section, the results showed that the greater traffic from or to ramps in section 1 gave the higher ERL in section 1. In addition, the fact that the distance between the ramps in section 1 is closer than that of section 2 also gave the higher ERL in section 1.

For the ERL by lane of the same segment, the ERLs of 1st and 3rd lane of the section were 0.574 and 0.426, respectively. In addition, the number of accidents of each lane was 11 accidents and 3 accidents for the periods. This result proves that the 1st lane was more dangerous than the 3rd lane. In case of section 2, the ERLs of the 1st and 3rd lane were 0.547 and 0.453, respectively, but the numbers of accidents in the lanes were 2 and 3, respectively. The ERL in the 1st lane was higher than that of the 3rd lane because the 1st lane was connected to ramps directly, and thus, the traffic flow from ramps caused a weaving flow situations in the 1st lane; This ramp connection brought about the higher risk of rear end collision the 1st lane than the 3rd lane (See Table 1(c)).

5.2 Results by Traffic Flow Conditions.

Investigating the risk of rear end collision compared with traffic flow conditions, the D area had the highest ERL except on the 3rd lane of section 2. In case of the risk on the 3rd lane of section 2, the ERL of the C area was a little higher than that of D area, but in terms of accident probability, there was little difference between these areas. C and D areas had higher ERL compared with those of A and B areas because the traffic in congested conditions stops and goes so frequently such that drivers have to accelerate or decelerate the vehicle more frequently, and the results showed that as the traffic becomes more congested, the risk becomes higher (See Table 1(c)).

TABLE 1(a) Results

Classification	Sample		$R^{75\%}$	
	1 st lane	3 rd lane	1 st lane	3 rd lane
Section 1	1579	1299	0.882	0.795
Section 2	885	808	0.891	0.881

TABLE 1(b) Results

Classification	By section		By lane	
	1 st lane	3 rd lane	1 st lane	3 rd lane
Section 1	0.638	0.612	0.574	0.426
Section 2	0.362	0.388	0.547	0.453

TABLE 1(c) Results

Classification	Section 1		Section 2	
	1 st lane	3 rd lane	1 st lane	3 rd lane
Area A	0.027	0.117	0.043	0.181
Area B	0.019	0.023	0.128	0.052
Area C	0.161	0.177	0.288	0.309
Area D	0.671	0.385	0.427	0.268

6. CONCLUSIONS

6.1 Summary

To develop the model that can overcome the limitations and problems in previous studies on accident analysis and safety evaluation models, the behaviors of driver were considered and the concept of accident occurrence probability was introduced.

The Risk Index was derived from ‘the Equivalent Sound Level’ and ‘the average of 75th percentile’, and from these measures, ‘Equivalent Risk Level’ was developed on the basis of a weighted average of the 75th percentile risk to evaluate the relative risk rank by considering the risk intensity and duration of the risk.

To examine the significance of the results, the ERL of each lane for each section was compared with the actual number of accidents and traffic conditions. According to the results, as the traffic becomes more congested, the risk of rear end collision increases, and the risk of the first lane, which is connected to on and off ramps directly, is higher than that of the third lane, which also shows a good agreement with the pattern of the accident data.

For the probability of the accident occurrence, the first lane of section 1, compared with other lanes, had the highest ERL and the risk of area D, compared with the other areas, had the highest ERL. Thus, these results showed that appropriate countermeasures for this section and traffic condition need to be prepared.

The methods used in developing the model in this study show what needs to be considered in developing a risk evaluation model. The model developed in this study is expected to play a major role in the various fields such as safety diagnosis, establishment of operation & management strategy for reliable traffic flow, and the algorithm of Advanced Safety Vehicle, etc.

6.2 Future Research

The instability of traffic flow can be caused by both car following and lane changing, but in this study we focused on the instability caused by car following, which may result in a rear end collision. However, to develop a more complete model for presenting instability of traffic flows, the effect of lane changing also should be considered as well as car following.

For the reaction time and response to some stimulus such as deceleration (or acceleration), a driver does not always show the same behavior. It is therefore necessary to find proper distribution functions for these factors and apply them to the model. Namely, the response by a driver as well as the responses between drivers also has a distribution, so these distributions must be found to obtain a more reliable model.

This study aimed to develop and validate a model, but also to apply the results to various fields such as road planning, preventative operations, and operation and management strategy development, etc.

Based on the methodology and the model developed in this study, if researches on the factors which affect the safety (or risk) of the transportation systems and on the applicability of these results continue, the ability to cope with the risk and accidents will be improved so that this will give us more reliability in using transportation than today.

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