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Research Article

An Investigation of the Safety Performance of Roundabouts in Korea Based on a Random Parameters Count Model

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It is well known that a roundabout is an efficient and safe intersection. However, the safety is generally influenced by the given various conditions. This study analyzed the effects of the geometric and traffic flow conditions on traffic accident frequency at roundabouts, constructed in Korea since 2010. Many previous studies have investigated the efficiency and safety effects of roundabout installation. However, not many studies have analyzed the specific influences of individual geometric elements and traffic flow conditions of roundabouts. Accordingly, this study analyzed the effects of various influencing variables on traffic accident frequency based on a random parameter count model using traffic accident data in 199 roundabouts. Using random parameters that can take into account unobserved heterogeneity, this study tried to make up for the weakness of the fixed parameters model, which constrains estimated parameters to be fixed across all observations. A total of eight variables were determined to be the main influencing factors on traffic accident frequency including the number and width of entry lanes, the presence of pedestrian crossings, the width of the circulatory lanes, the presence of central islands, the radius and number of entry lanes, and traffic volume influence accident frequency. Based on the study results, safer roundabout design and more efficient roundabout operation are expected.

1. Introduction

A (modern) roundabout is a circular intersection in which traffic travels circulating around a central island and the entering traffic must yield to circulating traffic. This roundabout was developed in the United Kingdom to resolve problems associated with traffic circles [1]. Changes of the driving rule to enter the circulatory lanes enabled the success of the modern type of a roundabout. The changed driving rule at a roundabout is that entering traffic must yield to circulating traffic. Through this driving rule change, the operation and safety of roundabouts have improved compared to signalized intersections as well as rotaries.

Some previous studies explained that roundabouts can improve efficiency and safety performance comparing other type of intersections and, more specifically, roundabouts can reduce conflict points at intersections and accident severity significantly [1–6]. However, roundabouts perform better than signalized intersections only for intermediate traffic demands and, for high traffic demands, signalized intersections generally perform better than roundabouts [7]. Furthermore, researches have shown that if existing signalized intersections are changed to roundabouts, the traffic accident frequency and severity can be reduced [8–14].

As other country experience, 484 roundabouts have been built since 2010 in Korea and great safety and efficiency effects have been made. And there were some studies to investigate those effects of roundabout constructions. However, some studies were conducted based on only a simple comparison of accident occurrences between before and after the installation of roundabouts. And there were only few studies to investigate the influence factors for roundabout safety in Korea.

Thus, this study was conducted to analyze the effects of the geometrics of roundabouts and traffic volumes on the traffic accident frequency at the 199 roundabouts in Korea. For this analysis, a random parameters model was used to consider heterogeneity that can occur in the data

Table 1: Number of roundabouts constructed since 2010 in Korea.

Year	2010	2011	2012	2013	2014	2015	2016	2017	Total
# of Roundabouts	87	97	85	96	54	24	18	23	484

Table 2: Accident reduction effects of roundabout construction.

Before/After Roundabouts	Average Annual Crashes				
	Total	Fatality	Severe Injury	Injury	Minor Injury
Before	571	15	258	274	24
After	308	5	118	171	14
%	-46.1%	-66.7%	-54.3%	-37.6%	-41.7%

Source: [15] Korean Roundabout Research Center (http://www.roundabout.or.kr/).

collection and unobserved heterogeneity of traffic accident data instead of a traditional count model. Through the regular count data model for traffic accident frequency used in most of previous studies can be developed based on assumption that influence of each variable is fixed and homogenous. In other words, the influence is not changeable in the data and model development. However, in real, the possibility of heterogeneity in them always exists, and this heterogeneity problem can reduce the contribution and precise of the traffic accident frequency models.

2. Literature Review

2.1. Roundabout Construction Projects in Korea. Even though there have been many suggestions from transportation experts to apply roundabouts in Korea since 2000, the construction of roundabouts began just in 2010. In many other countries, roundabouts have been implemented based on engineers' recommendations regarding alternative designs and operation methods of intersections. However, in Korea, a roundabout application project was conducted by leading federal governments, typically the Presidential Council on National Competitiveness. The roundabout construction projects by the Presidential Council on National Competitiveness were developed and accomplished by several government organizations including the Ministry of Land, Transport, and Maritime Affairs; the Ministry of Public Administration and Security; National Police Agency; and some research institutes [16].

Through this roundabout projects, there have been more than 480 roundabouts constructed in Korea with federal government subsidies since 2010 and it brought many positive impacts on intersection operation and safety. There were more than 80 roundabouts constructed every year between 2010 and 2013; after 2013, the number of roundabouts constructed with federal government subsides decreased every year, as shown in Table 1. However, there were many roundabouts constructed by local government budgets, which are not included in the Table 1. Overall, there have been observed reductions of the total numbers of crashes and fatalities of 46.1% and 66.7%, respectively, as shown in Table 2. This crash reduction of roundabouts in Korea is consistent with international observations, as shown in Table 3. United States is a country that started to apply a roundabout relatively late but has applied greatly a roundabout in recent. In 1990, there were only two roundabouts in the United Stated; however until 2016, about 3,200 roundabouts have been built and operated [17]. Typically, roundabouts in Minnesota have had over an 80% reduction in fatal and serious injury crashes. A 69% and an 83% reduction in the right angle crash rate and in the left turning crash rate, respectively, at intersections where Single Lane Roundabout have been installed [18]. The safety benefit was analyzed in view of economic saving in Pennsylvania. Through a before-after analysis with data from the fourteen intersections, they concluded that there was $35.6 million saving that include economic costs to society and the impact on driver's quality of life [19].

2.2. Previous Studies Regarding the Influences of Geometric Elements on Roundabout Safety. The safety performance of roundabouts has been mainly discussed based on the influences of geometric elements on roundabout safety including the number of circulatory lanes, inscribed circle diameter, the number of legs, AADT, entry width, angle between legs, splitter island width, and intersection sight distance. In general, the crash frequency increases as the inscribed circle diameter, the amount of vehicles entering the roundabout, and the number of legs to the roundabout increase [12]. Maycock and Hall observed a linear relationship between entry width and entering circulating crashes using statistical modeling [20]. For US roundabouts, it was also found that entry width has a direct relationship with entering-circulating crashes. However, this study concluded that there was no significant relationship between the number of entry lanes and entering-circulating crashes as entry width increases in the United States. Kamla and his coresearchers applied random parameters model to investigate geometric and traffic characteristics on accident frequency at roundabouts in the United Kingdom. They used data from 70 roundabouts. In random-parameter results, some variables were significant in the random parameter model including approach traffic rates, truck percentage, inscribed circle diameter, number of lanes, and presence of traffic signals. However, because only two variables for geometric conditions were included in their study, it is limited to explain influence of various geometric condition factors on traffic accident occurrence [21].

Meanwhile, there are some studies to investigate roundabout geometric characteristics and cycling safety. A VTI

Table 3: Mean crash reductions in various countries.

Country	Mean Reductions (%)	
	All Crashes	Injury Crashes
Australia	41-61%	45-87%
France	-	57-78%
Germany	36%	-
Netherlands	47%	-
United Kingdom	-	25-39%
United States	35%	76%

Source: [1] NCHRP Report 672, Roundabouts: An Informational Guide, p 5-16.

study summarized roundabout geometric characteristics influencing on cycling safety based on literature reviews including number of circulatory lanes, entry/exit number of lanes, number of legs and deflection angle, refuge and central island characteristics, and geographic location such as urban and rural areas [22].

There were Korean studies to analyze safety effects of driving environments in roundabouts. Park analyzed the relationship between traffic accident types and geometric conditions on roundabouts from 40 roundabouts, and he developed an accident frequency model using a negative binomial model [23]. Since he used accident data collected from 9 roundabouts in Korea, and 31 roundabouts in other countries, his model did not consider variety of driving environments of different countries. There was another study to investigate the influence of roundabout geometric and traffic conditions on traffic accident frequency. Na and Park developed traffic accident frequency model based on a Zero-Inflated negative binomial modeling method using 94 roundabouts [24]. However in these roundabouts used in the study, some were the (modern typed) roundabouts but others were the rotaries. Therefore the results from this study could not explain the real influence of geometric and traffic conditions in the roundabout. Kim investigated influencing factors of roundabout geometrics on accidents using the Classification and Regression Tree(CART) method [25]. She found that wider circulatory land width caused more accidents in roundabouts. Kim and Choi investigated crash data at roundabouts in order to identify the major factors influencing such events in South Korea [26]. They developed a crash prediction model using a negative binomial distribution with various independent variables including the number of approaches, number of entering lanes, entry width, flare width, number of circulating lanes, and circulating lane width. The data used for modeling in their study were collected from 14 roundabouts in Korea and 31 in other countries. Furthermore, some of 14 roundabouts in the data were operated as a rotary system not a roundabout. Therefore, their study result might be biased and mixed results between a roundabout and rotary as well as between Korea and other countries.

2.3. Previous Studies to Develop Traffic Accident Models Using Common Methods and RRPM. Random parameters modeling for count data such as accident frequencies is a recent development in the traffic safety field. Before applying random parameters, fixed parameters were a common method to model with count data. However, the major limitation of modeling with fixed parameters is that they cannot incorporate segment-specific or time variation effects, and this limitation called as a unobserved heterogeneity problem results in underestimation of the standard errors of coefficients. To find a solution to this unobserved heterogeneity, a count model with random parameters was introduced. Anastasopolus and Mannering used a random parameter negative binomial model to account for heterogeneity that could arise from road geometrics, traffic characteristics, driver behavior, pavement condition, vehicle type, and other unobserved factors [27]. Venkataraman and his coresearchers proposed the use of a random parameter negative binomial model to take into consideration the segment-specific insight into crash frequencies for the analysis of nine years of crash data on interstate highways in Washington, USA [28]. In many other studies [28, 29], the authors determined that some variables vary across observations, and considering random parameters is an alternative solution to solve the unobserved heterogeneity problem.

3. Methods

3.1. Random Parameters Count Model. Generally, count data modeling is used for accident frequency prediction models where the accident frequency is not continuous and is a non-negative integer value in nature. In this regard, Poisson and negative binomial models are the main methods employed to develop prediction models for count data [30]. For the basic framework of the Poisson model, the probability $P(y_i)$ of a roundabout i having y_i accidents is presented in

$$\mathrm{P}\left(y_i\right) = \frac{\exp\left(-\lambda_i\right)\lambda_i^{y_i}}{y_i!} \quad (1)$$

where λ_i is the Poisson parameter for the roundabout i (equal to i's expected number of accidents, $\mathrm{E}(y_i)$).

The Poisson model specifies the parameter of the expected number of accidents (λ_i) as a function of independent variables (in this study, geometrics and traffic characteristics) using the log-linear function shown in

$$\lambda_i = \exp\left(\boldsymbol{\beta}\boldsymbol{X_i}\right) \quad (2)$$

where $\boldsymbol{X}_i$ refers to a vector of independent variables and $\boldsymbol{\beta}$ is a vector of estimable parameters.

However, the Poisson model may not always be appropriate to analyze the accident frequency because the Poisson distribution constrains the variance and the mean to be equal ($E(n_i)=Var(n_i)$). If this constraint is violated, the data can be considered to be under-dispersed ($E(n_i)>Var(n_i)$) or overdispersed ($E(n_i)<Var(n_i)$), which results in incorrect and inconsistent inferences [27, 31]. In addition, most accident frequency data have been shown to have overdispersed characteristics, for which the Poisson model is not suitable [32, 33].

To account for the possibility of either underdispersion or overdispersion, the negative binomial model is derived by way of an errors structure as follows:

$$\lambda_i = \exp\left(\boldsymbol{\beta X_i} + \varepsilon_i\right) \tag{3}$$

where $\exp(\varepsilon_{ij})$ is a Gamma-distributed error term with mean 1 and variance α.

The addition of this term allows the variance to vary from the mean as follows:

$$\mathrm{Var}\left[n_{ij}\right] = E\left[n_{ij}\right]\left[1 + \alpha E\left[n_{ij}\right]\right] = E\left[n_{ij}\right] + \alpha E\left[n_{ij}\right]^2 \tag{4}$$

Thus, by integrating the error structure, the negative binomial probability density function has the following form:

$$P\left(n_{ij} \mid \lambda_{ij}, \alpha\right) = \frac{\Gamma\left((1/\alpha) + n_{ij}\right)}{\Gamma(1/\alpha)\, n_{ij}!}\left(\frac{1/\alpha}{(1/\alpha) + \lambda_{ij}}\right)^{1/\alpha}\left(\frac{\lambda_{ij}}{(1/\alpha) + \lambda_{ij}}\right)^{n_{ij}} \tag{5}$$

where $\Gamma(.)$ refers to a gamma function.

Here, the negative binomial model is an expanded model of the Poisson model as the dispersion parameter (α) is not close to 0, which means that the dispersion parameter is not statistically significantly different than 0.

This is the traditional Poisson and negative binomial model structure, which assumes that parameters are fixed across observations (in this study, the roundabout). To account for heterogeneity that may vary across observations, random parameters in count models can be considered [34]. The estimable parameters are expressed as

$$\beta_i = \beta + \varphi_i \tag{6}$$

where φ_i refers to a randomly distributed term($\lambda_i \mid \varphi_i = \exp(\boldsymbol{\beta}_i \boldsymbol{X}_i)$ in the Poisson model and $\lambda_i \mid \varphi_i = \exp(\boldsymbol{\beta}_i \boldsymbol{X_i} + \varepsilon_i)$ in the negative binomial regression model for each roundabout i.

In addition, normal, log-normal, uniform, and other functional forms can be considered as potential density functions for random parameter estimations. The log likelihood with this random parameter can be written as follows:

$$\mathrm{LL} = \sum_{\forall i} \ln \int_{\varphi_i} \mathrm{g}\left(\varphi_i\right) P\left(n_i \mid \varphi_i\right) d\varphi_i \tag{7}$$

where $\mathrm{g}(\bullet)$ refers to the probability density function of φ_i.

Because the numerical integration of the count model with a random parameter distribution is computationally cumbersome, a simulation-based maximum likelihood method is used to maximize the simulated log-likelihood function. To estimate empirical parameters, Halton designed a potential method that was shown to provide a more efficient distribution of draws for numerical integration than random draws [35, 36]

With estimated coefficients of the parameter, the true effect of each independent variable on the dependent variable can be estimated by elasticity and a marginal effect based on the characteristics of the variable. Elasticity is the percentage change in every accident frequency due to a one percent change in the independent variable as follows:

$$E_{x_{ik}}^{\lambda_i} = \frac{\partial \lambda_i}{\lambda_i} \times \frac{x_{ik}}{\partial x_{ik}} \tag{8}$$

Equation (8) shows the elasticity of accident frequency with respect to the kth independent variable for section i.

The elasticity shown in (8) is only valid for continuous variables that do not take on a dummy variable. Another way to interpret the effect of an independent variable is the marginal effect, which reflects the effect of a "one unit" change of an independent variable on the dependent variable, calculated as the partial derivative $\partial\lambda_i/\partial x_{ik}$. It is similar to the elasticity mentioned above except estimating the effect of a change on the dependent variable with 1% change in X on the dependent variable(Y). It measures the effect of a "one unit" change in X on the dependent variable. In addition, although marginal effects are generated by each roundabouts, averages over the roundabout population will be presented.

4. Study Results

4.1. Data Description. A total of 199 roundabouts were utilized to construct the traffic accident frequency model that can be applied with the random parameters count model. The main variables used to develop the model were, region types(urban and rural area), type of intersection (three-way, four-way, or five-way), the curvature radius for each entry lane, the number of lanes, width of the entry lane to the roundabouts, lane width at the exit lane, presence of pedestrian crosswalks, distance between the yield line and pedestrian crosswalk, presence of a central island, presence of a vertical grade, channelization, traffic volumes, inscribed circle diameter, diameter of the central island, number of circulatory lanes, and width of circulatory lanes. All data regarding the geometric elements were obtained through field surveys. Data from the Traffic Accident Analysis System (TAAS) operated by the Korea Road Traffic Authority was utilized to collect the total number of traffic accidents from 2013 to 2015 and traffic volumes in the roundabout design stage.

Table 4 explains the descriptions of the key variables used in building the model via a random parameters negative binomial. The collected data show that urban areas (68%) have more roundabouts than rural areas (32%), and the most common roundabout type is the 4-legged roundabout (51%),

Table 4: Descriptive statistics of the variables.

Variable Description	Mean	Standard Deviation	Min.	Max
Region (urban: 1; rural: 0)	0.683	0.466	0	1
3-legged roundabout	0.357	0.480	0	1
4-legged roundabout	0.513	0.501	0	1
5-legged roundabout	0.131	0.338	0	1
Average radius of the entry lane (m)	20.872	12.121	5.5	98.75
Lane number of the entry/exit lane	1.170	0.395	1	3.2
Average lane width of the entry lane (m)	4.319	1.022	3	10.9
Average lane width of the exit lane (m)	4.556	1.068	2	10.1
Pedestrian crosswalk (yes: 1; otherwise: 0)	0.769	0.423	0	1
Distance between the stop line and pedestrian crosswalk	9.26	6.62	0	21
Central island (yes: 1; otherwise: 0)	0.950	0.219	0	1
Vertical grade (yes: 1; otherwise: 0)	0.412	0.493	0	1
Exclusive right turn lane (yes: 1; otherwise: 0)	0.231	0.423	0	1
Number of accidents per year	2.553	4.384	0	37
Logarithm of AADT	9.123	8.852	4.60	10.54
Diameter of the roundabout (m)	31.148	8.335	9	80
Diameter of the central island (m)	17.380	6.150	3	40
Number of circulatory lanes in the roundabout	1.116	0.336	1	3
Width of the circulatory lanes in roundabouts (m)	5.151	0.564	3.8	7

followed by 3-legged (36%) and 5-legged (13%) roundabouts. The curvature radius for each entry lane is 21 meter on average, the number of entry lanes is 1.2 lanes, the width of the entry lanes is 4.3 meter, and the width of the exit lanes is 4.6 m. A pedestrian crosswalk is installed in 77% of roundabouts, and a central island is installed in most roundabouts (95%). In total, 41% of the roundabouts contained a vertical grade, and an exclusive right turn lane to separate traffic volume is included at 23% of the roundabouts. The average number of traffic accidents is 2.5 annually, and the average of AADTs is 9,200 vehicle per year. The mean diameter of the roundabouts is 31 meter, and the mean diameter of the central islands is 17 meter. The average number of circulatory lanes in the roundabouts is one, and the average width of the circulatory lanes in the roundabouts is 5 meter. Using those variables, the factors that influence traffic accidents at roundabouts and their effects were analyzed in this study.

4.2. Model Development. Models of the traffic accident frequencies at roundabouts were developed using the random parameters negative binomial model, as shown in Table 5. The parameters in statistical models can work as fixed parameters or random parameters based on their basic characteristics. The statistical model showed improvement over the baseline fixed parameters negative binomial model, with an improvement in likelihood from -1,123.89 to -382.82. The overdispersion parameter is statistically significant, which indicates that the negative binomial model is more suitable than the Poisson model.

Whether a used parameter is random or fixed can be determined by the derived standard deviation for each parameter. In the case that the standard of deviation of the parameter density is statistically significant under 95% confidence level, the corresponding parameter is random. On the other hand, if the standard deviation of parameter density is not statistically significant, the parameter is considered fixed across the population. Through the analysis, a total of eight parameters was found to be statistically significant under 95% confidence level with regard to traffic accident frequency at roundabouts. Among them, four variables including the traffic volume, the average lane width of the entry lane, the presence of a central island, and the width of the circulatory lanes were fixed, while the other four variables including the radius of the entry lane, the number of approach/exit lanes, the presence of a crosswalk, and the presence of a vertical grade were determined to be random. For variables with random parameters, various distribution forms, normal, log-normal, uniform, and other distributions, were considered, but the normal distribution showed the highest statistical significance. Table 6 presents marginal effects and elasticity values, which explain the degree of the effect on traffic accident frequency for each parameter.

The interpretation of the parameters' effects on accident frequencies at roundabout begins with the analysis of fixed

Table 5: Estimation results of roundabout accident frequencies in Korea.

Variable	Constant Parameter		Random Parameter				
	Mean	t-statistic	Distribution	Mean	t-statistic	Standard Deviation	t-statistic
Constant	-1.82	-1.41		n.a			
Exposure							
Logarithm of AADT	0.23	2.51		n.a			
Geometrics							
Average width of entry lane (m)	0.16	1.96		n.a			
Presence of Central island	1.00	2.29		n.a			
Width of circle lanes(m)	-0.29	-1.93		n.a			
Radius of entry lanes(m)	n.a		normal	-0.04	-4.94	0.02	5.13
number of entry lanes	n.a		normal	0.14	3.34	0.07	4.4
Presence of Pedestrian crosswalk	n.a		normal	0.65	2.61	0.17	1.98
Vertical grade	n.a		normal	-0.63	-3.49	0.62	4.26
Scale Parameter for overdispersion	1.58	4.7					
Number of observations				199			
Log likelihood at convergence of RPNB model				-382.82			
Log likelihood with constant only				-1,123.89			

n.a: not applicable.

Table 6: Average marginal effects and elasticities for random parameter negative binomial models.

Variable	Marginal effect	Elasticity
Logarithm of AADT	0.34	0.23
Width of entry/exit lanes	0.24	0.70
Central island (yes: 1; otherwise: 0)	1.49	0.63
Width of the circle lanes in the roundabout (m)	-0.44	-1.54
Radius of the entry lanes (m)	-0.06	-0.87
Number of approach/exit lanes	0.21	0.16
Pedestrian crosswalk (yes: 1; otherwise: 0)	0.97	0.48
Vertical grade (yes: 1; otherwise: 0)	-0.93	-0.88

parameters. As can be seen in the estimation results, four variables were found to have fixed parameters. First, the logarithm of the AADT variable is positive, and it means that, as the AADT increases, the number of traffic accidents increases. This is a consistent result with other previous studies in which traffic accidents increase as the exposure rate increases. In terms of the elasticity viewpoint, an increase in traffic volume by 1% increases traffic accidents by 0.23%. The average width of the entry lane had a positive impact on crash frequency. This result implies that the vehicle speed usually increases with a wide lane, and the traffic accidents can occur more frequently at roundabouts due to difficulty of yield to circulating vehicles. To reduce the accident frequency and severity, geometry to force slow speed for entry vehicles should be considered. A central island is the generally raised area in the center of a roundabout around which traffic circulates, and it affects the increasing traffic accident frequency. A central island can be an obstacle to drivers due to inexperienced driving skills and out of control vehicles due to too high speed. The last variable as a fixed parameter is the width of the circulatory lanes in the roundabout. This variable affects the decrease of vehicle accidents. Wider circulatory lanes make too high speed on circulatory lanes, and this too high speed causes traffic accident with entry vehicles due to aggressive gap acceptance decision at entry lanes.

Meanwhile, variables that have random parameters are as follows: the radius of entry lanes, the number of entry lanes, the presence of pedestrian crosswalk, and vertical grade. The radius of the entry lane affects the decrease in likelihood of traffic accidents. The radius of the approach lane has a normally distributed random parameter with a mean of -0.04 and a standard deviation of 0.02. Given these distributional parameters, 97.72% of roundabouts show a decrease in accident frequencies and 2.28% of roundabouts show an increase in accident frequencies as the radius of the approach lane increases. As a result, proper design combination of the radius and width of the entry lane mentioned above is needed for increasing safety.

The number of approach and exit lanes affects traffic accidents positively with a normal distribution having a mean of 0.14 and a standard deviation of 0.07. This result indicates that, as the number of approach and exit lanes increases, the traffic accident frequency also increases at most roundabouts. Since the number of lanes is correlated with exposure rates like traffic volume, the likelihood of vehicle crashes increases with the number of lanes. Also, if the number of entry and exit lanes are more, more conflict points exist. In terms of the marginal effect, a one-lane increase in approach and exit lanes would increase the mean number of accidents by 0.21, as reflected in the marginal effect values shown in Table 6. Pedestrian crosswalks influence the occurrence of vehicle crashes. The derived mean of 0.65 and standard deviation of 0.17 show that, under a normal distribution, most roundabouts experienced an increasing number of crashes.

The last variable that has a random parameter is vertical grade, with a mean of -0.63 and a standard deviation of 0.62 with a normal distribution. This result reveals that 84.5% of roundabouts with a vertical grade experienced accident frequency reduction, and 15.5% of roundabouts without a vertical grade show an increase in accident frequency. This result could be because the vertical grade increases safety by influencing vehicle speed and driver's caution.

5. Conclusions

This study determined the effects of geometrics and traffic flow conditions on traffic accident frequency at roundabouts in Korea. Although many roundabouts have been installed in recent years in Korea, most studies have been focused on the general effects of roundabouts in view of efficiency and safety. Furthermore, some studies have been conducted in safety viewpoints based on a simple comparison of accident occurrences before and after installation of roundabouts. However, for safer design and operation of roundabouts, it is important to know which elements have positive or negative effects on traffic accident frequency. This study contributes to understanding which factors realistically affect traffic accident occurrence. In particular, this study applies random parameters, thereby taking considering unobserved heterogeneity across roundabouts, which was not explained properly in previous studies.

The estimation results showed that eight parameters that significantly affect vehicle crashes can be derived. Among them, traffic volume, average lane width of the entry lane, central island, and width of the circle lane were found to be fixed effects, which means that they produce the same effect on all roundabout. The other four parameters including the radius of the entry lane, the number of approach and exit lanes, the presence of a pedestrian crosswalk, and the vertical grade were found to be random effects, which means that they affect traffic accidents differently depending on the roundabout. The traffic volume, average width of the entry lane, presence of a central island, number of approach and exit lanes, and presence of a pedestrian crosswalk are regarded as variables that increase vehicle crashes, while the other variables are regarded as factors that reduce vehicle crashes.

This study contribute to identifying elements that significantly affect traffic accidents and to applying a random parameter count model to consider unobserved effects in the variable. However, this study has some limitations. Although in this study, a random parameter negative binomial model was applied to understand the relationship between traffic accident frequency at roundabouts recently installed in Korea and geometries for the first time, more in-depth analyses are needed for further understanding. Also, an appropriate offset, which is a distance between a stop line and a pedestrian crosswalk, needs to be calculated in relation to the installation of crosswalks. If a crosswalk is too close to the roundabout, it can be beneficial for pedestrians by reducing walking distance. However, it can result in more conflict with drivers who want to enter the roundabout, which can be a threat to safety. In contrast, if a crosswalk is installed too far from the roundabout, pedestrians have to walk farther than necessary such that jaywalking can occur frequently, which threatens the safety of pedestrians. Accordingly, it is necessary to find the right distance of a crosswalk from the stop line of a roundabout to satisfy the needs of drivers and pedestrians even current Korea roundabout design guideline recommends that there should be more than six meter offset for pedestrian safety.

Another limitation of this study is a matter of universality for database and analysis results. The all data used in this study was from Korea roundabouts, and because Korea is in the early stage of the roundabout application, there have been many safety and operation problems that does not occur in other countries. Therefore, for more universal results, safety improvement change by time series should be kept studying in the future.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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