Available online at www.sciencedirect.com

ScienceDirect

Transportation Research Procedia 00 (2018) 000–000

Transportation Research Procedia

www.elsevier.com/locate/procedia

International Symposium of Transport Simulation (ISTS'18) and the International Workshop on Traffic Data Collection and its Standardization (IWTDCS'18)

An analysis of risk factors for rear-ender accident on urban expressway considering accident severity

Satoshi Hyodo[a] Tomoyuki Todoroki[a]

[a]Department of Transportation Systems Engineering, College of Science and Technology, Nihon University, 7-24-1 Narashinodai Funabashi-City, 274-8501 Chiba, Japan

Abstract

The purpose of this study is to investigate the impact of the traffic accidents factors on rear-ender collision accident risk by accident severity. This study is to clarify a relationship between the traffic states and rear-ender collisions accident risk using generalized linear model analysis for accident severity level. As the result, it is confirmed that the different influencing factors by accident severity level. Both property damage only and slight injury accident models were found to be significant increase of accident risks in Congested flow state and Mixed flow state, while only the Mixed flow state showed a significant increasing effect on the serious and fatal accidents risks. Furthermore, the heavy vehicles ratio showed a decreasing effect on the property damage only and slight injury accident risks. On the other hand, it is found that the highest heavy vehicles ratio variable (more than 40%) was only significant increasing in serious and fatal accidents risks.

Keywords: Type your keywords here, separated by semicolons ;

1. Introduction

Road accidents are one of major social problem around world. So, effective traffic safety management of limited resources is essential in our modern society. In general, road traffic accidents are a result of many factors. In order to carry out an effective traffic safety measure, it is vital to identify the relationship between the likelihood of occurrence and the accident factors has to be understood.

In the past many researches focused on the relationship the factors of traffic accidents and accident risk (usually defined as accidents per year per 10^8 veh-km). The accident risk is considered to be affected by both static road

2352-1465 © 2018 The Authors. Published by Elsevier Ltd.

structures and dynamic traffic conditions. As for the static ones, a lot of statistical analyses have been done and they showed that road design and alignment has strong impact on the frequency of traffic accidents (Shankar et al, 1995; Milton and Mannering, 1998).

As for the dynamic ones, due to the limitation of data availability, insufficient analyses have been done. Several analyses have been done using traffic volume over capacity ratio (V/C) and hourly traffic volume, as a proxies to measure the traffic flow characteristics. For example, Zhou and Sisiopiku (1997) showed an inverse relationship between V/C and road fatalities. In addition to, Martin (2002) investigated the relationship between crash risk and hourly traffic flow on French motorways. It is shown that the crash risk are higher in light traffic flow than heavy traffic flow. Furthermore, Wang (2009) investigated the relationship on the M25 motorway. It suggested that traffic congestion has little or no impact on the frequency of road accidents. However, in these study, some other factors such as the weather factors, road structure factors were not considered.

In contrast, identifying the factors that significantly influence the injury severity of traffic accidents is the main objective of the previous studies. Therefore, these studies have been carried out to investigate injury severity of traffic accidents, in relation to driver factors, vehicle characteristics, and road conditions. Several types of statistical models have been applied to analyze the accident injury severity. The logit model and the ordered probit model are of the most practical ones used in the analysis. For example, Abdel-Aty (2003) estimated an ordered probit model to analyze the driver injury severity levels. The estimation models were developed for roadway sections, signalized intersections, and toll plazas in Central Florida. As the results, it is shown that not wearing a seat belt will have a higher probability of a severe injury. Additionally, Yamamoto and Shankar (2004) estimated a bivariate ordered-response probit model to analyze the both driver and passenger injured passenger's severity. The estimation results also reveal the effects of driver characteristics, vehicle attributes, types of fixed objects and environmental conditions on both driver and passenger injured passenger's severity. Conroy et.al (2008) used the logistic regression model to determine independent predictive factors for severe injurys. There were significant differences in the type of object contacted.

As above, those studies mainly have been carried out to investigate the impact of driver's factors and road environmental conditions in determining accident severity.

On the other hand, as mentioned above, the other factors, such as traffic states and environmental conditions, which have also been recognized as important determinants of accident severity risk. For example, the traffic states in congestion may lead to more accidents due to increased traffic volume, while those accidents may be less severe. In other words, it suggested that there may be an inverse relationship between traffic congestion and serious injury accident risks. Therefore, it is important to understand the association between traffic states and road accident risks so that effective countermeasure can be implemented to control both congestion and road safety. Earlier research, Das and Abdel-Aty (2011) have been conducted to understand main factors affecting number and severity of crashes at different road locations. As the results, it is shown that higher Average Daily Traffic (ADT) is more likely to result in more crashes.

However, these analyses never deal with the relationship between the traffic states (e.g., flow vs. density) and the accident rates per vehicle-kilometer for the accident severity. Thus, the relations are unclear.

This study investigates the hypothesis that accident injury levels are affected by traffic states variables. In order to identify the importance of the significant factors for each severity level on rear-ender accidents, this study is to clarify a relationship between the traffic states and rear-ender accidents risk using generalized linear model analysis for accident severity level.

2. Methodology

2.1. Accidents severity level

This study provided the quantitative analysis of the rear-ender collision accidents. In most accident databases, four unique categories exist such as property damage only, slight injury, serious injury and fatality. These definitions are consistent with the accident databases. In this study, the accident severity level was categorized as three types of accident as follows：

(i) Property damage only accidents

(ii) Slight injury accidents
(iii) Serious injury and fatality accidents

2.2. Accident risk estimation model

In terms of statistical models used for explaining rare and non-negative events, Poisson based models are often used to examine the significant factors that have impacts on accident occurrence. However, the observed variance is actually greater than the observed mean which is called “Over dispersion” problem. In solving this problem, some studies found that a negative binomial distribution has proven to be more preferable model for these case. Therefore, for the robustness of model estimates, this study considered about two model specifications: Poisson regression model and Negative binomial regression model.

A Poisson regression model is given as:

$$\Pr\left(Y_j^m=y\middle|\lambda_j^m\right)=\frac{e^{-\lambda_j^m l_j}\left(\lambda_j^m l_j\right)^y}{y!} \tag{1}$$

A Negative binomial regression model is given as:

$$\Pr\left(Y_j^m=y\middle|\lambda_j^m\right)=\frac{\Gamma\left(y+\frac{1}{\theta}\right)}{\Gamma(y+1)\Gamma\left(\frac{1}{\theta}\right)}\left(\frac{1}{1+\theta e^{-\lambda_j^m l_j}}\right)^{\frac{1}{\theta}}\left(\frac{\theta e^{-\lambda_j^m l_j}}{1+\theta e^{-\lambda_j^m l_j}}\right)^y \tag{2}$$

$$\log(\lambda_j^m)=a^m+\sum_{k=1}^{n}\beta_{jk}^m x_k \tag{3}$$

Where,
The category j denotes the road traffic condition classification. This study choses the variables which are traffic flow rate, average speed, heavy vehicles volume, precipitation, curvature, gradient, number of lanes, merging/diverging section and toll plaza as the classification characteristics. The m denotes the discrete observed categories of accident severity types, which was categorized into three groups: (1) property damage only accident, (2) slight injury accident, (3) serious injury and fatality accident. $Y_j{}^m$ is the number of accidents occurred in the category j （j=1,2,3,..,7784） and accident severity type m over an exposure l_j. In this study, the exposure is described as the product of traffic volume and the length of each road section. $\lambda_j{}^m$ is the expected mean accident risks in j classification or criterion variables and the accident severity type m, x_k is representing the explanatory variables in the category j. α is the constant coefficient, β is the coefficients to be estimated. θ represents the dispersion parameter to be estimated.

2.3. Variable description

In the model analysis, the traffic conditions at a time interval are employed as independent valuables in addition to relevant factors used in previous studies, such as precipitation, curvature, gradient, number of lanes, merging/diverging section and toll plaza as shown in following.

The primary objective of this study is to investigate the impacts of traffic conditions on accident risk by severity types. Firstly, traffic states and heavy vehicles ratio are picked out to express the traffic conditions. This study established three phases, free flow state (F), mixed flow state (M) and congested flow state (C) on the two-dimensional relationship such as Q-K plane for traffic states measurement is required. The methodology proposed is described as follows. Firstly, we postulated the fundamental diagram as shown in Fig1. In this study, using the capacity q_c (=1800 [veh/h/lane]) and critical density k_c (=30 [veh/km/lane]), the fundamental diagram was formed. The fundamental diagram was represented by two straight lines, which the slopes of the lines in free flow phase and in congested flow phase are set as 60 [km/h] and -20 [km/h] respectively. Then, each traffic state is defined as below.

(1) Free Flow state: The mean speed is higher than or equal the critical speed v_c of 60 [km/h] and the traffic density is lower than the critical density k_c of 30 [veh/km].

(2) Mixed Flow state: The mean speed is lower than the critical speed v_c of 60 [km/h] and the flow rate q_s is lower than -20k+2400.

(3) Congested Flow state: The mean speed is lower than 60 [km/h] and the flow rate q_s is higher than -20k+2400. The criteria of categorizing heavy vehicles ratio [%] are as 5 classes [HV< 10 % /10%≦HV≦20%/ 20%≦HV≦30% / 30%≦HV≦40% /HV＞40 %].

Then, radius of curvature [m], vertical gradient [%], number of the lanes and the merging/diverging/toll plaza section are picked out to express the road segments and geometry characteristics. The road segments are 100m length and are considered to be homogeneous. The criteria of categorizing these variables are as follows: 3 classes [R=∞m / R<500m / R≧500m] at the curvature, 3 classes [G<-0.5% /-0.5%≦G≦0.5% /G＞0.5%] at the gradient, 2 classes [NL < 3 lanes / NL ≧3 lanes] at the number of lanes and 14 classes [Upstream of merging / Merging/ Downstream of merging/ Upstream of diverging, Diverging/Downstream of diverging / Upstream of on-ramp/ On-ramp/ Downstream of on-ramp/ Upstream of off-ramp/ Off-ramp/ Downstream of off-ramp/ Toll plaza/Basic road section] at the merging/diverging/ toll plaza section. Finally, 2 classes [No precipitation (0mm/h)/Precipitation (1mm/h -)] at the precipitation dummy variable are considered as a road environmental variable.

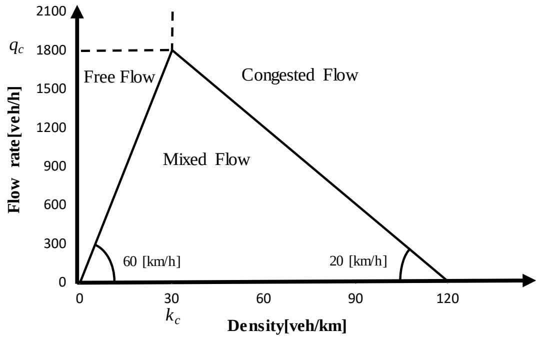

Fig. 1. Diagram of flow-density

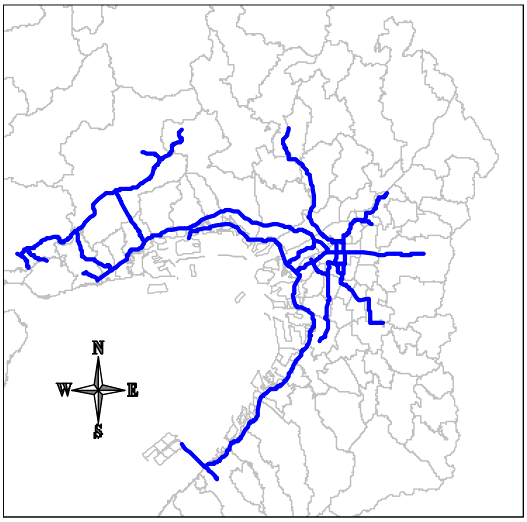

Fig. 2. Study area

3. Data description and study area

3.1. Study area

The parameters have been estimated from the observation data on Hanshin expressway road network in Osaka metropolitan area, which has approximately 250km length, 900,000 trips / day and 6,000 accidents per year as shown in Fig 2.

3.2. Traffic detector data

Traffic states can be determined at every 5minutes at every road section using the traffic detectors, which are installed at 500 - 1,000 m intervals during 8 years and 2 months from April 1, 2005 to May 31, 2013. Traffic detector data provides average speed, volume, high vehicles volume and occupancy aggregated over the lanes into five minutes intervals. In this study network, there are 827 detectors at 388 stations and the data is observed at every 5 minutes.

3.3. Accident data

The accident data provides reported accident time, location of the accident (kp), type of the accident, number of cars involved in the accident, type of cars and so on. The accidents are recorded in a unit of 0.1km. Note that, the time of accident may not show exact time, since it is reported by road administrators after the accident occurrence. For this reason, the time 5 minutes before the recorded time is used in this analysis.

The data were obtained from the Hanshin expressway road network for between April 1, 2005 and May 31, 2013. The total number of accidents obtained for this period was 18,266. The severe distributions included 15,763 (86.3%) property damage only accidents, 2,418 (13.2%) slight injury and 85 (0.5%) serious injury and fatality, respectively as shown in Fig 3.

3.4. Road structure data

The roadway geometries and structure data provides the number of lanes, curvature, gradient, the location of merging/diverging section and the toll plaza section at every 100 m. The total number of 4,818 sections obtained for this study network.

3.5. Weather record data

The data were collected from the Japan Meteorological Agency. The Japan Meteorological Agency (JMA) operates a meso-scale observation network called AMeDAS (Automated Meteorological Data Acquisition System) of over 1300 observation stations with an average spacing of 17km. The weather record shows hourly precipitation around the study area. The data from 6 weather stations close to the study area, from April 1, 2005 to May 31, 2013, were used.

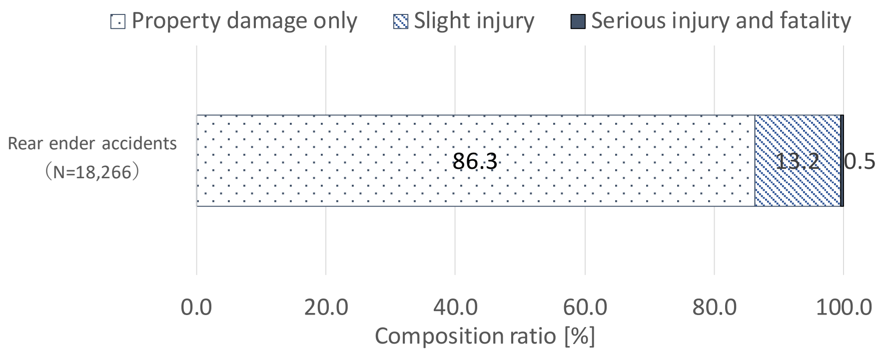

Fig. 3. Composition ratio for injury severity levels.

Table. 1. Estimation model results for injury severity levels.

Variable	Property damage only Model type: NB			Slight injury Model type: NB			Serious injury and fatality Model type: Poisson		
	Coefficient	Standard error	*p* -value	Coefficient	Standard error	*p* -value	Coefficient	Standard error	*p* -value
Constant	3.16	0.08	0.00	1.41	0.12	0.00	-2.11	0.17	0.00
Traffic states									
Mixed Flow	1.99	0.06	0.00	1.81	0.13	0.00	1.21	0.26	0.00
Congested Flow	2.68	0.07	0.00	2.37	0.16	0.00			
Heavy vehicle ratio									
10-20%	-0.22	0.07	0.00						
20-30%	-0.50	0.08	0.00	-0.28	0.14	0.05			
30-40%	-0.68	0.09	0.00	-0.71	0.20	0.00			
40%<	-1.41	0.11	0.00	-0.85	0.22	0.00	0.78	0.30	0.01
Number of lanes	-								
More than three									
Curvature									
R = ∞ m	0.18	0.06	0.00	0.32	0.12	0.01			
R < 500 m									
Gradient									
-0.5% ≦G≦ 0.5%	0.27	0.06	0.00						
G <-0.5%	0.38	0.07	0.00				0.43	0.24	0.07
Merging/diverging section and toll plaza									
Upstream of merging	0.23	0.12	0.05						
Merging	0.82	0.10	0.00						
Downstream of merging									
Upstream of diverging	0.49	0.13	0.00	0.73	0.28	0.01			
Diverging	0.96	0.10	0.00	0.70	0.25	0.01			
Downstream of diverging	0.28	0.13	0.03						
Upstream of on-ramp									
On-ramp									
Downstream of on-ramp									
Upstream of off-ramp							1.09	0.37	0.00
Off-ramp									
Downstream of off-ramp									
Toll plaza	2.16	0.10	0.00	1.93	0.23	0.00	1.52	0.72	0.03
Precipitation (1mm/h -)	0.72	0.06	0.00	0.73	0.14	0.00			
Dispersion parameter θ		1.42			2.69			-	
Sample size		7,784			7,784			7,784	
Log-likelihood at constant		-8640			-3177			-268	
Log-likelihood at convergence		-6971			-2683			-249	
AIC		13,975			5389			510	
ρ^2		0.19			0.16			0.07	

**p<.01, *p<.05

4. Results

In this study, we evaluate the impacts of the accident factors on specific accident severe level. This resulted in three categories of rear-ender accidents: (1) property damage only accidents (2) slight injury accidents and (3) fatal and serious injury accidents.

As such, two models were estimated for each of the two specifications such as (1) Poisson model, (2) Negative binomial model. The variables available for this model were shown in Table 1 and backward variable selection was used to determine the most significant variables at a 10 % level. The results of the analyses are shown for property damage only, slight injury accident, and serious - fatal injury rear-ender accidents.

4.1. Property damage only accidents model

From the result of the analysis for property damage only rear-ender collision accidents as shown in the first column of Table 1. The log likelihood ratio for this model was 0.19.

It shows that the factors of traffic states, heavy vehicle ratio, radius of curvature, gradient, merging/diverging section and toll plaza, precipitation had significant impacts on the accident risk. However, number of lanes was found to be statistically insignificant. Both factors of mixed flow and congested flow in the traffic states have strong positive impacts on the risk. Especially, the accident risk tends to be higher in the congested flow state. On the other hand, dummy variable used to represent heavy vehicle ratio showed significant decreasing effect on the accident risk. Roadway geometries and structure characteristics that found to impact the injury severity are the straight section ($R=\infty$), flat section ($-0.5\% \leqq G \leqq +0.5\%$) and down-grade section ($-0.5\% < G$). In addition to, the factors of merging / diverging section and toll plaza significantly affect the accident risk. Precipitation has significant impact on the accident risk.

4.2. Slight injury accidents model

The second column of table 1 shows the result of the analysis for slight injury rear-ender collision accidents. It shows that several road structure and traffic states factors affect the accident risk for slight injury accidents. The log likelihood ratio for this model was 0.16. It shows that the factors of traffic states, heavy vehicle ratio, radius of curvature, gradient, merging/diverging section and toll plaza, precipitation had significant impacts on the accident risk. However, number of lanes was found to be statistically insignificant as well as property damage only accidents model.

Slight injury accident risk showed significant increase in the congested flow state and the mixed flow state. On the other hand, accident risk showed significant decrease with an increase in heavy vehicle ratio. Dummy variable used for the straight section ($R=\infty$) showed an increasing effect on the accident risk. Also, the factors of merging / diverging section and toll plaza significantly affect the accident risk. Furthermore, precipitation variable has significant impact on the accident risk.

4.3. Fatal and serious injury accidents model

As shown in the third column of table 1, it represents the result of the analysis for the fatal and serious injury rear-ender accident risks. The log likelihood ratio for this model was 0.07. This low value is usual for traffic accident estimation because of many factors which were not measurable such as human factors. However, it shows that traffic states, heavy vehicle ratio, gradient and diverging section coefficients were statistically different from zero at the 10 percent level.

For fatal and serious injury accidents, the accident risk tends to be higher in the Mixed Flow state than others. It is found that the highest heavy vehicles ratio variable (more than 40%) was only a significant increasing in serious and fatal accidents risks. Dummy variable used for toll plaza section significantly affect the accident risk. This type of accident is only likely to be caused by Off-ramp section. In addition to, only for fatal and serious injury accidents, coefficient estimate of precipitation represent statistically insignificant.

5. Conclusions and discussions

In this study, we conducted to understand the relationship between accident risk and traffic states by accident severity types. This paper developed an accident risk estimation model for accident severity types, considering the traffic states, road structure and environment factors. The model is applied to the actual data on Hanshin Expressway Networks in Osaka Metropolitan area.

As the results, it is shown that the different effects of accidents risk influencing factors by accident severity level. Additionally, the traffic states have significant impact on accident risk for all accident severity types. As for the risks of property damage only, slight injury rear-ender collision accidents, the accident risks in the mixed flow and congested flow are higher than that in the free flow. On the other hand, the risk of the fatal and serious injury rear-ender accident in the mixed flow is more than three times of the risk in other traffic states. It confirmed that rear-ender accidents are highly related with congestion. In contrast, it indicated that a serious rear-ender accidents were more probable under the mixed flow state than others. It is expected that a serious rear-ender accidents often involve multiple vehicles with the leading vehicle suddenly decelerating, under the mixed flow state. Furthermore, heavy vehicle ratio showed a decreasing effect on the risks of property damage only, slight injury rear-ender collision accident risks. However, it is found that the highest heavy vehicles ratio variable (more than 40%) was only significant increasing in serious and fatal accidents risks. In addition to, the results showed that dummy variable used for toll plaza section significantly affect an accident risks for all kinds of accident severity level.

On the other hand, both property damage only and slight injury models showed increase of accident risks in precipitation, however, the effect of precipitation was not found to be a significant for fatal and serious injury accidents. It can be implied that drivers become more cautious to prepare for road conditions in precipitation, so the probability of driver injury may decreases relative to dry conditions. The estimation model can reveal the relative accident risk in space and time for accident severity types. Furthermore, the proposed methodology and some research findings provide insights for developing effective countermeasures to reduce rear-end accidents injury severities and improve traffic system safety.

The future analysis is needed, which considers the temporal transition of traffic flow etc., for improving the model. Additionally, one limitation of study is that only urban road way. Further study is needed to analyze traffic accidents on other road ways such as principal arterial, minor arterial and collector roads.

Acknowledgements

The traffic detector data and accident data for the empirical analysis was contributed by Hanshin expressway Co., Ltd. We express our heartfelt gratitude for the contribution.

References

Shankar, V., Mannering, F., and Barfield, W., 1995 Effect of roadway geometrics and environmental factors on rural freeway accident frequencies, Accident Analysis and Prevention, Vol. 27, 371-389.

Milton, J. and Mannering, F., 1998. The relationship among highway geometrics, traffic related elements and motor-vehicle accident frequencies. Transportation, 25(4), pp. 395-413.

Zhou, M. and Sisiopiku, V., 1997. Relationship between Volume-to-capacity Ratios and Accident Rates. Transportation Research Record 1581, 47-52.

Martin, J, L., 2002. Relationship between Crash Rate and Hourly Traffic Flow on Interurban Motorways. Accident Analysis and Prevention, Vol.34, 619-629.

Wang, C., Quddus, M.A. and Ison, S. G., 2009. Impact of traffic congestion on road accidents: a spatial analysis of the M25 motorway in England. Accident Analysis and Prevention, Vol.41, 798-808.

Mohamed Abdel-Aty, 2003. Analysis of driver injury severity levels at multiple locations using ordered probit models, Journal of Safety Research 34, pp.597-603.

Toshiyuki Yamamoto, Venkataraman N. Shankar, 2004. Bivariate ordered-response probit model of driver's and passenger's injury severities in collisions with fixed ob-jects, Accident Analysis and Prevention 36, pp.869-876.

Carol Conroy, Gail T. Tominaga, Steve Erwin, Sharon Pacyna, Tom Velky, Frank Kennedy, Michael Sise, Raul Coimbra, 2008. The influence of vehicle damage on injury severity of drivers in head-on motor vehicle crashes, Accident Analysis and Prevention 40, pp.1589-1594.

Das,A.,Abdel-Aty, M.A., 2011.Acombined frequency-severity approach for the analysis of rear-end crashes on urban arterials. Safety Science 49 (8–9), pp.1156–1163.