A Study on the Development of the Expressway Traffic Accident Damage Model in the Winter Season

J. J. Park,* I. K. Seo, D. Y. Kang, D. S. Son
Transportation Research Division, Korea Expressway Corporation Research Institute, Gyeonggi 445-812, Korea
*E-mail: jjpark@ex.co.kr, Phone: +82-31-371-3315, Fax: +82-31-371-3319
*Corresponding Author

ABSTRACT

Expressway traffic accidents account for 1.2% of the total traffic accidents. They are characterized by great loss of human life when they do occur on expressways. In particular, the fatality rate per traffic accident in the winter season is higher than the average rate of traffic accidents in each of the other seasons except winter. The cost of personal damage for three years (2009–2011) due to traffic accidents in winter season is estimated at about KRW 97.1 billion, which is about 20 times as much as the physical damage of about KRW 4.8 billion. Accordingly, this study tried to analyze the characteristics of the traffic accidents in winter by using the evaluation indexes of unified traffic accident damage costs. This study derived potential variables through principal component analysis and suggested them as explanatory variables because driver factors can be classified into various factors. The linear regression model of the traffic accident damage cost in winter season was constructed by selecting the potential accident factors, accident response, and human factors as explanatory variables. This study is considered to be able to be used as important judgment indicators in establishing the future measures to reduce large-scale traffic accidents in winter seasons.

1. INTRODUCTION

1.1. Background and Purpose of the Study

As a foundation for transportation of goods and passengers, roads play a pivotal role in national territory development and have continuously developed in the process of economic growth. However, the social cost that arises from traffic accidents has also increased by 10.0% compared to the previous year, reaching KRW 13 trillion, which accounts for 6.4% of the national budget in 2011. Apart from the personal and physical damages caused by the traffic accidents, Korea is also suffering tremendous loss due to its tarnished reputation of being one of the countries with a high rate of traffic accidents.

In general, expressway traffic accidents account for 1.2% of the total number of traffic accidents but they are characterized by great loss to human life with a fatality rate of 5.1%, because large-scale traffic accidents that are caused by the high-speed driving are more likely to occur on the expressways than on general national roads or local roads because expressways that are constructed on the basis of higher standards have better linear conditions.

The fatality rate per expressway traffic accident in the last three years is 11.9%. In particular, the fatality rate per accident in the winter season is 12.1%, which is 0.3% higher

than the average fatality rate in each of the other seasons except the winter season. This high rate of accident severity is considered to have been caused by the fact that the drivers needed more braking distance than usual due to heavy snow and the freezing of the road surface and they had difficulty controlling their cars.

The cost of personal damage for three years (2009–2011) due to the traffic accidents in winter season is estimated at about KRW 97.1 billion, about 20 times as much as the physical damage of about KRW 4.8 billion, which makes it necessary to carry out in-depth research on the accidents that cause personal damage.

Accordingly, this study will analyze how the major factors such as drivers, cars, roads, and environments, which are involved in expressway traffic accidents in the winter season, are related with the traffic accident damages. It is hoped that this study's result will be used for the establishment of future traffic safety policies to minimize the traffic accident damages by discovering the explanatory variables that are closely related with traffic accident damages.

1.2. Research Contents and Methods

The expressway accident level is classified into 4 levels (Level A–D) based on the amount of accident damage, the number of the deaths, and the number of the associated vehicles. In other words, it is classified into selection types, not based on unified accident severity. Thus, it lacks consistency because of the wide selection range on each level. Accordingly, this study analyzed the characteristics of traffic accidents in the winter season by using the evaluation indexes of unified damage costs.

To this end, this study used the data of the traffic accidents that occurred in the winter season during the last three years (2009–2011). In particular, this study also considered the fact that Korea has each different frequency and reason for traffic accidents in each of the four seasons with its own distinct seasonal characteristics.

To analyze the effect of traffic accidents on the accident damage cost, this study excluded the Level D accident with slight personal and physical damages from the analysis range because it has the possibility of causing Zero-Inflation error. In addition, the expressway traffic accidents that occurred in the expressway shoulder bays, bus stops, and emergency parking bays were also excluded from the analysis in principle because they occurred not during the driving of the vehicles, but during parking or as the passengers were getting on and off the vehicles.

For the personal damage cost, the accident damage cost per death and injury estimated annually by the Road Traffic Authority was used and the physical damage cost included both the facility and vehicle damage costs.

This study analyzed the characteristics of traffic accidents in the winter season by dividing them into driver factor, vehicle factor, as well as road and environment factors. However, as the driver factors can include various factors, this study derived the potential variables through principal component analysis and suggested them as explanatory variables.

Accordingly, with the potential accident factors, human factors, and road geometric structure factors as explanatory variables, this study constructed the linear regression model to analyze the characteristics of the traffic accidents that incur great damage costs

among the various types of traffic accidents in the winter season.

2. RELATED STUDY AND REVIEW OF TRAFFIC ACCIDENT DAMAGE COST ESTIMATION METHOD

2.1. Previous Studies

The domestic and foreign research literatures about the estimation of traffic accident damage cost are summarized as follows;

Jeong, Cheol Woo (2006) studied the relationship between the overall costs associated with the traffic accident damages caused by drivers and human factors, with an emphasis on the human factors (physiological and psychological) among the factors that cause various traffic accident costs. His study result suggested that the different measures such as the increase of the number of driver education and insurance premium be implemented because of the difference in relative seriousness of the traffic accidents caused by the male or female drivers. However, he did not apply the violation records before 2000 to his study on the ground that they were not computerized, which is pointed out as a limit of his study [1].

Lee, Ju Yeon (2008) suggested that the road and environmental factors are connected with the traffic accidents by constructing the structural equation using the direct and indirect effect factors such as geometric road structure, driver behavior, vehicle types and weather, which are involved in the traffic accidents that occurred on the general national roads [2].

Kelvin K. W. Yau (2004) analyzed the effect on the injury in traffic accidents using the traffic accident data of Hong Kong. He suggested that the vehicle types, road width, gender of the drivers, the year when the vehicle was manufactured, time zone of the accident, and road lightings are the factors that determine the severity of the injury[3].

Yan, Randwan et al (2005) studied the relationship between a series of potential accident factors, divided into driver characteristics, road environments and vehicle types, and rear-end collision accidents [4].

Bhagman Persaud (2000) proved that the accident frequency is high in the curved part of the roads through his sectional method of study on straight part and curved part of the roads [5].

The result of review on previous studies shows that there have been various researches on the correlation between the traffic accidents and accident factors conducted at home and abroad while the researches on the traffic accident damage cost has not been sufficiently carried out, which makes it necessary to conduct the further relevant study.

2.2. Method of Traffic Accident Cost Estimation

Since 1988, the Road Traffic Authority has estimated the road traffic accident cost on annual basis. The whole road traffic accident cost is divided into physical damage cost,

personal damage cost, and social institution cost, and the average cost of each kind of traffic accident reflects the cost of traffic accident handling institutions.

The net average cost of the personal damages is estimated in consideration of the gender and age of the drivers separately for the dead and injured in the traffic accident, and the most recent data is the cost estimation data of 2011 published in 2012.
It was estimated that a total of 5,299 people died in traffic accident in 2011, with the total production loss to the males estimated at about KRW1 trillion and 680 billion (average about KRW 404 million per male) and with the total production loss to the females at about KRW 180 billion (average about KRW 128 million), about 29% of the loss to the males in average. The net average cost that applied the estimated production loss was KRW 417 million per person.

A total of 341,391 people were injured in 2011, with the total production loss to the males estimated at about KRW 250 billion and the total production loss to the females at about KRW 59 billion, about 21% of the loss to the males. The net average cost that applied the estimated production loss was KRW 3 million per person.

In this study, the personal damage cost was estimated by applying the net average cost/person of those who died or were injured during 2009–2011 to the relevant years.

3. TRAFFIC ACCIDENT OCCURRENCE IN THE WINTER SEASON AND ITS CAUSAL ANALYSIS

3.1. Traffic Accident Occurrence

The Korea Expressway Corporation, the institute for expressway management, established the management standards for each accident level (Level A–D) that considered the personal and physical damage and the number of the vehicles involved in the accident, as shown in Table 1 below.

Table 1 - Korea Expressway Corporation Traffic Accident Management Standards

Level	Standards
Level A	More than 3 deaths, more than KRW 10 million of damage, more than 20 injured people, more than 10 vehicles involved in the accident
Level B	More than 1 death, more than KRW 2.5 million of damage, more than 5 injured people, more than 5 vehicles involved in the accident
Level C	More than 0 death, more than KRW 0.3 million of damage, more than 1 injured people, more than 3 vehicles involved in the accident
Level D	Other types of accident

The accident level based on the traffic accident management standard is decided even when one of the management standard items, such as the personal damage, accident damage cost, and the number of the involved cars, meets the standard. So it is a little difficult to regard it as an application of consistent standard. Accordingly, to analyze the severity of the traffic accident in the winter season by selecting the unified indicator, this

study set the traffic accident damage cost as the standard.

A total of 7.250 traffic accidents occurred on the expressways in the last three years (2009–2011) and a total of 744 people died in the accidents. Among them, a total of 1,708 traffic accidents occurred in the winter season, causing a total of 180 deaths, which showed the high rate of severity with the probability of death in one traffic accident estimated at 10.5%.

As the result of estimating average traffic accident damage cost per one traffic accident, as shown in Table 2 below, the average cost of traffic accidents that occurred in winter season was analyzed at about KRW 57 million, higher than total average traffic accident cost, which shows that the severity of traffic accidents in winter season is higher than that of other seasons.

Table 2 - Traffic Accident Damage Cost

(unit : million Won)

Cost	Winter Season	All Seasons
Average damage cost per one accident	57	55
All damage costs	83,305	413,175

3.2. Analysis of the Characteristics of Winter Season Traffic Accident

The analysis of the damage cost of the traffic accidents caused by the drivers in each age group showed that the higher the age group of the drivers, the higher damage cost is incurred, though with lower frequency of the traffic accidents, as shown in <Table 3> below. In other words, this shows that the physical changes reduce the ability of driving performance and can be connected to the expansion of traffic accident damages because of the difficulty in taking proper measures when an emergency occurs.

Table 3 - Traffic Accident Damage Cost Caused by the Drivers in Each Age Group

(unit : million Won)

Age Group	Number of Accidents	Total Cost	Average Cost
20~30	233	10,252	44
30~40	384	19,968	52
40~50	465	25,576	55
50~60	317	17,752	56
Higher than 60 years of age	74	7,252	98

The traffic accident damage cost incurred by each cause of the accident is shown in Table 4 below, and the number of traffic accidents caused by the drivers was analyzed to be 1,308 cases, accounting for about 88.9% of the total number of the accidents. The average damage cost of the traffic accidents caused by the drivers was KRW 59 million, analyzed to be higher than damage cost of the traffic accidents caused by the car defects and other causes of the accidents.

Table 4 - Traffic Accident Damage Cost incurred by Major Causes of the Accident

(unit : million Won)

Cause	Number of Accidents	Total Cost	Average Cost
Driver	1,308	77,637	59
Car Defect	112	5,006	44
Others	53	661	12

The traffic accident damage cost incurred by each vehicle type is shown in Table 5, which shows that the average traffic accident damage cost incurred by vans is KRW 101 million, higher than all the other vehicle types, mainly because the van has more passengers than other vehicle types, incurring high damage to human lives when the traffic accidents do occur. Therefore, the measures for the prevention of traffic accidents by vans are considered necessary.

Table 5 - Traffic Accident Damage Cost incurred by Each Vehicle Type

(unit : million Won)

Vehicle Type	Number of Accidents	Total Cost	Average Cost
Passenger car	827	44,658	54
Van	104	10,504	101
Truck	396	20,592	52
Special Vehicle	146	7,154	49

Table 6 shows the result of analyzing traffic accident damage costs by dividing the vertical alignment of the roads into a downward section, plane section, and upward section. The traffic accident damage cost in downward and upward sections was more than KRW 60 million, much higher than the damage cost in plane section, because the drivers tend to drive at high speed particularly in downward section causing high severity of accident.

Table 6 - Traffic Accident Damage Cost in each Vertical Alignment of the Roads

(unit : million Won)

Section	Number of Accidents	Total Cost	Average Cost
Downward	505	34,845	69
Plane	572	24,593	43
Upward	396	23,760	60

Table 7 shows the result of traffic accident damage cost analysis according to the wearing of the safety belts. The wearing of the safety belts in all the seats has been made obligatory on the expressways but most drivers and passengers still do not wear their safety belts due to their existing driving habits and lack of police crackdown. While drivers

and passengers who do not wear safety belts incur the traffic accident damage cost of average KRW 507 million, those who wear the safety belts incur the damage cost of KRW 39 million, about 13 times lower.

Table 7 - Traffic Accident Damage Cost according to the Wearing of Safety Belts

(unit : million Won)

Wearing or Non-wearing	Number of Accidents	Total Cost	Average Cost
Wearing	1,419	55,341	39
Non-wearing	54	27,378	507

4. AN ANALYSIS OF THE IMPACT OF TRAFFIC ACCIDENT DAMAGE COST

4.1. Principal Component Analysis

Expressway accidents are caused by the roads, drivers and vehicles. Among them, the traffic accidents caused by the drivers have various factors. Accordingly, to solve the problem of redundancy of the external variables of the accidents caused by the drivers and to understand the pattern the independent variables are composed of, the principal component analysis was conducted. Initiated by Burt, the principal component analysis has developed into multivariate statistical analysis and processing method by several researchers like Benzecri, Lebart, among others. By reducing the dimensions through principal component analysis (extraction of potential variables considering redundancy, etc, in the driver factors), the core variables of the data can be extracted and used as major variables that can explain the traffic accident damage cost in winter season.

To satisfy the dimensional reduction of explanatory variables, the principal component analysis is considered to have an explanatory power if the Eigenvalue is higher than 1 and the cumulative contribution ratio is higher than 60%. When any principal component whose dimension is reduced has the largest absolute value of the loading, it is categorized into the relevant component and utilized for the selection of representative words.

As shown in Table 8, the result of the principal component analysis shows that there are four representative principal components with the Eigenvalue of higher than 1 and the cumulative contribution ratio of higher than 60%, which are considered appropriate to explain the causes of the accident by the drivers.

Table 8 - The Principal Component Analysis Result

Principal Component / Name of Variable	Component Loading			
	1	2	3	4
Speeding	-0.935	-0.038	-0.241	-0.135
Negligence in Keeping a Safe Distance	0.024	0.003	0.124	0.895
Drunk Driving	0.014	0.002	0.066	0.203
Drowsy Driving	0.416	0.807	-0.328	-0.154
Negligence in keeping eyes forward	0.478	-0.776	-0.318	-0.152
Excessive Handling of a Steering Wheel	0.063	0.009	0.932	-0.297
Improper Passing	0.017	0.002	0.078	0.846
Eigenvalue	1.282	1.254	1.161	1.066
Contribution Ratio(%)	18.310	17.914	16.584	15.231
Cumulative Contribution Ratio(%)	18.310	36.224	52.808	68.040

It was analyzed that the largest value in each factor, such as speeding in component 1; drowsy driving and negligence in keeping eyes forward in component 2; excessive handling of a steering wheel in component 3; negligence in keeping a safe distance, drunk driving and improper passing in component 4, is the variable that can explain each principal component. The representative words to best explain each principal component are as follows;: speeding for component 1, careless driving for component 2, unskilled driving for component 3, and traffic rule violation for component 4.

4.2. Construction of Winter Season Traffic Accident Damage Cost Model

4.2.1. Model Selection

A prediction model was developed using various independent variables, such as driver factors, vehicle factors, and road and environmental factors that have effect on traffic accident damage cost. As the traffic accident damage cost can be quantitatively calculated according to the traffic accident severity, a linear model is considered suitable.

A multiple linear regression analysis model set up in this study is a regression analysis model that has more than two independent variables belonging to one dependent variable, and it is the most suitable model for analysis of diverse factors that have effect on traffic accident damage cost.

The determination coefficient (R^2) of a multiple linear regression analysis model is defined as shown in Formula (1), and the determination coefficient can be represented by the formula $0 \leq R^2 \leq 1$, which means that the closer it is to 1, the greater its significance.

$$R^2 = \left(\frac{SSR}{TSS}\right) = 1 - \frac{SSE}{TSS} \qquad (1)$$

here, SSR : sum of squares due to regression
TSS : total sum of squares
SSE : sum of squares due to error

As the number of explanatory variable increases, the value of R^2 tends to increase. Thus, in the regression model, which has more than two explanatory variables, it is desirable to explain the goodness of fit of the model using Adjusted R^2(Adj-R^2) to complement the tendency. The Adjusted R^2(Adj-R^2) is shown in Formula (2).

$$Adj - R^2 = 1 - (1 - R^2)\frac{(n-1)}{(n-p-1)} \qquad (2)$$

here, n : the number of individuals
r : the number of explanatory variables
R^2 : determination coefficient

4.2.2. Traffic Accident Damage Cost Model Construction

To understand the characteristics of traffic accidents that occur in winter season, a linear regression model was constructed by selecting the traffic accident damage cost as a dependent variable. The explanatory variables in this model were classified into accident factor, accident type, traffic controllers' response to accident, driver's properties, and road and weather condition factors. Especially for the accident factor, the inherent potential variables were selected as explanatory variables by scoring the factors of the loading of the driver.

Table 9 - Explanation of Variables

Classification		Variable	Content
Traffic Accident Cost		Y_1	personal injury,physical damage cost
Accident Factor	Speeding	X_1	component 1 score
	Careless Driving	X_2	component 2 score
	Unskilled Driving	X_3	component 3 score
	Traffic Rule Violation	X_4	component 4 score
Accident Type	Vehicle Type	X_5	otherwise:1, car:0
	the Number of Accident Vehicles	X_6	single unit:1, two units:2, more than three units:3
	Accident Pattern	X_7	vehicle-facilities:1, vehicle only:0
Road and Weather Condition	Vertical Alignment	X_8	flat land:1, otherwise:0
	Road Shape	X_9	main line:1, otherwise:0
	Weather	X_{10}	fine:1, otherwise:0
Controller's Response	Accident-handling Time	X_{11}	-
Driver's Properties	Age	X_{12}	under sixties:1, over sixties:0
	Non-Wearing of the Seat Belt	X_{13}	wearing:1, otherwise:0

In a linear regression model, the goodness of fit of the model is judged by the sign

condition of the estimated coefficient, the significance (the magnitudes of t-value and p-value) of the estimated coefficient and adjusted R^2(Adj-R^2) with the selected coefficient as the judgment standard. In the first place, the value of Adj-R^2, which determines the goodness of fit of the model, was analyzed at 0.307. This means that it has a low explanatory power. Nevertheless, it is considered to make a meaningful contribution to understanding the major factors that influence the traffic accident damage cost.

The vehicle type and the driver factors such as age, unskilled driving and failure to wear the seat belt turned out to be the variables that greatly influenced the traffic accident damage cost, and the accident-handling time and the number of accident vehicles were analyzed to be significant at the 95% confidence level.

In other words, when a male driver of a full-size van or a heavy vehicle without wearing the seat belt causes a traffic accident because of speeding and careless driving, he incurred the highest traffic accident damage cost. Although traffic accidents are frequently caused by young drivers under fifties, traffic accident severity is higher in elderly drivers over sixties who are relatively slow in their reaction. Hence, careful driving is considered necessary.

Table 10 - Analysis Result

factors		coefficient	t-value	p-value
accident factor	speeding	0.027	1.165	0.244
	careless driving	0.007	0.307	0.759
	unskilled driving	-0.049	-2.187	0.029**
	traffic rule violation	-0.021	-0.912	0.362
accident type	vehicle type	0.082	3.545	0.000**
	the number of accident vehicles	0.143	5.696	0.000**
	accident pattern	0.022	0.963	0.336
road and weather condition	vertical alignment	0.030	1.345	0.179
	road shape	0.016	0.678	0.498
	weather	-0.003	-0.144	0.885
driver's reaction	accident-handling time	0.151	6.083	0.000**
driver's properties	age	0.068	3.101	0.002**
	non-wearing of the seat belt	-0.453	-20.328	0.000**
R^2		0.314		
$Adj - R^2$		0.307		

** : A significance exists at the 95% confidence level.

5. CONCLUSION AND FUTURE RESEARCH TASKS

The traffic accidents that occur in winter season require a longer braking distance because of the heavy snowfall and freezing of the road surfaces than the traffic accidents in other seasons. Thus, the large-scaled traffic accidents are more likely to occur in winter season than the other seasons because it is not easy to control the car.

According to expressway traffic accident statistics, the traffic accidents in Level A make few seasonal difference, while the fatal traffic accidents in Level B occur 0.6 % more in winter season than other seasons. The traffic accident damage cost is divided into personal damage cost and physical damage cost, and the personal injury cost turns out twenty times higher than the physical damage cost, which makes it necessary to conduct a research to identify the major reasons for that.

This study detailed the driver factors, a vehicle factors, and road and environment factors and analyzed their effects on the traffic accident damage cost, which are summarized as follows;

First, it was analyzed that, among the driver factors that account for about 88.9% of the entire traffic accidents, the unskilled driving such as unskilled handling of the steering wheel and failure to wear the seat belt increase the traffic accident damage cost. Hence, it is deemed necessary for the drivers to fully understand the safe driving tips to respond to dangerous situations during winter season, and to establish an information system to inform drivers of dangerous sections.

Second, with regard to vehicle factors, it was analyzed that fatal injuries that frequently occur in the accident were caused by vehicles bigger than vans that carry lots of passengers. Hence, it is deemed necessary to conduct special safety training for the drivers of vans and heavy vehicles.

Third, it was analyzed that the traffic accident damage cost is greatly incurred according to the number of accident-prone vehicles and the traffic accident handling time. In Korea, the accident scene management and traffic flow control in a traffic accident are handled by the National Police Agency and the Emergency Management Agency, while the Road Management Agency is in charge of the support work. Hence, it is necessary to make efforts to prevent the secondary fatal injuries through the prompt response to the accidents by integrating the Road Management Agency, the National Police Agency, and the Emergency Management Agency, which are in charge of the pre- and post-control of traffic accidents.

It is considered that the results presented by this study can be utilized as important evaluation indicators in establishing the measures to reduce the fatal accidents in winter season.

REFERENCES

1. Chung, C-.w. (2006). A study on degree of impact factors of accident damage cost (TADC) at the intersection (focused on driver human factors). Police Science. Vol. 6, No. 3, pp.125–149.
2. Lee, J-.y., Chung, J-.h., and Son, B-.s. (2008). Analysis of traffic accident severity for Korean highway using structural equations model. Korea society of Transportation. Vol. 26, No. 2, pp.17–24.

3. Kelvin, K. and Yau, W. (2004). Risk factors affecting the severity of single vehicle traffic accidents in Hong Kong. Accident Analysis and Prevention. Vol.36, pp.333–340.
4. Yan, X., Randwan, E., and Abdel-Aty, M. (2005). Characteristics of rear-end accidents at signalized intersections using multiple logistic regression model, Accident Analysis and Prevention. Vol. 37, pp.35-46.
5. Persaud, B., Retting, R.A., and Lyon, C. (2000). Guidelines for identification of hazardous highway curves. Transportation Research Record. Vol. 1717, pp.14-18. 2000.