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Estimation of Legibility Distance for Portable Variable Message Signs

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Abstract: Variable Message Sign (VMS) is one of the major components of intelligent transportation systems (ITS), which is useful for providing real-time information on weather, traffic and highway conditions. In particular, portable variable message signs (PVMS) are very useful in managing traffic events including work zone, special events, and incidents. It is essential that PVMS locations and message operations should be designed with the proper consideration of driver's legibility distance. A variety of factors would affect the legibility distance, such as drivers' travel speed and driver characteristics etc. This study aimed at establishing a functional relationship between legibility distance and causal factors based on extensive field experiments. A specially manufactured PVMS was used for the experiment. A 500-meter tangent segment having 4 lanes (2 lanes for each direction) was selected for field experiments at the Hanyang University at Ansan, Korea. A differential global positioning system (DGPS) in a control vehicle was used to obtain drivers' legibility distances. Data collection and analysis were undertaken to develop an estimation model for the drivers' legibility distances using regression modeling techniques. The proposed model would be greatly useful for ITS designers and planners when making decisions on PVMS locations and message operations for better traffic management.

Key Words: *Human Factor, Intelligent Transportation Systems, Portable Variable Message Sign , Legibility Distance*

1. INTRODUCTION

Portable variable message sign (PVMS) is one of the useful tools for managing traffic in real time, which provides various traffic information including incidents, work zone, congestion, and weather etc. PVMS messages should not only be recognizable to drivers, but should also be coherent and legible from a distance. Therefore, installation and message operations considering drivers' legibility performance are very important. Drivers' legibility distances are dependent on various factors, such as geometric conditions, travel speed, and driver characteristics etc. However, there have not been many efforts to explore the relationship between the drivers' legibility distance and the above causal factors.

In this study, extensive field experiments were conducted using a specially manufactured PVMS to develop an estimation model for drivers' legibility distance. A 500-meter tangent segment having 4 lanes (2 lanes for each direction) was selected for field experiments at the Hanyang University at Ansan, Korea. An in-vehicle Differential global positioning system (DGPS) in a control vehicle was used to obtain drivers' legibility distances.

We conducted literature review in Chapter 2. Experimental conditions and method to obtain data are discussed in Chapter 3. Statistical data analysis and model development are presented in Chapter 4. Finally, findings are discussed along with future research.

2. LITERATURE REVIEW AND RESEARCH OPPORTUNITY

There have been a variety of relevant research studies and experiments on legibility performance for VMS. Armstrong et al (1994) first emphasized reflecting ergonomic factors into designing a VMS, and suggested legibility distance models through experiments that compare legibility of fiber-optic and Light-Emitting Diode(LED) characters. Upchurch et al (1992) released results from a research on legibility distance, which used the Distance Measurement Instrument (DMI) under a target to use three types of VMS, the fip disk, the LED and fiber optics for information expression technology. Carsong and Hawkins (2003) researched and analyzed legibility of general road signs using sheeting technology under actual driving environs instead of applying the VMS under experimental environs. Ullman et al (2005) researched and analyzed legibility distance for the VMS with letters in sizes of 18" or smaller. As for PVMS related research, Ullman et al (2005) analyzed information interpreting ability for various virtual scenarios of the PVMS and VMS, using driving simulators according to each different number, display and form of words in a message. Wang, J. H. and Yon, C. (2005) developed a PVMS information legibility model with number of lanes and number of lines of messages as the main variables, and age and gender as other variables, using driving simulators. Recently, in Korea Oh et al. (2007) performed an on-site investigation on the VMS, and suggested a legibility distance model with the number of lanes, travel speed and heights of letters as independent variables. Also, several studies were conducted for better operation of PVMS to manage traffic flow in the work zone (Finger et al., 2009; Ulman et al., 2007; Anon, 1988)."

As reviewed above, there have been many studies dealing with legibility for VMS. There have not been many attempts to study legibility performance for PVMS, which is essential for traffic event management. Therefore, the purpose of this study was to develop an estimation model for PVMS legibility distance that would be dependent on various causal factors.

3. EXPERIMENT DESIGN AND DATA ANALYSIS

3.1. Experiment Design and Data Collection

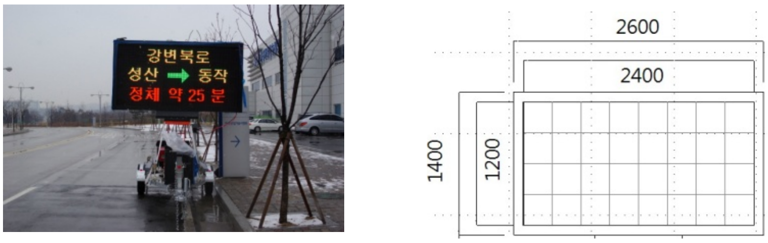
A specially manufactured PVMS was used in this study. A 500-meter tangent segment having 4 lanes (2 lanes for each direction) was selected for field experiments at the Hanyang University at Ansan, Korea as shown in <Figure 1>. In this study, 22 message display scenarios (10 sets of letters at a height of 20cm, 4 sets of letters at a height of 30cm, 4 sets of letters at a height of 40cm, and 4 sets of letters at a height of 50cm) were prepared by considering the heights of letters and number of words in messages on the PVMS. An operator and participant drove on the experiment site in an equipped vehicle as shown in

<Figure 2>. The operator collected data on the legibility distance and driving patterns can be represented by the change in speed and acceleration.

<Figure 1> Experiment Site

(a) Equipment

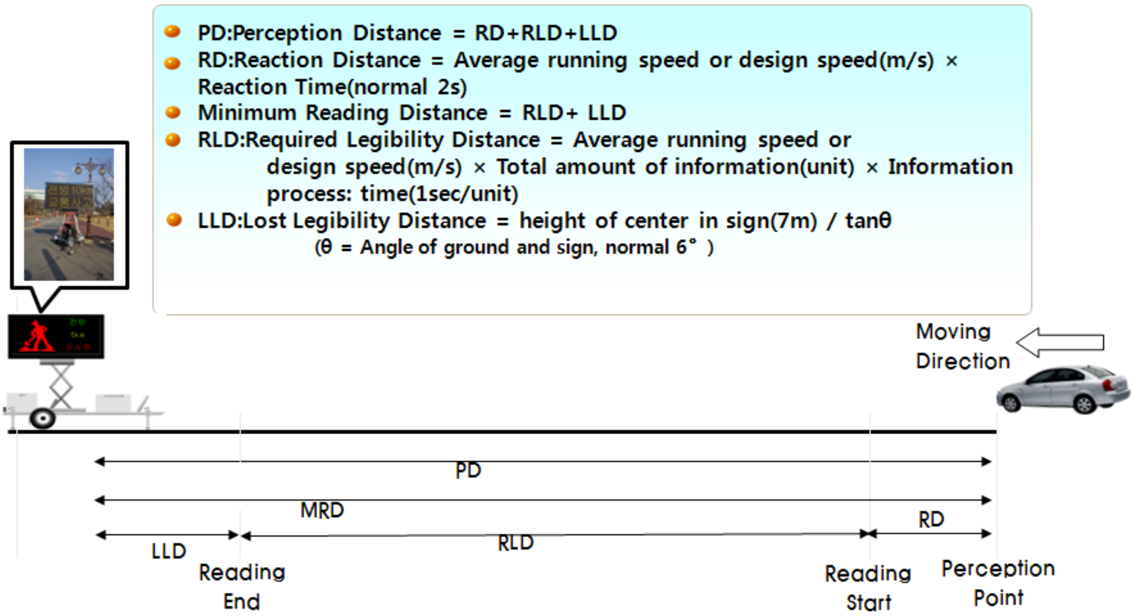
(b) Equipped vehicle



(c) PVMS(mm) Specification

<Figure 2> Experiment Equipment

Another operator controlled PVMS messages using a software (PVMS Server: a program which enables to generate and express messages with adjustable variables related to operating a PVMS, such as heights of letters, fonts, colors, messaging frequency etc.). As shown in <Table 1>, scenarios used in the experiments were built such that the number of lines and words in messages differed as heights of letters increased. To measure legibility distance, the investigator recorded the positions using a DGPS device once as the driver passed the reading location, using a DGPS device (at that moment, the driver signaled to the investigator that he would begin reading), and again when the driver passed the PVMS installation, the records of which were used for computation. Travel speed and spot speed of the vehicle, collected every 1 second by the DGPS, were used as traffic parameters. Experiments were conducted from the 23^{rd} of January to the 1st of February 2008. <Figure 3> illustrates the drivers' legibility process.

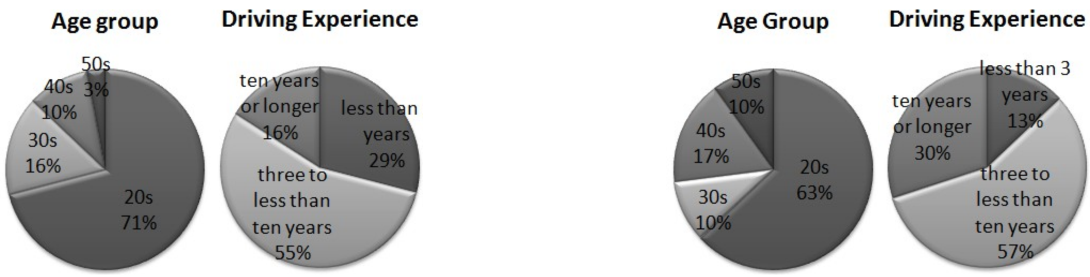


<Figure 3> Legibility Process

<Table 1> Message Examples for Field Experiment

Scenario ID	Character height(cm)	Information unit	Scenario
2	20	6	올림픽대로 마포 ➔ 동작 정체 약 20 분 소요
3		3	여의상류 진출 어려움
13	30	4	63빌딩 부근 4중 추돌사고
14		5	올림픽대로 동작 ➔ 영동 정체 약 24분
17	40	3	교통사고 1차로 차단
18		4	마포➔한남 정체약20분
20	50	3	전방10km 교통사고
21		2	결빙구간 감속운행

A total of 61 subjects participated in the legibility distance experiment, such as 31 participants for daytime and 30 participants for nighttime experiments. Each participant has a valid Korea driver's license and actual driving experience greater than one year. There were 48 males participants and 13 female participants. More detailed characteristics of the participants are shown in <Figure 4>.



(a) Daytime experiment (b) Nighttime experiment

<Figure 4> Characteristics of participants

<Table 2> Legibility Distances

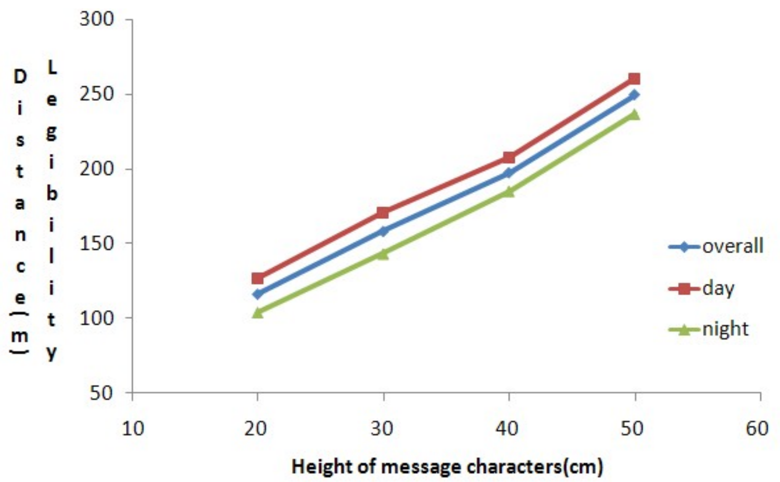
Legibility Distance(m)			Height of Letters(# of participants)							
			20cm(40)		30cm(40)		40cm(40)		50cm(40)	
			Avg.	Standard Deviation	Avg.	Standard Deviation	Avg.	Standard Deviation	Avg.	Standard Deviation
Overall	20	M(18)	120.771	29.630	169.928	41.188	210.033	52.128	259.854	57.594
		F(5)	100.376	23.424	126.253	30.800	159.740	34.049	212.871	34.381
	30	M(4)	120.787	35.727	152.969	44.369	192.895	54.246	257.494	63.282
		F(1)	111.448	24.829	155.401	14.237	178.853	17.298	266.963	41.964
	40	M(4)	110.032	40.004	148.107	48.179	199.198	53.480	265.278	62.766
		F(4)	120.699	20.090	184.702	21.560	220.258	18.248	267.611	19.687
	50	M(2)	65.915	19.272	66.313	26.753	107.049	15.377	156.884	46.331
		F(2)	141.664	18.155	170.013	5.977	185.053	15.918	304.284	93.102
	Avg.		116.534	34.077	158.363	46.295	197.455	52.418	249.505	61.181
Day	20	M(18)	127.983	26.232	177.593	33.298	216.973	51.433	263.397	51.690
		F(5)	106.544	23.963	137.978	23.640	168.833	32.459	219.827	37.982
	30	M(3)	130.891	41.688	161.295	55.117	202.556	69.225	270.119	72.566
		F(1)	111.448	24.829	155.401	14.237	178.853	17.298	266.963	41.964
	40	M(2)	146.392	16.883	192.677	7.381	247.423	14.340	318.960	38.217
		F(2)	120.699	20.090	184.702	21.560	220.258	18.248	267.611	19.687
	50	M(0)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
		F(1)	141.664	18.155	170.013	5.977	185.053	15.918	304.284	93.102
	Avg.		127.058	29.584	171.114	35.321	207.798	49.946	260.359	53.932
Night	20	M(17)	112.596	31.185	161.241	47.415	202.169	52.218	255.840	63.837
		F(1)	84.144	11.216	96.943	27.705	137.009	28.022	195.481	12.645
	30	M(3)	110.684	25.451	144.643	30.447	183.235	34.017	244.868	52.532
		F(0)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	40	M(2)	136.455	42.684	184.569	51.346	229.150	54.127	288.132	60.500
		F(2)	93.279	39.658	130.141	58.487	177.993	53.355	214.143	60.915
	50	M(2)	65.915	19.272	66.313	26.753	107.049	15.377	156.884	46.331
		F(1)	82.010	33.588	102.781	17.714	155.420	23.415	176.607	25.813
	Avg.		104.131	34.890	143.336	52.900	185.265	52.858	236.713	66.756

Collected PVMS legibility distances were sorted by character heights, and the data from the experiment were separated into day and night sections considering environmental conditions. Legibility distance data are summarized in <Table 2>. The travel speed at the reading location was 25-75 kph, and the legibility distance ranged from a minimum of 16.56m and a maximum of 432.66m with an average of 163.03m. PVMS legibility distances were found to range between 100m and 250m.

3.2. Data Analysis

3.2.1. Legibility Distance Analysis by Day Daylight Conditions

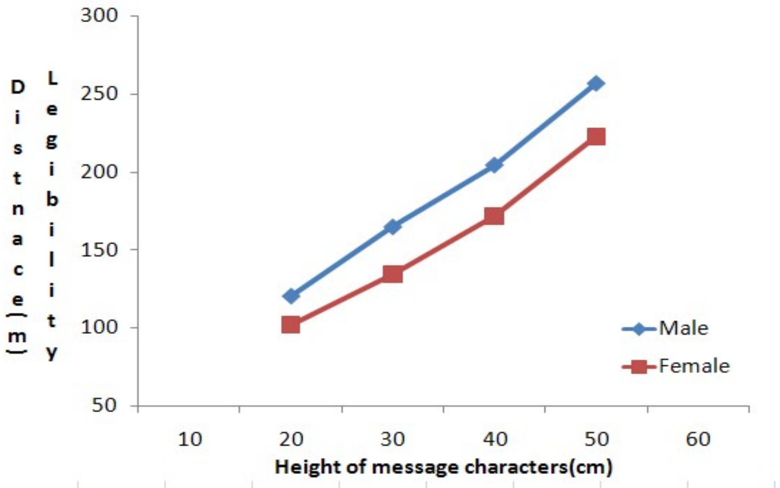
Drivers will have different legibility depending on time of day, thus legibility distance data are divided into overall, day and night categories, and are presented in <Figure 5> by height of message characters. When classifying by day or night, legibility distance tended to be relatively higher during the day. To verify this, we conducted a hypothesis test comparing averages of the population using the t-test. The analyzed results are presented in <Table 3>. The difference of legibility distance between day and night was 23.21 m and the t-value was 9.44, which indicates statistical significance. Therefore, it is evident that legibility distance during the day is greater than that at night.



<Figure 5> Comparison of Legibility Distances for Daylight Conditions

<Table 3> t-test Result (Daytime vs. Nighttime)

	Avg.	N	Standard Deviation	Paired-sample statistics
Legibility Distance During the Day(m)	172.32	616	62.95	Avg. : 23.21m Standard Deviation : 60.99m Standard Error of Avg. : 2.46m 95% Confidence Interval : 18.38~28.03 t-value : 9.44 Degree of Freedom : 615 Significance Level : 0.00
Legibility Distance During the Night(m)	150.11	616	70.20	



<Figure 6> Comparison of Legibility Distances for Gender

<Table 4> t-test Result (Gender)

	Avg.	N	Standard Deviation	Paired-sample statistics
Legibility Distance During the Day(m)	169.42	286	83.30	Avg. : 26.66m Standard Deviation : 76.25m Standard Error of Avg. : 4.51m 95% Confidence Interval : 17.78~35.53 t-value : 5.91 Degree of Freedom : 285 Significance Level : 0.00
Legibility Distance During the Night(m)	142.76	286	60.44	

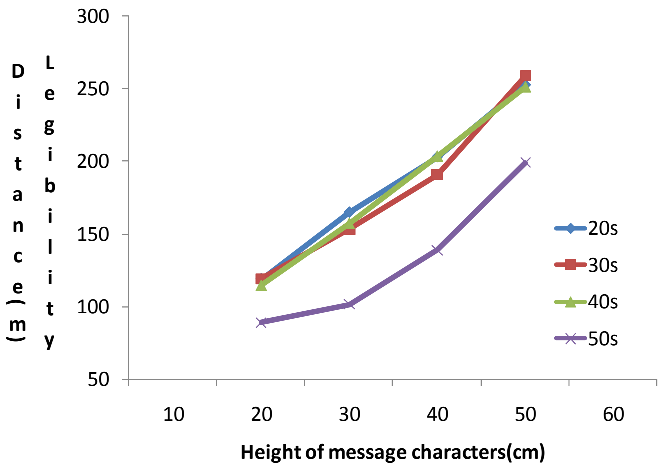
3.2.2. Legibility Distance Analysis by gender

In terms of legibility distance according to gender, as shown in <Figure 6>, male drivers had greater distances of legibility than female drivers. The t-test was conducted to statistically verify the difference according to the gender, results are presented in <Table 4>. The average difference between the two sexes appeared to be 26.66 m, where the standard deviation was 76.25 m and the standard error was 4.51m. The t-value was 5.91, which is statistically significant. Hence, male drivers have greater legibility distances than female drivers.

3.2.3. Legibility Distance Analysis by Age Group

Legibility distance was analyzed by different age groups separated into categories ranging from their 20s to 50s. As shown in <Figure 7>, drivers in their 20s to 40s showed similarity in the behavioral aspects, but those in their 50s showed smaller legibility, compared with people in other age groups. To statistically verify legibility distance by age group, we performed an ANOVA (Analysis of variance) and the result is presented in <Table 5>. The ANOVA resulted in an F value of 12.90 and a p-value of 0.000. The hypothesis that the averages in different age groups would be the same is rejected. Therefore, legibility distance for different heights of letters may be different in different age groups.

As a further analysis, we conducted the Waller-Duncan method to investigate if there is a possibility to distinguish different groups from one another. It was identified that participants in their 50s formed a group and all the others formed another group. This implies that the participants in their 50s had a different average legibility distance from others in other age groups.



<Figure 7> Comparison of Legibility Distances for Age

<Table 5> ANOVA Results (Age)

	Sum of square	Degree of freedom	Mean square	F	Significance probability
Cross-groups	175562.85	3	58520.95	12.90	0.000
In groups	6067516.4	1338	4534.77		
Total	6243079.2	1341			

3.2.4 Legibility Distance Analysis by Driving Experience

The participants were divided into three groups such as driving experience of less than three years, from three to less than ten years, and ten years or longer. Drivers of experience of less than three years had the highest legibility distance, where all the others yielded approximately the same result. To statistically verify the difference in legibility distance by driving experience, we used the ANOVA, as shown in <Table 6>.

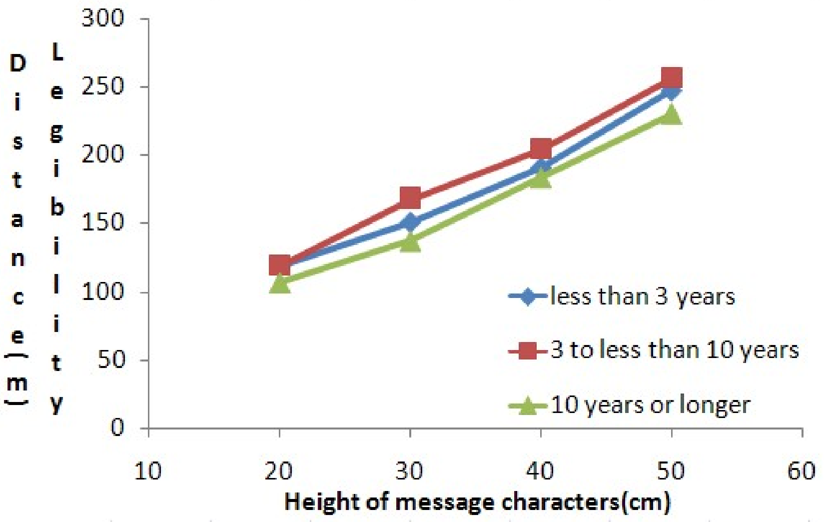
<Table 6> ANOVA Results (Driving Experience)

	Sum of square	Degree of freedom	Mean square	F	Significance probability
Cross- groups	65480.99	2	32740.49	7.097	0.001
In groups	6177598.3	1339	4613.591		
Total	6243079.2	1341			

Concerning legibility distance of each driving experience group, the average legibility distance of the group of less than three years was 176.96m, while that of three to less than ten years was 187.30 m, and ten years or longer indicated a value of 164.78m. As a result of the ANOVA, the F value was 7.097 and the p value was 001, thus the hypothesis that the average of drivers with different experience would be approximately the same may be rejected by the indicated p-value. Therefore, legibility distance for different heights of letters may be different in groups with varying experience. It was also identified by the Waller-Duncan method that the participants with experience from three to less than ten years had greater legibility distances compared to others as shown in <Table 7>. Waller-Duncan method is one of the statistical tests to identify the similarity of means based on the statistical significance

<Table 7> Result of Waller-Duncan test

driving experience	N	Subset for alpha=.05	
		1	2
Greater than 10 years	133	164.78	
Less than 3 years	264	176.96	
3 – 10 years	945		187.30



<Figure 8> Comparison of Legibility Distance for Driving Experience

4. MODEL DEVELOPMENT

A multiple linear regression modeling approach using a stepwise method was used to establish a functional relationship between legibility distance for PVMS and several key independent variables as shown in <Table 8>. Several categorical variables, such as gender (e.g. female = 0, male = 1) and daylight conditions (nighttime = 0, daytime = 1) were represented as dummy variables.

<Table 8> Candidates for independent variables

Traffic Conditions	PVMS message display conditions	Driver's characteristics	Daylight conditions
• Spot speed when message is legible • Average travel speed on the test site	• The number of words • Height of message characters	• Age • Gender • Driving Experience	• Daytime • Nighttime

As a result of multiple regression analysis, heights of message characters, time of day, gender, and age were selected for independent variables having statistically significant influence on legibility distance. The results from the multiple regression analysis are summarized in <Table 9>. The height of message character represented highest standardized coefficient, 0.815, which is the influential variable on the legibility distance.

<Table 9> Regression Modeling Results

Model		Legibility distance $=4.359x_1+26.776x_2+28.201x_3 -0.272x_4$ [Adj.R2=0.942F-Value:5449.283Sig.Prob:0.000]			
Variables		x_1 (Character height)	x_2 (Day·Night)	x_3 (Gender)	x_4 (Age)
Unstandardized coefficients	B	4.359	26.776	28.201	-0.272
	Standard error	0.089	2.207	2.459	0.087
Standardized coefficients		0.815	0.111	0.141	-0.050
t-value		48.720	12.135	11.470	-3.124
Significance probability		0.000	0.000	0.000	0.02

Statistics concerning the model built, such as ANOVA and regression coefficients, are presented in <Table 9>. Among standard coefficients in <Table 9>, the height of letters was 0.815, which is relatively high compared with other independent variables, thus it was found to be the most influential variable on legibility distance. The model built in this research, as well as the VMS legibility distance model of PVMS information property variables, indicates longer legibility distance as height of letters increases.

Concerning driver aspects, the younger age group appears to have greater legibility distance. This seemed to be affected by the low value of the 50s group presented in <Figure 7>. The differences between day and night, and male and female, which are independent variables inputted as dummy variables, yielded high coefficients. It was also identified that male drivers have greater legibility distance than females, as presented in <Figure 6>. Regarding the daylight conditions, the distance becomes greater during the day than at night. This result complied with a study by Upchurch (1994) reporting that legibility becomes lower at night than during the day. It would be because cone cells in optic nerves, which detect color, are inactive, where only rod-shape cells are active at night, and location of rod-shaped cells is not restricted to retina but is distributed around the yellow spot, requiring more time to accurately recognize images at night than during the day.

5. CONCLUSION

A variety of ITS projects have been implemented to alleviate traffic congestion and enhance driving conditions. Advanced traffic information systems (ATIS), which is a product of such ITS projects, provide useful information to users to support their decision for selecting route, speed, and lane. In particular, PVMS is an important and useful tool for guiding drivers when traffic events including work zone and incident etc. The purpose of this study was to establish a model to estimate legibility distance for PVMS, which is essential for locating PVMS and operating message displays.

This study conducted extensive field experiments using specially manufactured portable VMS to obtain data to be analyzed for the model development. A 500-meter road tangent segment having 4 lanes (2 lanes for each direction) was selected to conduct field experiments at the Hanyang University at Ansan in Korea. Data collection and analysis were undertaken to explore the legibility distance and various influential factors. The results of data analysis indicated that the average legibility distance of male drivers was 169.42m and that of females was 142.76m, clearly indicating a difference. With regard to age group, drivers in their 20s to 40s had an average legibility distance of 160m to 170m, while those in their 50s had a remarkably lower legibility distance of 120.15m. Concerning driving experience, drivers of experience of less than three years had 176.96m of legibility distance, while from three years less than ten years had 187.3m, while ten years or longer had 164.78m.

A multiple regression modeling technique using a stepwise independent variable selection method was applied to develop a legibility distance estimation model in this study. It was identified that height of message characters, gender, age, and daylight were significant variables affecting the legibility distance.

The PVMS legibility distance model proposed in this research is expected to be utilized as useful material for better installation and management guides of PVMS. However, it should be noted that the limited number of participants could not cover the wide potential range of age groups represented in the driving population. Therefore, more field experiments with larger groups of participants should be conducted to derive more realistic and reliable models. Additionally, there need to be experiments on real roadway conditions to validate the proposed model.

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