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Analysis of Road Sign-Related Factors Affecting Driving Safety with Respect to City Size

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Abstract: With the increasing popularity of digital navigation systems and smartphones, the role of road signs during driving is gradually diminishing. However, owing to the inaccessibility of the technology to certain portions of the population, e.g., the elderly, and the risk of failure of communication networks, road signs continue to be an essential public tool to ensure driving safety. Although some research has been conducted on road sign-related topics, e.g., road sign recognition and image analysis, the comprehensive safety of road sign functions has not yet been researched. Accordingly, this study analyzed the factors of road signs affecting driving safety based on ordinal logistic regression analysis and derived their implications through a public survey. To improve driving safety, it is necessary to improve the intuitiveness of guide information (Daytime recognition (odds ratio): 1.547, Understanding of guide information: 1.222), select user's necessary information (Sufficiency of guide information: 1.449) and provide variable information (Real-time guidance according to situation), establish a road guide system for various future mobility modes (Customized guidance for various forms of mobility: 1.112), and link and integrate with surrounding road facilities (Location/frequency adequacy: 1.128, Integrated installation of road facilities: 1.116).

Keywords: road sign; road guide; driving safety; ordered logit model

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1. Introduction

The introduction of navigation systems in the 2000s and the popularization of smartphones since 2010 have provided the public with accessible sources of information on destinations and road networks, thereby diminishing the role of road signs in ensuring driving safety. However, certain portions of the population, e.g., the elderly, are not well versed with such technology. Further, communication networks may fail without warning, limiting access to digital information. As a result, road signs continue to be essential to driving safety. In 2002, the Ministry of Land, Infrastructure and Transport designated the Korea Institute of Construction Technology as the Comprehensive Road Sign Management Center (henceforth referred to as "Road Sign Center") and entrusted it with the operation and management of road signs. The Road Sign Center performs comprehensive road sign-related tasks, e.g., operating the road sign information management system based on the road sign system, reviewing existing and new road signs, amending road sign rules, and providing other technology, policy, and research support. Completed tasks to ensure driving safety include developing illuminated signs, improving reflectivity, limiting the number of signs installed above lanes spanning the road, increasing font size and brightness, and unifying English notation. However, these tasks were conducted on the basis of individual requirements in the past—systematic studies have not been conducted to evaluate factors affecting driving safety comprehensively. Additionally, driving environments on roads and road information density depend on the city size; however, such factors have not been adequately researched. In this study, road sign-related factors affecting driving safety were classified and analyzed based on city size using a road sign recognition survey, and certain implications were derived.

2. Literature Review

Studies related to road signs can be broadly classified into the following categories: road sign recognition, application, and image analysis, which are all directly or indirectly related to driving safety. Experimental studies on road sign recognition from the driver's perspective have been conducted targeting sign recognition, sign comprehension, and visual movement [1–5]. However, as these studies focused primarily on pictogram-based traffic safety signs, we could not confirm whether international tourists would recognize road signs in the present study. In South Korea, a greater number of recognition studies have been conducted on road signs compared to those on traffic safety signs. Examples include the degree of confusion in drivers regarding road signs using graph theory [6], the design of information to enhance the intuitiveness of road sign design [7], a sign design study to improve the contextual visibility of road signs [8], a case study on the application of universal designs in road signs [9], and a misreading rate analysis in elderly drivers considering the ergonomic characteristics of signs [10]. However, these studies were conducted as individual unit studies, and the overall influencing factors of road signs, such as recognition, accuracy, and improvement needs, were not considered.

Research on road sign application includes studying variable message signs (VMSs), system construction, and other topics. For VMSs, studies have been conducted on VMS expression and safety in a construction area [11,12] and the optimal VMS expression method based on luminance analysis and a preference survey [13]. These studies focused on VMS-based road signs, which can be used to provide variable and real-time road information and guidance. Thus, they are significant in expanding the role of traditional road signs that depict fixed information. However, as information is only provided unidirectionally in such signs, they do not completely address the requirements of drivers. In the case of system construction, research on the management aspect is the main focus, such as road sign infrastructure management and a system database for setting the influence area of place names [14–16]. In addition, the impact analysis of public bicycle guide signs [17] and roadside advertising signs [18] have been studied; however, road sign research that comprehensively considers the rapidly changing traffic environment, such as autonomous driving and the use of AI big data, is insufficient.

Existing research related to road sign image analysis is as follows: Overseas, traffic safety sign recognition for vehicle advanced driver-assistance systems (ADASs) and autonomous driving support have been studied [19–21]. In Korea, image recognition research on road signs has been conducted [22–26]. A road sign condition evaluation study to find a road sign requiring repair has also been conducted [27]. Therefore, the need for improvement of advanced technologies/services and facility safety management related to road signs must be addressed, in consideration of the future traffic environment.

Although road sign-related accident data due to misreading of road signs and confusion of guidance information have not been statistically analyzed, it is judged that driving safety is influenced by the characteristics of road signs that guide and guide drivers. Therefore, this study intends to analyze factors affecting driving safety based on a citizen survey, and as it is based on a survey. BLR (Binary Logit Regression) and OLR (Ordered Logit Regression) can be used as analysis models. This study used OLR based on a five-point scale to increase the reliability of the questionnaire analysis by inducing a more ordered response rather than dichotomizing the response to driving safety, which is the dependent variable. Although an OLR-based analysis of road signs has not yet been performed, this technique has been used in some related studies, such as traffic signs. Examples of this are studies on the impact of traffic safety signs, traffic accidents targeting VMSs, and driver compliance behaviors [28,29]. Broadening the scope to vehicles, analyses of the factors affecting road traffic accidents [30–33] and the influence of weather conditions on driving and traffic accidents [34–36] have been conducted. In the case of other transportation fields, an OLR-based analysis has been used for new commuter rail systems, subways, and electric bicycles [37–39]. Thus, the OLR-based analysis has been widely utilized in the transportation field to analyze influencing factors with mainly ordinal dependent variables, such as satisfaction, severity, and importance. Policy implications and response strategies have also been derived based on these studies. However, there has been no research on road signs installed to provide drivers with road information and improve driving safety. In this context, this study drew meaningful conclusions by performing an OLR-based analysis on nearly 3000 samples taken from a 2020 public survey.

3. Research Scope and Methodologies

3.1. Research Scope

In South Korea, road signs are classified into two categories (Figure 1): 1. Traffic safety signs, which concern speed limits, regulations, instructions, etc. and fall under the jurisdiction of the National Police Agency; 2. Road signs, which offer information on routes to destinations, directions, streets, etc. and fall under the jurisdiction of the Ministry of Land, Infrastructure and Transport. This study focuses on road signs of the second type—installed to help drivers use road facilities and arrive at their desired destination easily. In South Korea, urban structures and population densities are significantly dependent on city size in each upper-level local government. Therefore, road sign information, such as road and place names, should also depend on city size. Considering the characteristics of Korean urban structures, we classified the spatial scope by adding Gyeonggi Province, which is a part of the Seoul Capital Area (SCA), to the existing upper-level local government classifications of Seoul City, metropolitan city, and provinces (cities and counties).

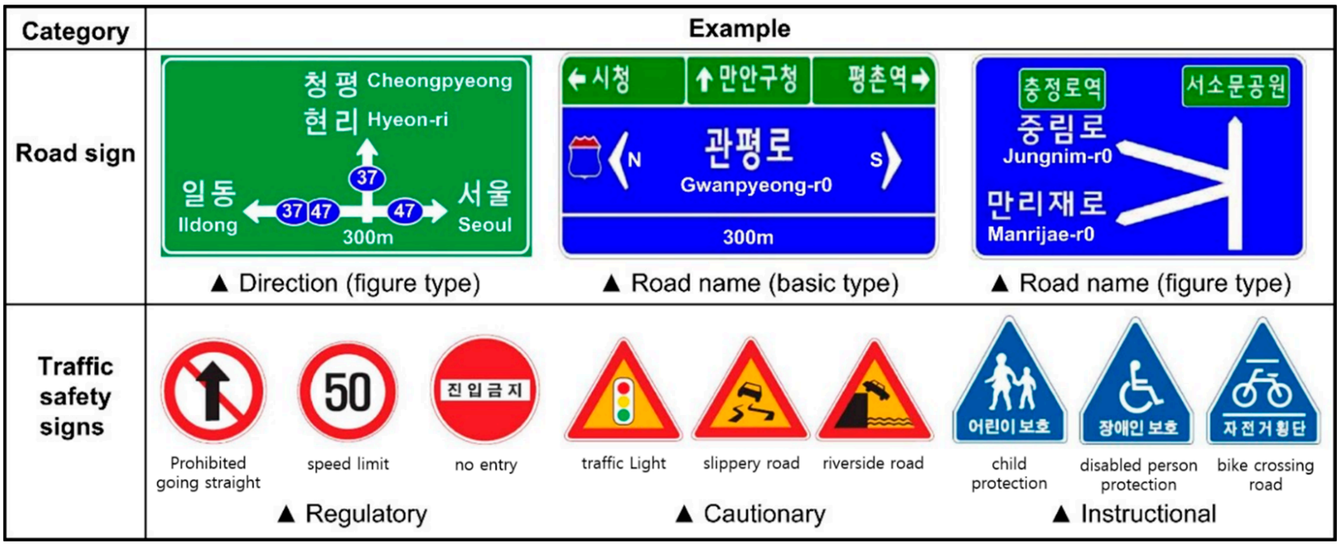

Figure 1. Categories of South Korean road signs.

3.2. Methodologies

In this study, OLR was performed on survey data of the 2020 Road Sign Development Plan implemented by the Road Sign Management Center of the Ministry of Land, Infrastructure and Transport as part of the research method. ORL can adopt the items of the ordinal scale among the questionnaire data as the dependent variable. In addition, ORL has the advantage of adopting various other items, such as nominal scale, ordinal scale, and ratio scale as independent variables. Therefore, the effects of demographic characteristics, vehicle driving characteristics, road sign satisfaction, and road sign improvement requirements on road safety-related driving safety were analyzed and classified based on different city sizes. An additional analysis was performed to derive certain implications (Table 1).

Table 1. Survey and analysis method.

Classification	Contents
Date (n)	15 October–4 November 2020 (n = 2884)
Sampling method	Extraction of proportional allocation by gender, age, and region based on national police agency driver's license status statistics
Sampling error	±1.8 at 95% confidence level
Object	Road sign development plan
Survey contents	Demographic characteristics, vehicle driving characteristics, road sign satisfaction, and road sign improvement requirements, related driving
Analysis method	Ordered logit regression
Analysis target	Analysis by city size

The ordered logit model—an extension of the binary logit model—was used to estimate the selection probability for ordinal variables and is distinct from the multinomial logit model, which uses nominal variables as dependent variables. The ordered logit model assumes defined relationships of criteria with an order, such as 'important,' 'normal,' and 'not important' (i.e., a kind of leveled preference) [40]. Accordingly, this study configured a range with five orders of 'driving safely through road signs,' with g (g $\geq$ 4) possible outcomes for the dependent variable. $\mathbf{P}(\boldsymbol{Y} \leq \boldsymbol{j})$ in Equation (1) is the cumulative probability of driving safety as a dependent variable and is modeled through logit transformation as in Equation (2). Here, $\boldsymbol{\mu_i}$ is a scalar value that determines the range of latent variables, and $\sum_{k=1}^{K} \boldsymbol{\beta_k x_k}$ is a row vector representing the independent variables in this study, such as demographic characteristics, driving characteristics, road sign satisfaction, and road sign improvement requirements. When the outcome is measured on a ranked scale from 1 to g, the results obtained from an ordered logit model can be interpreted as odds ratios representing cumulative probability. The equation for the dependent variable, Y, belonging to category j or lower is as follows [41]:

$$\mathbf{P}(\boldsymbol{Y} \leq \boldsymbol{j}) = \boldsymbol{\pi_1} + \cdots + \boldsymbol{\pi_j},\ \boldsymbol{j} = \mathbf{1}, \cdots, \boldsymbol{j} \quad (1)$$

$$\log\left[\frac{\mathrm{P}(y \leq j\mathrm{lx})}{1 - \mathrm{P}(y \leq j\mathrm{lx})}\right] = \mu_i - \sum_{k=1}^{K} \beta_k x_k \text{ (but, } j = 1,\ 2,\ \ldots,\ J - 1) \quad (2)$$

The odds ratio of the model for the independent variable is as follows:

$$\mathbf{log\ \ddot{y}P}(\boldsymbol{Y} \leq \boldsymbol{j}) = \boldsymbol{\alpha_1} + \cdots \boldsymbol{\beta_x},\ \boldsymbol{j} = \mathbf{1}, \cdots, \boldsymbol{j} - \mathbf{1} \quad (3)$$

$$\left[\frac{\boldsymbol{P}(\boldsymbol{Y} \leq \boldsymbol{j}\boldsymbol{l}\boldsymbol{X} = \boldsymbol{x_2}) / \boldsymbol{P}(\boldsymbol{Y} > \boldsymbol{j}\boldsymbol{l}\boldsymbol{X} = \boldsymbol{x_2})}{\boldsymbol{P}(\boldsymbol{Y} \leq \boldsymbol{j}\boldsymbol{l}\boldsymbol{X} = \boldsymbol{x_1}) / \boldsymbol{P}(\boldsymbol{Y} > \boldsymbol{j}\boldsymbol{l}\boldsymbol{X} = \boldsymbol{x_{1)}}}\right] \quad (4)$$

4. Results

4.1. Survey Overview

The Road Sign Center of the Ministry of Land, Infrastructure and Transport conducted a public survey between 15 October and 4 November 2020 to explore measures required to utilize and develop road signs effectively. The survey targeted road users—participants eligible to apply for a driving license and those with pre-existing drivers' licenses aged over 18 years. The samples were proportionally extracted with respect to gender, age, and region based on the National Police Agency's statistics on the status of driver's license holders, and 2884 valid samples were selected in aggregate by excluding careless responses. In addition to the respondents' basic information, the survey content included road information provision means, usage of road signs while driving, degree of recognition and importance of road signs, contribution of road signs to route search, and contribution of road signs to driving safety. The last topic was the core focus of this study. The survey also included satisfaction items for road sign functions and status states, such as daytime visibility, nighttime visibility, sign size, and understanding of guide information. Finally, it also surveyed the importance of road sign improvement measures derived from the Road Sign Advisory Committee for current road sign information, future road sign development, and facility maintenance and management measures. Based on the data collected in this survey, we analyzed factors affecting driving safety and drew relevant conclusions.

4.2. Road Sign Recognition Survey

The means for vehicle drivers to identify road information can be largely divided into road signs, navigation systems, and experience based on self-learning. The usage ratios of road information identification means were surveyed for each road type, including all road areas, intersections, and unknown areas. Navigation systems exhibited the highest usage ratio, accounting for an overwhelming proportion of 64.1% for unknown areas. On the other hand, road signs exhibited higher usage rates for all items compared to experience, with over 30% usage each corresponding to exits, intersections, and complex areas (Table 2).

Table 2. Road information identification means.

Road Area	Road Information Identification Means		
	Road Sign (%)	Navigation System (%)	Experience (Self-Learning) (%)
All driving areas	26.5	47.9	25.5
Intersection areas	32.2	43.7	24.1
Unknown areas	27.8	64.1	8.1
Exits	34.5	47.8	17.8
Complex areas (multi-intersections, etc.)	30.3	52.0	17.8

The primary uses and types of road signs, as well as road types, were surveyed to investigate the usage of road signs in greater detail. Acquisition of information regarding road facilities, such as rest areas and toll gates, was the most popular use of road signs, accounting for 58.6% of the total usage, followed by checking for exits (54.9%) and identification of difficult roads, such as multilevel intersections (53.2%). Signs depicting place names or directions were the most commonly used types of road signs, accounting for 79.9% of total usage, followed by road facility guide signs, e.g., those corresponding to rest areas and parking lots (63.3%), and distance signs depicting the remaining distance to a place (58.8%). The proportion accounted for by route signs (21.5%) within the total usage was relatively low as drivers in South Korea are usually familiar with the name-based guide system. Finally, expressway signs accounted for the highest share at 42.0% with respect to road signs sorted by road type, followed by general national highway signs (32.5%) and urban road name signs (25.5%). This was regarded as a reflection of South Korea's road environment, in which the road name system was established recently (2014) (Table 3).

The road sign recognition survey estimated utilization, importance, contributions to route search, and driving safety of road signs based on a five-point scale. The importance of road signs exhibited the highest score with an average of 4.08, and contribution to route search (3.95) and contribution to driving safety (3.85) also corresponded to relatively high scores. However, the score of road sign utilization was relatively low, with an average of 3.61. The Pearson correlation coefficient between road sign utilization and driving safety was calculated to be 0.421 in the survey (significant at the 1% level), indicating a high correlation. Hence, road sign utilization can be considered to be directly proportional to its contribution to driving safety, indicating the need to explore measures to promote the use of road signs (Table 4).

Table 3. Road sign usage states.

Main Use *	Percentage	Main Road Signs Type *	Percentage	Main Road Types	Percentage
Acquiring road facility information (rest areas, toll gates, etc.)	58.6%	Direction signs	79.9%	National expressways	42.0%
Checking exits	54.9%	Road facility information signs (rest areas, etc.)	63.3%	General national highways	32.5%
Identifying difficult roads (multilevel intersections, etc.)	53.2%	Distance signs	58.8%	Road names (city)	25.5%
Acquiring road information for all areas	47.6%	Other information signs (tourist sites, city hall, etc.)	40.6%	-	-
Crosschecking with navigation system	45.3%	Road information guide signs (guidance, notices, etc.)	31.8%	-	-
Acquiring additional information (tourist sites, etc.)	36.0%	Boundary signs (administrative zone)	22.4%	-	-
-	-	Route signs	21.5%	-	-

* For main use and main road sign type, multiple selections were permitted.

Table 4. Road sign recognition survey.

Road Sign Recognition Item	Mean	Very High	High	Normal	Low	Very Low
Road sign utilization	3.61	218	1488	1017	149	12
Road sign importance	4.08	810	1551	465	53	5
Contribution to route finding	3.95	570	1695	539	77	3
Contribution to driving safety	3.85	457	1632	713	78	4

4.3. Variable Configuration

The response to ‘driving safety through road signs’ on a five-point scale (5: Very safe, 4: Safe, 3: Normal, 2: Not safe, and 1: Not safe at all) was taken to be the dependent variable in this study. The independent variables were broadly classified into demographic characteristics, driving characteristics, satisfaction with each road sign item, and road sign improvement measures. Of these, demographic characteristics and driving characteristics consisted of dummy variables. For gender, male was represented using 1 and female using 0 (reference); for age, 40–50 was selected as the reference variable, and 30 or younger and 60 or older were used as dummy variables. Usage of the navigation system was represented using 1 and nonusage using 0 (reference). For driving experience, 4–10 years was selected to be the reference variable, and 3 years or less, 11–20 years, and 21 years or more were used as dummy variables. For average weekly driving time, 3–4 h was selected to be the reference variable, and less than 2 h, 5–7 h, and 8 h or more were used as the dummy variables. Road sign satisfaction was measured on a five-point scale consisting of seven variables—daytime and nighttime recognition, adequacy of sign size, comprehensibility of guide information, sufficiency of guide information, route accuracy, location/frequency adequacy, and esthetic/safety management. The road sign improvement measures devised by the Road Sign Advisory Committee mentioned above consisted of customized guidance for desired location, customized guidance for various forms of transportation (current road sign information improvement), real-time guidance according to situation, preparation for future roads (requirement for future road sign development), integrated installation of road facilities, and facility safety management (facility maintenance measure). The importance of each item was also measured on a five-point scale (5: Very important, 4: Important, 3: Normal, 2: Not important, and 1: Not important at all) and treated as an ordinal variable (continuous variable). Based on this, we analyzed the road sign-related factors affecting driving safety, derived classification and analysis results with respect to city size, and discussed the implications of the results (Table 5).

Table 5. Variable configuration.

Item	Variable			Frequency	Percentage	Mean	STD
Dependent variable	Road sign driving safety					3.85	0.711
Independent variable	Demographic characteristics	Gender (dummy)	Male	1693	58.7%		
			Female (reference variable)	1191	41.3%		
		Age (dummy)	30 or younger	1021	35.4%		
			40–50 (reference variable)	1317	45.7%		
			60 or older	546	18.9%		
	Driving characteristics	Use of navigation system (dummy)	Use	2825	98.0%		
			Do not use (reference variable)	59	2.0%		
		Driving experience (dummy)	3 years or less	350	12.1%		
			4–10 years (reference variable)	829	28.7%		
			11–20 years	825	28.6%		
			21 years or more	880	30.5%		
		Average weekly driving time (dummy)	Within 2 h	936	32.5%		
			3–4 h (reference variable)	1126	39.0%		
			5–7 h	591	20.5%		
			8 h or more	231	8.0%		
	Road sign satisfaction	Daytime recognition				3.89	0.641
		Nighttime recognition				3.19	0.879
		Adequacy of sign size				3.63	0.761
		Understanding of guide information				3.41	0.813
		Sufficiency of guide information				3.30	0.841
		Route accuracy				3.46	0.805
		Location/frequency adequacy				3.38	0.799
		Esthetic/safety management				3.59	0.789
	Road sign improvement measure	Current road sign information improvements	Customized guidance by location (fog, tourism, etc.)			3.88	0.839
			Customized guidance for various forms of mobility			3.56	0.898
		Requirements for future road sign development	Real-time guidance according to situation (events, accidents, etc.)			3.86	0.818
			Preparation for future roads			3.39	0.860
		Facility maintenance measures	Integrated installation of road facilities			3.64	0.792
			Facility safety management			3.83	0.789

4.4. Analysis of Road Sign-Related Factors Affecting Driving Safety

4.4.1. Analysis of Participants' Responses

First, we analyzed road sign-related factors affecting driving safety corresponding to all 2884 samples. We performed a multicollinearity test to determine the correlation among the independent variables (Table 6). The variable inflation factor (VIF) was observed to lie within 1.018–2.609, indicating low correlation among the variables. The Chi-square value was observed to be 633.798 (p-value < 0.0001), indicating the viability of the model, and the Nagelkerke R^2 was 0.224, indicating that the model exhibited good explanatory power. In logistic regression analysis, the Nagelkerke R^2 values of 0.2–0.3 are regarded as favorable [42]. For ease of analysis, we focused on the odds ratio—the probability ratio for the reference variable of each variable with an exponential value.

Table 6. Analysis of all responses.

Item		Variable		β	Odds Ratio	Std_Error	*p*-Value
Dependent variable		Intercept1		−0.113	-	0.677	0.867
		Intercept2		2.995 ***	-	0.480	0.000
		Intercept3		5.855 ***	-	0.481	0.000
		Intercept4		8.966 ***	-	0.500	0.000
Independent variable	Demographic characteristics	Gender (reference (0): Female)		0.127	1.135	0.085	0.136
		Age (reference: 40–50)	30 or younger	0.168	1.183	0.102	0.099
			60 or older	−0.242 *	0.785	0.111	0.029
	Driving characteristics	Use of navigation system (reference 0: X)		−0.258	0.772	0.263	0.326
		Driving experience (reference: 4–10 years)	3 years or less	−0.098	0.907	0.130	0.452
			11–20 years	−0.347 ***	0.707	0.107	0.001
			21 years or more	−0.382 **	0.682	0.130	0.003
		Average weekly driving time (reference: 3–4 h)	Within 2 h	0.059	1.061	0.090	0.510
			5–7 h	0.050	1.051	0.102	0.625
			8 h or more	−0.250	0.779	0.145	0.085
	Road sign satisfaction	Daytime recognition		0.436 ***	1.547	0.065	0.000
		Nighttime recognition		0.020	1.021	0.049	0.676
		Adequacy of sign size		0.104	1.109	0.059	0.078
		Understanding of guide information		0.201 ***	1.222	0.056	0.000
		Sufficiency of guide information		0.371 ***	1.449	0.058	0.000
		Route accuracy		0.194 ***	1.215	0.057	0.001
		Location/frequency adequacy		0.128 *	1.137	0.059	0.031
		Esthetic/safety management		0.028	1.029	0.056	0.612
	Road sign improvement needs	Current road sign information improvements	Customized guidance by location (fog, tourism, etc.)	0.093	1.097	0.054	0.083
			Customized guidance for various forms of mobility	0.112 *	1.118	0.048	0.020
		Requirements for future road sign development	Real-time guidance according to situation (events, accidents, etc.)	0.148 **	1.160	0.051	0.004
			Preparation for future roads	−0.011	0.989	0.050	0.826
		Facility maintenance measures	Integrated installation of road facilities	0.116 *	1.124	0.055	0.034
			Facility safety management	0.211 ***	1.234	0.055	0.000
Chi-square (model fit)				633.798 ***			
Nagelkerke R^2 (explanatory power of model)				0.224			

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

In terms of demographic characteristics, the influence of road signs on driving safety decreased by 21.5% (significant at the 5% level) among drivers aged 60 years or more compared to those in their 40s and 50s (reference variable). In this case, the following variables were insignificant: aged 30 or younger and gender. Compared to respondents with 4–10 years of driving experience (reference), the influence of road signs on driving characteristics decreased by 29.3% (significant at the 0.1% level) among respondents with 11–20 years of experience and by 31.8% (significant at the 1% level) among those with 21 or more years of experience. The following variables were insignificant in this case: 3 years or less of driving experience, average weekly driving time, and use of navigation system.

As all road sign satisfaction variables are continuous variables based on an ordinal scale, and their influences can be compared in terms of their odds ratios. The odds ratio of daytime recognition satisfaction was 1.547 (significant at the 0.1% level), exhibiting the highest influence, closely followed by that of guide information sufficiency at 1.449 (significant at the 0.1% level). It can be interpreted that driving safety improved by 54.7% in daytime road sign recognition satisfaction and 44.9% by sufficiency of guidance information. In terms of influence on driving safety, the two aforementioned variables were followed by comprehensibility of guide information (odds ratio = 1.222, significant at the 0.1% level), route accuracy (odds ratio = 1.215, significant at the 0.1% level), and location/frequency adequacy (odds ratio = 1.137, significant at the 5% level).

In the context of current road sign information improvements required for road signs devised by the Road Sign Advisory Committee, the variable of customized guidance for users of different types of mobility was significant (odds ratio = 1.118, significant at the 5% level). In the context of future road sign development requirements, the variable of real-time road information guidance based on the situation (important events, accidents, construction zones, etc.) was found to be significant (odds ratio = 1.160, significant at the 1% level). In terms of facility maintenance measures, the variables of both facility safety management (odds ratio = 1.234, significant at the 0.1% level) and integrated installation of road facilities (odds ratio = 1.124, significant at the 5% level) were found to be significant.

4.4.2. Analysis with Respect to City Size

Because urban complexity, road congestion, population structure, and place name guide characteristics depend on city size characteristics, the classification of the spatial scopes of Seoul City, metropolitan cities, Gyeonggi region, and provinces is essential to compare their relative influences. Seoul is one of the largest cities in the world, with a high population density and a population of nearly 10 million. As a result, it is the city with the highest number of operating vehicles in South Korea.

Seoul also features a complex urban structure and road network, with the irregular roads of old towns mixed with the grid-based road networks of new towns. Based on the ITS National Traffic Information Center, Seoul Traffic Information System, and 21 autonomous district control centers, the city government has established the nation's highest-level transportation system infrastructure in Seoul. It hosts various mobility projects, such as personal mobility and bike-sharing, and has undertaken the construction of future mobility infrastructure, such as electric and hydrogen vehicles. Metropolitan cities in South Korea typically exhibit populations exceeding 1 million and a level of transportation infrastructure that is higher than that of provincial settlements, but lower than that of Seoul. In contrast, the level of transportation infrastructure in provincial cities and counties is relatively low owing to the financial constraints faced by local governments; they also exhibit low population densities and demographics with high proportions of elderly residents. The Seoul Capital Area (SCA) of South Korea, comprising cities with high populations that have expanded around Seoul, exhibits the characteristics of a megacity-scale urban belt. According to resident population statistics from March 2022 (National Statistical Portal, KOSIS), the population of Seoul is 9,506,778, whereas the population of the Gyeonggi Province, which is a part of the SCA, is approximately 1.4 times larger than that of Seoul at 13,575,936. The Gyeonggi Province exhibits characteristics that are distinct from those of

Seoul, metropolitan cities, and other cities and counties. To alleviate the high population density in Seoul, the first- and second-phase new town development policies have dispersed and spread the Seoul population, leading to a mix of Seoul citizens and existing residents in the Gyeonggi Province. Goyang City and Seongnam City, with populations of 1.08 million and 930,000, respectively, include representative first-phase new towns, such as Ilsan and Bundang, due to population dispersion policies. According to KOSIS statistics, high proportions (over 30%) of the population in several sections of the Gyeonggi Province—including Gwacheon City (47.6%), Hanam City (46.7%), Gwangmyeong City (43.5%), Guri City (40.9%), Namyangju City (33.3%), and Goyang City (32.4%)—commute to work or school from the Gyeonggi Province to Seoul. Additionally, because Gyeonggi Province is adjacent to Seoul, its urban structure and road environment also combine characteristics of new towns with those of rural areas in the outskirts of the Gyeonggi Province. Considering the characteristics of each city, we compared and analyzed the road sign-related factors affecting driving safety.

As can be seen in Table 7, the influence of road signs on driving safety was observed to decrease by 61.6% among drivers aged 60 years or more compared to those in their 40s and 50s (reference) in rural areas (other cities and counties). Compared to drivers with 4–10 years of driving experience (reference), the influence of road signs on the driving characteristics of drivers with 11–20 years of experience was 57.4% lower (significant at the 0.1% level) and that of drivers with 21 years or more driving experience was 42.9% lower (significant at the 5% level) in metropolitan cities. In comparison, in other cities and counties, the influence of road signs on the driving characteristics of those with driving experience of 21 years or more was 53.1% lower than the reference figure (significant at the 1% level). These observations are in contrast with the insignificant results found in Seoul and Gyeonggi Province, which are part of the SCA.

In the context of road sign satisfaction, daytime recognition was observed to be significant in all city size categories (with influences varying between 37.8 and 73.5%). In particular, the greatest influence of daytime recognition was observed in Seoul, with an odds ratio of 1.735 (significant at the 0.1% level). For reference, in Seoul, all variables except daytime recognition were insignificant. Nighttime recognition was significant only in the case of other cities and counties, with an odds ratio of 0.823 (significant at the 5% level)—its increase was observed to decrease driving safety by 17.7%. Satisfaction with guide information sufficiency was observed to be significant in cities of all sizes except Seoul—the largest influence was exhibited in the Gyeonggi Province, with an odds ratio of 1.768 (significant at the 0.1% level). The route accuracy variable was significant in the case of metropolitan cities (odds ratio = 1.364, significant at the 1% level) and other cities and counties (odds ratio = 1.747, significant at the 0.1% level). Thus, route accuracy safety outside the SCA influenced driving safety, and the influence was greater in the provinces at 74.7%. The variables of sign size adequacy, location/frequency adequacy, and esthetic/safety management were found to be insignificant.

The road sign improvement requirements were also classified and analyzed in terms of present and future items and facility maintenance. In terms of the improvement of current road sign information, customized guidance based on location was observed to be significant only in metropolitan cities (odds ratio = 1.302, significant at the 5% level). Customized guidance for various forms of mobility was significant only in Seoul (odds ratio = 1.363, significant at the 1% level). In the context of future road sign development requirements, real-time guidance according to the situation was observed to be significant in metropolitan cities (odds ratio = 1.335, significant at the 1% level) and the Gyeonggi Province (odds ratio = 1.350, significant at the 1% level). The variable of preparation for future roads was not significant. In the context of facility maintenance measures, the variable of integrated installation of road facilities was significant only in the provinces (other cities and counties) (odds ratio = 1.340, significant at the 1% level). Facility safety management was significant in Seoul (odds ratio = 1.399, significant at the 5% level) and the Gyeonggi Province (odds ratio = 1.536, significant at the 0.1% level).

Table 7. Analysis results with respect to city size.

Item		Variable		Odds Ratio			
				Seoul City	**Metropolitan Cities**	**Gyeonggi Province**	**Other Cities and Counties**
Dependent variable		Intercept1(β)		2.816 *	-	1.770	-
		Intercept2(β)		4.880 ***	2.897 **	4.630 ***	0.495
		Intercept3(β)		7.910 ***	5.638 ***	7.343 ***	3.907 ***
		Intercept4(β)		11.326 ***	9.004 ***	10.336 ***	7.227 ***
Independent variable	Demographic characteristics	Gender (reference (0): Female)		1.487 *	1.060	1.292	1.060
		Age (reference: 40–50)	30 or younger	1.095	1.061	1.206	1.057
			60 or older	2.475 **	qae0.500 **	1.452	0.384 ***
	Driving characteristics	Use of navigation system (reference 0: X)		0.490	0.854	0.219 *	1.098
		Driving experience (reference: 4–10 years)	3 years or less	1.142	0.698	1.384	0.723
			11–20 years	0.898	0.426 ***	0.891	0.672
			21 years or more	0.888	0.571*	0.820	0.469 **
		Average weekly driving time (reference: 3–4 h)	Within 2 h	0.915	1.156	0.918	1.342
			5–7 h	1.167	1.212	0.797	1.084
			8 h or more	1.158	0.593	0.993	0.748
	Road sign satisfaction	Daytime recognition		1.735 ***	1.378 *	1.443 **	1.561 ***
		Nighttime recognition		0.955	1.145	0.993	0.823 *
		Adequacy of sign size		1.265	1.142	1.176	1.035
		Understanding of guide information		1.216	1.341 *	1.111	1.072
		Sufficiency of guide information		1.236	1.450 **	1.768 ***	1.393 **
		Route accuracy		1.036	1.364 **	1.005	1.747 ***
	Location/frequency adequacy			0.982	1.095	1.235	1.089
	Esthetic/safety management			1.009	0.939	1.108	1.193
Road sign improvement needs	Current road sign information improvements	Customized guidance by location (fog, tourism, etc.)		1.247	1.302 *	1.128	0.999
		Customized guidance for various forms of mobility		1.363 **	1.166	0.944	1.001
	Requirements for future road sign development	Real-time guidance according to situation (events, accidents, etc.)		1.102	1.335 **	1.350 **	0.921
		Preparation for future roads		1.015	0.967	0.933	1.016
	Facility maintenance measures	Integrated installation of road facilities		0.981	1.062	0.961	1.340 **
		Facility safety management		1.399 *	1.206	1.536 ***	1.204
Chi-square (model fit)				132.565 ***	221.690 ***	211.417 ***	223.431 ***
Nagelkerke R^2 (explanatory power of model)				0.244	0.304	0.264	0.269

* $p < 0.05$, ** $p < 0.01$, and *** $p < 0.001$.

5. Discussion

5.1. Road Sign Recognition Survey

The primary results obtained from the road sign recognition survey are as follows: Navigation systems were observed to be the most common means to access road information, although road signs also exhibited a considerable utilization rate of approximately 30%. Road signs were primarily used to acquire information on road facilities (rest areas, toll gates, etc.), check for exits, and identify difficult roads (multilevel intersections, etc.). Similarly, the most commonly used types of road signs were direction signs (place names and directions), distance signs (remaining distance to a place), and road facility guide signs. This study revealed that road signs fulfil their purpose of enabling drivers to use road facilities easily and arrive at their desired destinations. Compared to the importance of road signs and their contributions to route search and driving safety, road sign utilization exhibited relatively low scores. Owing to its high correlation with driving safety, appropriate measures must be adopted to promote the use of road signs.

5.2. Analysis of Participants' Responses

The primary results of the analysis and their implications are summarized below. First, the variables of daytime road sign recognition (odds ratio: 1.547) and comprehensibility of guide information (1.222) exhibited a high degree of influence on driving safety. Therefore, road sign designs should be improved by considering the intuitiveness of guide information, avoiding excessive information, and appropriately selecting the guide information required by users to enhance driving safety. Additional road sign improvements that were deemed to be necessary include supplementing signs depicting the actual geometry of roads (e.g., complex intersections), implementing highly intuitive and legible designs such that drivers can comprehend the entire sign rather than individual elements, and providing guide information from the perspective of user experience rather than that of public management. Guide information sufficiency (1.449) and situation-specific real-time guide information (1.148) were observed to be statistically significant, motivating the development of variable signs capable of displaying information required by road users in real time. Although real-time traffic information is currently provided via VMSs, they impart fixed road traffic information. It is essential to provide guide information that satisfies the needs of several drivers over a short time period, such as information on routes to destinations with temporary events, e.g., local festivals or construction sites. Given the limitations of road signs, which are fixed infrastructure, new types of signs incorporating VMSs should be developed, and effective display methods, such as displays built into vehicles, should be explored. Further, the variable of customized guidance corresponding to various forms of mobility (0.112) was observed to be statistically significant. Given the rapid increase in the number of modes of transportation sharing the roads (personal mobility, bicycles, etc.), a new mobility road guidance system should be designed to prevent road accidents. In particular, future forms of mobility, such as autonomous cars and unmanned aerial vehicles, should be considered. Further, the variables of sign location/frequency adequacy (1.128), facility safety management (1.234), and integrated installation of road facilities (1.116) were observed to be statistically significant. These variables share a common feature—the excessive installation of signs (including traffic safety signs) and sporadic construction of other road facilities (traffic lights, street lights, CCTV, etc.) degrade the legibility of guide information and road esthetics and even threaten the safety of facilities during abnormal weather conditions, such as typhoons. Addressing such problems is challenging because road facilities are managed by different institutions. Nevertheless, different types of facilities should be linked and integrated based on policy proposals from higher-level institutions and close consultation between management institutions.

5.3. Analysis with Respect to City Size

The dependence of the aforementioned conclusions on city size is as follows: First, the variable of daytime road sign recognition (odds ratio: 1.443~1.735) was observed to be significant for all city sizes, indicating the need to promote road sign improvement regionally. This can be achieved by improving designs to enhance intuitiveness, avoid excessive information, and select necessary information based on user requirements. Second, the variable of customized guidance for various forms of mobility (1.363) exhibited statistical significance only in Seoul. Owing to its high population density, Seoul's roads feature a mixture of traditional vehicles and various other forms of mobility, e.g., personal mobility and bicycles, thereby increasing traffic congestion. As this directly affects driving safety, a new mobility operation system should be developed, and road signs should be constructed to provide guidance. Such a system should first be piloted in Seoul. Third, the variable of real-time guide information based on situation (1.335, 1.350) was significant in Gyeonggi Province, which is part of the SCA, and metropolitan cities. This variable is relevant in situations involving temporary conglomerations (e.g., local events, large-scale conventions, etc.), which are typically arranged in the aforementioned regions. In this context, relevant technologies capable of displaying variable information should be researched and implemented primarily at sites of large-scale events, e.g., convention centers and large parks. Fourth, intensive road sign improvement should be undertaken in the provinces (other cities and counties). In these regions, the average age (0.384) and experience (0.469) of the drivers are relatively high, and the influence of road signs on the driving safety of this demography was observed to be relatively low. Thus, campaigns to raise awareness about driving and promote road sign usage among elderly and experienced drivers are critical. Additionally, nighttime recognition satisfaction (0.823) of road signs was observed to be inversely related to driving safety in provincial areas, indicating the need to improve road illumination in these regions (by installing illuminated signs, improving street lights and guide lights, etc.). Moreover, the influence of route accuracy (1.747) was high in the provinces. Therefore, in these areas, route accuracy should be continuously improved by checking for errors in the guide information of existing signs and ensuring the continuity of guide names.

6. Conclusions

Based on a public survey (n = 2884), this study analyzed road sign recognition and road sign-related factors affecting driving safety. Additionally, we classified the overall spatial scope of the study into Seoul City, metropolitan cities, the Gyeonggi Province, and provinces (cities and counties) in terms of population and compared the influencing factors with respect to city size. This study conducted an OLR-based analysis to investigate the influence of road sign-related factors on driving safety with respect to demographic characteristics, driving characteristics, satisfaction with each road sign item, and road sign improvement measures. Through this, it was possible to suggest improvement plans for the overall current road signs, future development directions, and customized improvement plans for each city size characteristic. In addition, this study was significant as it was the first to analyze the road sign-related factors affecting driving safety with respect to city size based on a public survey. It was especially important as the role of road signs has diminished recently owing to the growing popularity of navigation systems and smartphones. However, as this study analyzed factors affecting the rather macroscopic variables of road sign satisfaction and road sign improvement measures, it was not able to suggest specific measures corresponding to each item. Moreover, because it used public survey statistics rather than vehicle accident statistics to obtain driving safety-related data, and the vehicle speed factor was not considered, direct causal relationships could not be inferred. Follow-up studies on concrete in-depth measures corresponding to each conclusion derived in this study should be actively conducted in future. Further, empirical and policy-based research should be conducted to investigate on-site conditions, and statistical analysis should be performed based on actual accident data. In particular, the Ministry of Land, Infrastructure and Transport and the Road Sign Center applied the road sign improvement plan in this study to the actual field. Accordingly, we expect that such efforts will provide the public with safe road guidance services.

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