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)

Effect of Road Pavement Types and Ages on Traffic Accident Risks

Takahiro Tsubota[a]*, Celso Fernando[a], Toshio Yoshii[a], Hirotoshi Shirayanagi[a]

[a]*Graduate School of Science and Engineering, Ehime University, 3 Bunkyo cho, Matsuyama 790-8577, Japan*

Abstract

This study aims to reveal the relationship between the age of road pavement and traffic accident risks through empirical analysis. The current pavement maintenance is planned based on the road surface survey that measures the physical damage on the pavement surface. The indices for the physical damage on road surface are good representation for the structural healthiness and the driving comfort, but they do not measure the traffic safety levels of the pavement. This limitation hinders planning the pavement management scheme ideal in achieving safer driving environment. This study empirically analyses the relationships between the pavement conditions and accident risks. The pavement conditions are represented by the pavement age – the years since construction or last repair of the pavement. The accident frequency is modelled based on the Poisson regression analysis. The model estimation results show that the age of road pavement has a positive effect on the accident risk, and that the age affects differently in difference pavement types. The results also show that the accident risk is different if the pavement types are different.

Keywords: traffic accident risk; pavement; road safety; expressway

1. Introduction

This study aims to empirically reveal the relationships between the age of road pavement and traffic accident risks. Traffic accidents are a big concern of society in many countries. In Japan, for example, the years from late 1950s to 1970 is known as traffic war period for the annual fatality due to traffic accidents (Oguchi, 2016). Traffic

* Corresponding author. Tel.: +81-89-927-9827; fax: +81-89-927-9821.
E-mail address: t.tsubota@cee.ehime-u.ac.jp

accidents have three major causes: human behavioural factors, vehicle mechanical factors, and driving environmental factors. Among these three, the driving environment has been a major interest to road authorities concerning the road safety. The driving environment is characterised by various elements, such as traffic states, weather, road geometries and pavement conditions, each of which have significant influence on the other two factors in many ways; moreover, the elements of driving environment are controllable for road authorities to increase the road safety level by devising traffic safety measures. Therefore, many studies have evaluated the driving environment elements on the traffic accident risks by developing accident risk estimation models based on the family of Poisson regression models (Ching and Quddus, 2003; Lee, Hellinga and Saccomanno, 2003; Son, Kweon and Byungkyu '"Brian"' Park, 2011; Shiomi *et al.*, 2018), Bayesian networks (Hossain and Muromachi, 2012; Yu, Abdel-Aty and M Ahmed, 2013) and decision trees (Pande and Abdel-Aty, 2006). While most study have successfully identified the impact of road geometries, weather and traffic states on the accident occurrence, the impact of road pavement conditions has not been investigated.

In the current state of the practice, the pavement is repaired based on road surface surveys conducted every few years (Chan *et al.*, 2010; Fwa, 2017). The survey measures three main indices related to the road pavement damage: rut depth, crack ratio and International Roughness Index (IRI). They represent the degree of physical damages on the road pavement, and are good indicators to measure the structural healthiness. However, the current indicators do not consider the traffic safety aspect, which hinders planning the pavement management scheme considering the driver safety.

This study aims to empirically analyse the relationships between the pavement conditions and accident risks. The pavement conditions are represented by the pavement age – the years since construction or last repair of the pavement. This study considers the road geometry types, weather, and pavement materials in relating the pavement age to accident risks, in order to identify when and where to repair the pavement for increasing the traffic safety levels. The finding will be a useful input in developing an asset management scheme, which considers not only the cost of construction and repairs, but also the cost of traffic accidents.

2. Methodology

2.1. Definition of accident risk

Traffic accident risk is defined at each road section (e.g. 100-meter long). It indicates the number of accidents normalised by an exposure variable, vehicle kilometre traveled (VKT). It is calculated for each road condition categories using equation (1):

$$R_i = \frac{y_i}{L_i} \times 10^8, \tag{1}$$

where

R_i: traffic accident risk in road condition category i [accidents/100 million VKT],

y_i: number of traffic accidents in road condition category i [accidents], and

L_i: total vehicle kilometre travelled in road condition category i [VKT].

2.2. Road condition categories

In calculating the traffic accident risk, this study considers the pavement age, road geometry and weather condition. Traffic condition categories in equation (1) are determined using the factors summarised in Table 1. The pavement types are detailed in section 4.1. The number of traffic accidents and the VKT are aggregated for each pavement age, road geometry type and weather, and the accident risk for each category is calculated by equation (1).

2.3. Accident risk estimation model

Traffic accident is a rare event, and the number of accidents within a time interval (i.e., a year) is considered to follow the Poisson distribution. Therefore, a Poisson regression model is employed to model the number of traffic accidents in each road condition category. Since it is reasonable to assume that the number of accidents in a road condition category is proportional to the exposure, the VKT of the category, the response variable, number of accidents, is formulated as a product of traffic accident risk and the VKT as presented in Equation (2) and (3).

Table 1. Factors that define road condition categories.

	Factors	Variables
Road Geometry factors	Flat section	Dummy (1 if the gradient >= -3.0% and <=3.0%)
	Downgrade section (<-3.0%)	Dummy (1 if the gradient < -3.0%)
	Tight Curve section	Dummy (1 if the curve radius <= 500m)
	Curve section	Dummy (1 if the curve radius > 500m and <=1000m)
Weather factor	Rain	Dummy (1 if precipitation > 0mm/hour)
Pavement type factors	DPSA	Dummy (1 for sections paved with DPSA)
	DPSGTA	Dummy (1 for sections paved with DPSGTA)
Pavement condition	Pavement age	Years since last maintenance or construction [years]

$$P(Y = y_i|\lambda_i t_i) = \frac{e^{-\lambda_i t_i}(\lambda_i t_i)^{y_i}}{y_i!}, \tag{2}$$

$$\lambda_i t_i = exp\,(a + b_1 x_1 + b_2 x_2 + \cdots + b_n x_n) t_i, \tag{3}$$

where
$P(Y = y_i|\lambda_i t_i)$: the probability of observing y_i road accidents in traffic condition category i,
λ_i: expected number of accidents per unit VKT in road condition category i (i.e., traffic accident risk) [accidents/100 million VKT],
t_i: exposure variable (i.e., VKT),
x_k: road accident factors ($k = 1 \sim n$), and
a, b_k: unknown parameters ($k = 1 \sim n$).

3. Study Site and Data

3.1. Study site

The study site is in the Hanshin Expressway network, an urban expressway network with 239.3 km length in total, surrounding Osaka area in Japan. This study selects two of the busiest routes for the study site: Ikeda route and Higashi-Osaka route (Fig. 1).

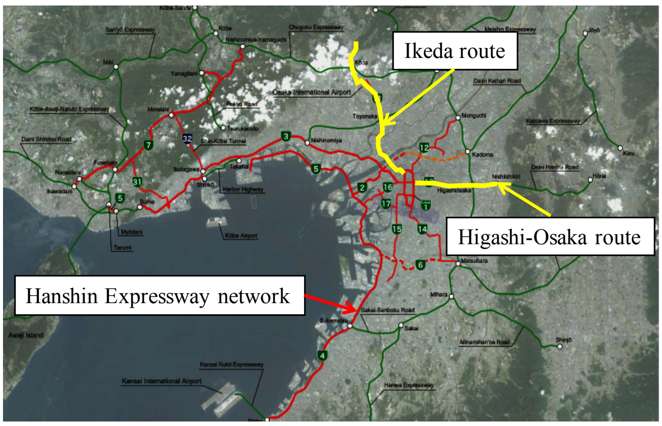

Fig. 1. Study site: Ikeda route and Higashi-Osaka route in Hanshin Expressway

3.2. Study data

3.2.1. Overview of the study data

This study employs the five main data sources: traffic accident data, road surface maintenance record, traffic volume data, road geometry data and weather data.

The traffic accident data is recorded by the road authority of the study site, the Hanshin Expressway Co., Ltd., from April 2010 to March 2016. The accident data includes the date and time of accident occurrence, detailed information on accident location, and accident types. The accident location information records the route name and kilo post (KP) where the accident occurred, but it does not provide the lanes

The road surface maintenance record has been developed by Hanshin Expressway since the beginning of its operation in 1964. The record provides the information on the opening date and/or the start and end dates of road maintenance works as well as the pavement material for each road section and lane. The record also relates the road section identifiers to the route name and KP.

The traffic volume data is an automated measurement collected by fixed ultrasonic detectors placed along the study site. It provides vehicle counting aggregated every five minutes. The section length covered by detector ranges from 200m to 300m. This study uses the count data collected between April 2010 and March 2016.

The road geometry data describes the vertical and horizontal alignment of the study site every 100m (0.1KP). The vertical alignment refers to the slope percentage [%], and the horizontal alignment is characterised by the curve radius [m].

The weather data includes te precipitation in the study area measured by a weather station near the study site from April 2010 to March 2016. The data is collected by Japanese Meteorological Agency, and is open to public in their website. The precipitation is aggregated every hour in a scale of 0.5 mm.

3.2.2. Database construction

The study data is compiled in a database for the following analysis. The database is constructed so that the VKT and number of accidents are calculated for each road condition category. In order to relate the number of accident and traffic volume to the other factors such as pavement age, road geometry and weather, the database should be comprised of the entries with appropriate resolution in space and time dimension; the study site and period is divided into cells of 100m length in space and one hour in time, respectively; then the study data is aggregated for each cell to be an entry into the database (Fig. 2).

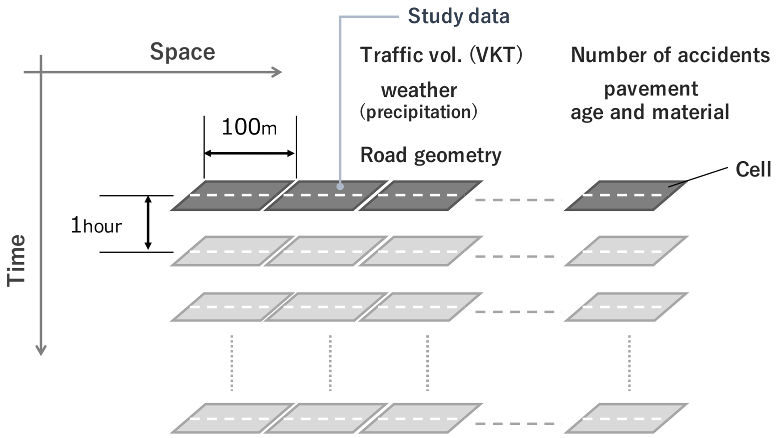

Fig. 2. Space and time resolution of the study database

The pavement age of the cell in section s and time t is calculated by equation (4).

$$Age_{s,t} = int\left(\frac{d_{s,t} - d_{s,t}^{r}}{365.25}\right), \tag{4}$$

where
$Age_{s,t}$: pavement age of the cell in section s and time t,
$d_{s,t}$: date of the cell in section s and time t,
$d^r_{s,t}$: the last end date of maintenance work or the opening date of the cell in section s and time t, whichever closer to $d_{s,t}$, and
The denominator 365.25: average number of days a year considering the leap year.

The pavement age and types are assigned to each cell based on the road surface maintenance record. However, if cells are in the following conditions, the pavement information cannot be determined, and thus such cells are categorised in *unknown* condition, and are excluded from the analysis:

- The cell under maintenance period;
- The cell paved in which pavement materials are different lane by lane; and
- The cell within which the pavement age changes.

4. Results

4.1. Pavement types and number of accidents

After removing the cells of *unknown* condition, three pavement types are identified in the study site: drainage pavement (DP), dense particle size ascon (DPSA), and dense particle size gap type ascon (DPSGTA).

Drainage pavement (DP) is a pavement with permeability function. The rainwater falling on the road surface is conducted through the pores on pavement surface. This absorption capacity of the DP enhances the skid resistance of the pavement during the rainy weather which consequently reduces the accident risk.

Dense particle size ascon (DPSA) has the surface composed of the aggregates uniform in size. The size of aggregates is around 13mm diametre; the holes between the aggregates define the surface macrotexture, because of which, this pavement provides a good lateral water drainage. The macrotexture is desireble under the rainy condition for its contribution to accident reduction, but it is undesireble on normal weather because it has low friction capacity.

Dense particle size gap type ascon (DPSGTA) has the surface made of the aggregates with different sizes ranging from 13mm diametre, to 2mm and even to 0.6mm. Due to the composition on surface of this pavement type, the holes between larger aggregates are filled with medium and small aggregates. Thus, this pavement type does not provide a good drainage system; on the other hand, due to the micro-texture on surface of the pavement, the friction is higher, which contributes to reducing the accident mainly on a lock brake situation.

The DP is the most common pavement material in the study site, and therefore, the majority of accidents occurred in the cells paved by the DP pavement. The number of accident samples of each pavement type is summarised in Table.2.

Table 2. Number of accident samples of each pavement type.

Pavement type	Number of accidents
Drainage pavement (DP)	2,139
Dense particle size ascon (DPSA)	275
Dense particle size gap type ascon (DPSGTA)	833
Total	3,247

4.2. Relationship between pavement age and accident risks

Figure 3 summarises the relationship between pavement age and accident risks. The Figure 3(a) shows the relationship for different pavement types. The figure shows that the accident risks are remarkably different among the pavement types; the sections paved with the DP has the lowest accident risks among the three pavement types, whereas the sections with the DPSGTA has the highest risk. However, the figure does not exhibit noticeable tendency of the accident risks with the changes in the pavement ages. This is partly because of the limitation in available samples from the study site; that is, the pavement ages of DPSGTA and DPSA ranges only from zero to two years, due to which the relationships between the age and the accident risks are hardly observed for these two pavement types. Further, Figure 3(a) does not consider any factors that may affect the accident risk, other than the pavement types. Figure 3(b) gives a particular attention to the DP type pavement, and relates the pavement ages and accident risks in different weather conditions, sunny and rain conditions. For the first three years, the accident risks are comparable in both weather conditions. However, from the age of 5 years, the difference starts to be remarkable; the accident risk in rain condition becomes higher, whereas the risks in sunny condition stays similar as in the first three years. A possible explanation on this observation would be that the permeability capacity of the DP pavement degrades as the pavement age increases, and consequently, the accident risks in rain condition increase.

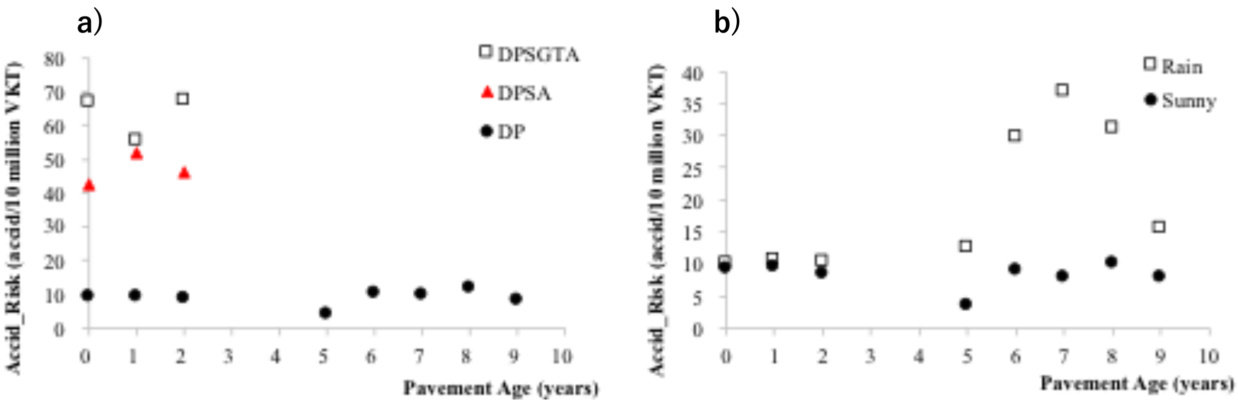

Fig. 3. Relationship between pavement age and accident risks (a) for each pavement type, and (b) in different weather conditions for DP type

4.3. Accident risk estimation model considering the pavement age

The observations in section 4.2 are confirmed through a statistical test based on the Poisson regression model as presented in Equation (2) and (3). In addition to the factors listed in Table.3, interaction terms are added to the explanatory variables in order to assess the influence of pavement age under different pavement types, road geometries and weather.

Table 3. Number of accident samples of each pavement type.

Explanatory variables	coefficients	Z-value	P-value
Weather Factor			
Rain	0.47	7.1*	0.00
Road Geometry Factor			
Dummy of Flat sections	-1.00	-7.6*	0.00
Pavement Type Factor			
DPSA	1.86	27.0*	0.00
DPSGTA	2.39	54.4*	0.00
Interaction with Pavement Age			
Constant (Pavement Age)	0.04	6.9*	0.00
Dummy of Age*Curve*Rain	0.10	7.5*	0.00
` Dummy of Age*Curve*DPSA	-0.09	-6.4*	0.00
Dummy of Age*Tight Curve*Rain	0.15	6.9*	0.00
Dummy of Age*Tight Curve*DPSGTA	-0.11	-5.7*	0.00
Constant	1.97	58.0*	0.00
Number of samples	404		
Log-likelihood ratio (ρ^2)	0.457		*: 5% significant

Table 3 summarises the parameter estimation results of the Equation (2) and (3). The log-likelihood ratio (ρ^2) exhibits 0.457, which confirms that the model fits to the data in reasonable level.

The estimated model shows that pavement age has a positive and significant effect on the accident risk. The impact of the pavement age itself is not very strong, contributing to 4% increase ($= e^{0.04}$) in accident risks when the age increases by one year. However, under particular situations, the age plays more significant role in traffic safety; the interaction of the pavement age with curve section and rain condition has a positive and significant effect; the tighter the curve is, the higher the accident risk becomes as the age increases. This interaction suggests that, the risk of accident caused by the age of the pavement under the rainy condition vary depending on the radius of curvature of the road section.

The result suggests that the effect of the pavement ages on the accident risk is much more evident in the rainy condition than under the normal weather condition. It is reasonable to assume that, as the time passes, the pavement loses its permeability function on the DP pavement, and therefore the skid resistance of the pavement decreases, under the rainy condition.

On the other hand, when looking at the interaction of the pavement age with curve and DPSA, the coefficient shows that curve sections paved with DPSA are less accident-prone over the time. The similar result is found is the interaction of the age with tight curve and DPSGTA. This result shows that the accident risk tends to decrease in curve section with DPSA and in tight-curve sections with DPSGTA, which suggest that, at least for the first three years of the DPSA and the DPSGTA pavement, the accident risk decreases in normal weather condition over the time. This decrease in the accident risk could be associated with the change in the pavement surface that may increases friction of the pavement (Leden, Olli Hämäläinen and Esa Manninen, 1998), and also to the drivers' awareness of the danger in the curve sections.

5. Discussion and Conclusions

This study explored the effect of pavement types and their ages on the accident risk on urban expressway routes. Three pavement types were compared: drainage pavement (DP), dense particle size ascon (DPSA) and dense particle size gap type ascon (DPSGTA). From the accident risk estimation model based on the Poisson regression analysis, we found that the age of the pavement has a positive significant effect on the accident risk. The impact is smaller under the normal weather condition. However, under the rain condition on curve section and tight-curve sections, the effect becomes remarkable.

The accident risk analysis for drainage pavement (DP) showed that the accident risk is comparable in sunny and rainy condition for the first three years (0, 1 and 2 years). However, from the fifth year, the difference on accident risk start to be remarkable. This could be due to the change in permeability capacity over time; in the first few years, the DP pavement exhibits its permeability and keeps the surface dry even in rainy weather; but as time passes, the drainage performance decreases because the pores are filled with dusts. This effect results in reduction in the permeability capacity of the pavement surface, which allows rain water stays on the pavement surface. The presence of the water on surface reduces the skid resistance of the surface. This is in line with Fwa, et al. (2017), which states that the skid resistance of a wet pavement varies with the thickness of the water film on the pavement surface.

The analysis for dense particle size gap type ascon (DPSGTA) suggests that the risk of accident on tight-curve sections paved with DPSGTA tends to decrease on normal weather condition for the first years. This decrease in the accident risk can be explained by Leden et al. (1998), which found that lateral friction for gap-graded asphalt tends to increase with time if it was low right after the resurfacing. Moreover, the surface of DPSGTA is basically composed by micro-texture, which provides high friction.

For sections paved of dense particle size ascon (DPSA), the surface is basically composed of macrotexture. Thus, the decreasing trend of the accident risk along the time on curve sections could be associated with driver's awareness to danger. The macrotexture has a poor friction capacity, and curve sections are known to be accident prone geometry. Therefore drivers would be aware of the danger, and could feel forced to drive with caution.

Acknowledgements

The authors are grateful to Hanshin Expressway Co., Ltd. for providing the precious data for this research.

References

Chan, C. Y., Huang, B., Yan, X. and Richads, S. (2010) 'Investigating effects of asphalt pavement conditions on traffic accidents in Tennessee based on the pavement management system (PMS)', *Journal of Advanced Transportation*, 44(3), pp. 150–161.

Ching, H. C. and Quddus, M. A. (2003) 'Applying the Random Effect Negative Binomial Model to Examine Traffic Accident Occurrence at Signalized Intersection', *Accident Analysis and Prevention*, 35(2), pp. 253–259.

Fwa, T. F. (2017) 'Skid resistance determination for pavement management and wet-weather road safety', *International Journal of Transportation Science and Technology*, 6(3), pp. 217–227.

Hossain, M. and Muromachi, Y. (2012) 'A Bayesian network based framework for real-time crash prediction on the basic freeway segments of urban expressways', *Accident Analysis and Prevention*, 45, pp. 373–381.

Leden, L., Olli Hämäläinen and Esa Manninen (1998) 'The effect of resurfacing on friction, speed and safety on main roads in Finland', *Accident Analysis and Prevention*, 30(1), pp. 75–85.

Lee, C., Hellinga, B. and Saccomanno, F. (2003) 'Proactive freeway crash prevention using real-time traffic control', *Canadian Journal of Civil Engineering*, 30(6), pp. 1034–1041.

Oguchi, T. (2016) 'Achieving safe road traffic - the experience in Japan', *IATSS Research*, 39(2), pp. 110–116.

Pande, A. and Abdel-Aty, M. (2006) 'Assessment of freeway traffic parameters leading to lane-change related collisions', *Accident Analysis and Prevention*, 38, pp. 936–948.

Shiomi, Y., Watanabe, K., Nakamura, H. and Akahane, H. (2018) 'Assessing Safety of Signalized Intersections Influence of Geometric Attributes and Regionality on Traffic Accident Risk', *Transportation Research Record: Journal of the Transportation Research Board*, 2659, pp. 71–79.

Son, H. '"Daniel"', Kweon, Y.-J. and Byungkyu '"Brian"' Park (2011) 'Development of crash prediction models with individual vehicular data', *Transportation Research Part C*, 19(6), pp. 1353–1363.

Yu, R., Abdel-Aty, M. and M Ahmed (2013) 'Bayesian random effect models incorporating real-time weather and traffic data to investigate mountainous freeway hazardous factors', *Accident Analysis and Prevention*, 50, pp. 371–376.