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Effects of variable message sign on driver detours and identification of influencing factors

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Abstract: This study presents the results of an investigation made to determine the dominant influencing factors and their specific impacts on motorist detour making for variable message sign (VMS) placements on a freeway. This was necessary to provide engineers with a tool for evaluating VMS cost-effectiveness and feasibility. The research found that additional travel time delay is the most influential variable in determining motorist detour making. In addition, more than 70% of freeway motorists recognise adjacent national roads as detour routes and both average annual daily traffic and the distance to the entering point of the detour path are found to be dominating factors. A motorist detour ratio model as a function of VMS placement on a freeway was developed based on these observations. In the model validation, actual detour making behaviours observed by revealed preference values showed some discrepancies, but these were minimal. These research findings should be useful for cost-effective placement of VMS on freeways and it is recommended that the results be tested by practicing engineers in the intelligent transportation system sector.

1 Introduction

1.1 Research background and objective

Recently, the South Korean government has driven a nationwide effort to apply intelligent transportation system (ITS). As the most important road type in forming the national arterial road system, the successful use of ITS on freeways is of prime concern. Of various ITS devices, freeway traffic management system (FTMS) is one of the dominant ITS strategies applied on freeways. The main concept of FTMS is to encourage motorists on congested freeways to make detours to adjacent arterials, so that freeway motorists can be relieved from congestion and at the same time the reserved capacity of adjacent arterials can be utilised. To help FTMS function properly, several auxiliary electronic devices should be used together, and variable message sign (VMS) is one of them. In fact, VMS is pivotal to the success of FTMS because this device provides freeway motorists with real-time traffic information and directly influences motorist decision-making behaviour in detours [1–4]. However, there is a problem in VMS installation. That is because of its heavy cost, the cost-effectiveness of each VMS is being carefully examined prior to actual installation, but very few studies have examined cost-effectiveness of VMS in South Korea, leaving the South Korean manual for analysing the cost-effectiveness of VMS producing unreliable and inconsistent analysis results [5]. As a result, the public seems to doubt the feasibility of VMS, and this condition is actually blocking further VMS installations and may eventually discourage applications of FTMS in South Korea. There must be some action to deal with this problem such as developing a reliable method of examining the cost-effectiveness of VMS. In examining the cost-effectiveness of VMS, the determination of detour ratios for VMS is a very important task because engineers can determine how many motorists would make travel path changes only when detour ratios are available. As a follow-up process, with the number of these path changing motorists, travel time reductions associated with VMS installation can be determined and eventually linked to road user benefits.

The main objective of the research is to determine the detour ratios for VMS placement on freeways. Several motorist route changing behaviours and dominant influencing factors associated with VMS placements are also investigated.

1.2 Contribution of research

Although there are several studies on capturing some effects of VMS information on freeway motorists [3, 4, 6–19], few have provided any behavioural characteristics to support their analyses and recommendations. In addition, many of the studies have focused on estimating only grand effects of providing traffic information to motorists, ignoring detailed effects from highway types, motorist demographical characteristics, and traffic patterns [1, 2, 8, 11–13, 16, 20, 21]. Although several studies have been carried out to determine the effect of the distance to the entering point of

the detour path [12, 16, 20], very few studies have been successful. Finally, despite that detour ratios in the context of feasibility analysis of VMS have been assessed successfully in many countries, no such information is available in South Korea thus far. This paper demonstrates how the research examined these issues and tried to increase our understanding because the motorist behaviours in South Korea are quite different from other developed countries.

1.3 Research approach

The main objective of the research is reached by identifying dominant influencing factors concerning the detour ratio of freeway motorists who are given VMS information while driving and by performing a statistical analysis with a binary logit model based on field survey data [22, 23].

The research has the following tasks: First, based on the literature study, existing research results over the world on freeway detour behaviour induced by VMS are reviewed. Second, the behavioural analysis of South Korean freeway motorists is carried out using two types of analysis including an inquiry into the most important factors that influence detour ratios and a stated preference survey on nine freeway rest areas. Third, a revealed preference test is made to validate the stated preference results. A subsequent comparison was made between these two different survey results.

2 Review of existing studies

Emmerink *et al.* and Lee and Kim state that motorists who are travelling on freeways consider VMS information to be the same as radio information and the dominant factor deciding changes in their travel path is the distance to the entering point of the detour road [9, 14]. It was also found in this review that VMS information was not valued greatly. This finding is interesting because the research attempts to determine how much value South Korean freeway motorists will put on VMS placements. Besides, the research is eager to find the dominant factors. Acquiring the information, the research becomes more able to develop a realistic method of examining the cost-effectiveness of VMS.

In addition to the issues of the value of VMS, this paper also reviewed findings made by Wardman *et al*. [19] that the length of delay has a large effect on motorist behaviour in changing travel path [19]. The result was obtained by performing an SP analysis and a subsequent investigation of the detour ratio using the logit model. The result also showed that a longer delay usually involved higher detour ratios. Similarly, Erke *et al.* and Gan *et al.* state that if one freeway section is closed and the relevant traffic information including detour roads is provided by VMS, few drivers continue using the controlled freeway section and drive close to the closed road section [10, 11]. Meanwhile, Messmer *et al*. presents the design, implementation, and evaluation work performed by a European consortium for the development of VMS information and guidance system in the interurban Scottish highways [24]. Evaluation results, including monetary benefits, various technical indicators, safety and institutional aspects are reported in European DRIVE II project QUO VADIS (V2042). These international and domestic research results are useful, because this paper deals with motorist behaviours responding to VMS placements.

Last, regarding motorist behaviours with VMS messages and their probability of route diversion, Chatterjee *et al*. in the UK provides the results of a study on driver response to VMS information [6]. This study carried out questionnaire surveys to investigate the effect of different messages on route choice. A statistical analysis of the stated results enabled logistic regression models to be developed relating the probability of route diversion to driver, journey and message characteristics [6]. The models indicate that the location of the incident and the message content are important factors influencing the probability of diversion [6]. A survey of drivers' actual responses to a message activation showed that only one-third of drivers recognised the information presented to them and few of these drivers diverted, although many found the information useful [6]. Only one-fifth of the number of drivers actually diverted compared to that expected from the model [6]. In addition, 18% of the drivers stated they would divert immediately in response to unexpected congestion.

In summary, motorist behaviours as to VMS messages, travel path changes, as well as detour ratios are quite different for each country. This paper tries to capture South Korean characteristics and demonstrate how each country can apply them to examine the cost-effectiveness of VMS placements.

3 Factors influencing the detour ratio

When travelling on freeways and suddenly observing on a VMS incident-related traffic information and requests for detours, motorists may be uncertain about the travel path to take. There could be many factors affecting their decisions and the research attempts to identify the most prominent factors by analysing questionnaire surveys [25, 26]. For this purpose, motorist interviews were carried out at freeway rest areas after they were given VMS information while travelling on freeways. It was found that 70% of freeway motorists recognise the adjacent national roads as their detour routes and both the average annual daily traffic (AADT) and the distance to the entering point of the detour path are dominating factors in their detour decision-making. Table 1 summarises the field survey.

As a result of the field study, it was found that more than 50% consider the distance from VMS to the entering point of the detour road as the most important factor. At a level of 20%, other influencing factors include whether drivers are aware of the location of detour roads and also the amount of expected travel time reduction by making the detour. In fact, when first doing the research, travel time

Table 1 Summary of field study

	Contents
site	• Gyeongbu Freeway 1 site, West Seaside Freeway 1 site
date	• from December 1(Tuesday) to December 7(Monday)
method	• interview survey
number of samples	• 100 sheets per site, approximately • fnalysis of prominent factors for detour ratio
survey item	– distance of detour road, recognition of detour road, reduction of travel speed, type of detour road • analysis of type of detour road – expressway, national road, local road

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reduction was expected to have a higher percentage but, because motorists usually do not make very accurate travel time predictions, the actual percentage turns out to be low. It is to be noted that a similar statement was addressed by Emmerink Richard *et al.* [9].

Another task is to define both the distance of detour roads and the specific road type to be used for detours. This information must be provided by the VMS and then motorists will use this distance in their decision-making behaviour. Therefore to start, respondents were asked to state their usual detour roads. More than 70% of them stated the national road as their choice with freeways being the second choice. Second, respondents were asked to state their own detour distance definitions. In sorting these, the research decides to apply the distance from the next available exit ramp to the entering point of the detour road as the detour distance. In addition to these actual survey results, the research has adopted AADT as one of the important influencing factors for the detour ratio. This was necessary because detour making decisions tend to be influenced by not only the road type to receive the detouring vehicles but also the freeway types to send the detouring vehicles. In other words, AADT is a good source of information expressing the physical and traffic characteristics of a freeway section, and in the research it is considered realistic to select AADT as one of the important factors that influence detours on freeway.

4 Determination of detour ratio

4.1 Data collection and analysis method

Based on the general characteristics of some influencing factors for making detours on a freeway, the research made a set of field surveys to determine detour ratios for use in VMS cost-effectiveness analysis. Table 2 shows the characteristics of field survey sites. A preliminary review of detour roads and their distances from the freeway exit ramp indicates that the detour distance normally ranges from 1 to 2 km, so it was decided in the research that a distance categorisation of less than 1, 1–2 , and more than 2 km would be made. In terms of AADT, the sites had fairly large volumes and a volume categorisation of less than 60 000; 60 000–120 000; and more than 120 000 vehicles/day was made in this study. Also, each cell value in Table 2 represents the detour ratios to be used in practice, so at least one field survey site should be available, giving a total of nine sites in South Korea.

At the nine sites, the field survey was made during week days at freeway rest areas. People in the rest areas are actually vehicle drivers a little time ago, and they are easy to talk to and more relaxed and prepared to answer a lengthy questionnaire. Approximately 100 survey results per site make a total of 859 survey results in this study, and the results are refined and put into a table format that represents detour ratios under various conditions. To better understand the background of the respondents participating in the survey, Table 3 was prepared.

It is noted in Table 3 that the participating drivers demonstrate quite usual driver characteristics and, in terms of VMS information, they stated that they recognised its presence during their travel on the freeway. Broadly speaking, freeway drivers felt dissatisfied with VMS accuracy and its overall performance level was found to be rather poor.

Recognising Wardman *et al.* [19] research finding that travel time delay would have a strong impact on driver's detour making behaviours, the research examines these effects by gradually changing delay values. Subjects were asked as to how much time additional delay they want to convince themselves that making detours are beneficial at each different travel time levels. The additional delay levels used in the research were 5, 10, 15, 20 min. An option of making no detour regardless of additional delay was also available.

The research then applies a statistical analysis to determine how much impact each independent variable would have on detour makings by VMS placements on freeway. Total

Table 2 Description of SP survey sites

		Distance to detour roads		
		<1 km	1–2 km	>2 km
AADT (vehicles/day)	<60 000	Jecheon IC – Nam-wonju IC	Jangpyung IC – Dunnae IC	Gochang IC – Buan IC
	60 000–120 000	Munmak IC –Icheon IC	Seopyeongtaek IC – Bibong IC	Gyeongsan IC –Bukdaegu IC
	>120 000	Yongin IC– Buksuwon IC	Cheonan IC – Osan IC	Seoicheon IC – Hanam IC

Table 3 Description of survey participants

Variable	Variable description	Summary (Sample size 859)			
		Minimum	Maximum	Average	Standard deviation
age of drivers	teenage = 0; twenties = 1; thirties = 2; forties = 3; over fifties = 4	0	4	2.6347	0.9640
gender of drivers	male = 0; female = 1	0	1	0.2485	0.4328
number of travel on freeways	everyday = 0; over three times a week = 1; over one time a week = 2; over one time a month = 3	0	3	1.7156	0.8733
purpose of travel	business = 0; non-business = 1	0	1	0.4192	0.4942
recognition of VMS	yes = 0; no = 1	0	1	0.1377	0.3451
accuracy of VMS	very accurate = 0; accurate = 1; average = 2; inaccurate = 3; very inaccurate = 4	0	4	2.5479	0.7568
satisfaction levels with VMS	very satisfied = 0; satisfied = 1; average = 2; unsatisfied = 3; very unsatisfied = 4	0	4	2.6257	0.8493

Table 4 Description of variables applied in the research

Variable		Description
dependent variable	detour? Or not detour?	no detour = 0; detour = 1
independent variable	additional travel time	5 min = 5; 10 min = 10; 15 min = 15; 20 min = 20
	AADT	below 60 000 = 1; 60 000–120 000 = 2; over 120 000 = 3
	distance to a detour road	below 1 km = 1; 1–2 km = 2; over 2 km = 3

Table 5 Summary of statistical analysis results

Variable	β (coefficient)	odds ratio	*P*-Value
constant	− 11.376	0.000	0.000
additional travel time (x_1)	0.425	1.716	0.000
AADT (x_2)	0.328	1.069	0.004
distance to a detour road (x_3)	− 0.245	0.693	0.012

Number of observations = 3436; log-likelihood = 97.730; $\rho^2 = 0.2317$

samples amount to 3436 (859 survey results multiplied by four additional delay cases). Dependent variable is simply whether detour would occur or not, and independent variables are additional delay, AADT, and distance of detour road. Table 4 explains the variables applied in the statistical analysis. Ordered variable forms are applied for AADT and the distance to a detour road.

A binary logit model is used for this analysis and the SPSS program is used in the research [27]. A confidence level of 95% is used. The possible use of a mixed logit model was also considered but a binary model is finally selected because the authors understand that the three limitations of standard logit model [22, 23], in particular involving the random taste variation among survey participants, are not crucial in determining detour ratios in VMS cost-effectiveness study. In addition, categorising travellers by their taste for making detours on freeway routes is considered such a very complex task that engineers will experience much difficulty to undertake the task. Thus, the research applies a binary logit model. Table 5 summarises the results of applying a binary logit model.

Table 5 shows that additional travel time delay has the highest odd's ratio, implying that this item should be the most influential in determining motorist detour-making for VMS on freeways. It was also shown that higher AADT and shorter distance of detour road would lead to more frequent detour-makings for freeway motorists. *P*-values were mostly less than 0.05, and the ρ^2 value was 0.23, both are statistically significant.

4.2 Developed model and estimation of detour ratios

Based on the results in the previous section, the research now obtains the motorist detour ratio model as a function of VMS placement on freeway as in the following equation

$$f(x) = -11.376 + 0.425x_1 + 0.328x_2 - 0.245x_3$$
$$Z = \frac{\exp(f(x))}{1 + \exp(f(x))} \quad (1)$$

Table 6 Detour ratios determined in the research (unit: %)

Additional travel time	AADT	Distance to detour roads		
		Below 1 km	1–2 km	Over 2 km
5 min	below 60 000	0.0	0.0	0.0
	60 000–120 000	0.0	0.0	0.0
	over 120 000	0.0	0.0	0.0
10 min	below 60 000	0.1	0.1	0.1
	60 000–120 000	0.1	0.1	0.1
	over 120 000	0.2	0.1	0.1
15 min	below 60 000	0.7	0.6	0.4
	60 000–120 000	1.0	0.8	0.6
	over 120 000	1.4	1.1	0.9
20 min	below 60 000	5.8	4.8	3.6
	60 000–120 000	7.8	6.2	5.0
	over 120 000	10.6	8.5	6.7

where Z is the motorist detour ratio as a function of VMS placement on freeway

Equation (1) is used to estimate as many as 36 detour ratios for a whole set of available situations observable in South Korea. This set consists of average travel times, delay levels, AADT and detour distances. Table 6 shows the estimated detour ratios.

5 Model validation by revealed preference survey

To validate the model in the previous section, the research made a separate effort by including a revealed preference survey. Actually, this effort is required because the model in the previous section is based on a motorist preference survey, using 1:1 interviews with people in freeway rest areas. The problem with this approach is the argument that this survey only reflects the respondents' states of mind at that specific time and they may behave differently in a real-world travel situation. Therefore it is usual that the stated preference data are validated through a revealed preference survey.

In this validation effort, it was considered that sometimes engineers attempted to carry out a joint estimation by applying the stated preference and revealed preference data explicitly. However, this approach is only applicable when both the data show the same variable attributes. As demonstrated in Tables 4 and 6, data format for the two surveys show quite different types. Based on this consideration, the research decides to apply the present validation approach.

The revealed preference survey locations in the research were at toll-gates on a freeway. A total of three locations were selected. Field survey teams were dispatched to the survey locations when freeway traffic conditions were so bad that some motorists had to make detours to avoid congestion. Exiting motorists were queried by the survey crew about their detour-making behaviour.

Table 7 shows the observed number of vehicles at freeway exits. The research used this information to determine the actual detour ratios induced by VMS placements on freeway.

Having the actual and accurate number of detour vehicles shown in Table 7, the research now obtains revealed values for the motorist detour ratio. Table 8 shows the finalised revealed preference detour ratios.

Compared with the detour ratios in the stated preference survey, it can be seen that Table 8 values are slightly lower

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Table 7 Observed number of detours at the revealed preference survey

Time	West Seaside freeway Seopyeontaek tollgate				Jungbu freeway Seoicheon tollgate				Youngdong freeway Yongin tollgate			
	A	B	C	D	A	B	C	D	A	B	C	D
15:00	29	140	826	171	41	151	840	228	52	166	1242	389
16:00	33	146	703	159	39	148	884	233	53	159	1173	391
17:00	45	167	750	202	48	171	898	252	67	193	1218	423
18:00	43	170	759	192	45	189	1042	248	64	198	1411	456
sum	150	623	3007	724	173	659	3661	961	236	716	5033	1659

†A: be surveyed detour volume (veh/h); B: closed-circuit exit volume (veh/h); C: total exit volume (veh/h); D: detour volume (veh/h, A/B*C)

Table 8 Detour ratios obtained in the revealed preference analysis

Time	West Seaside freeway Seopyeontaek tollgate			Jungbu freeway Seoicheon tollgate			Youngdong freeway Yongin tollgate		
	Volume, veh/h	Detour volume, veh/h	Detour ratio, %	Volume, veh/h	Detour volume, veh/h	Detour ratio, %	Volume, veh/h	Detour volume, veh/h	Detour ratio, %
15:00	2911	171	5.9	3769	228	6.0	4012	389	9.7
16:00	2950	159	5.4	3462	233	6.7	4203	391	9.3
17:00	3187	202	6.3	3906	252	6.5	4515	423	9.4
18:00	3094	192	6.2	4118	248	6.0	4262	456	10.7
average	–	–	6.0	–	–	6.3	–	–	9.8

for all locations. To be specific, the SP values and RP values at Seopyongtaek Tollgate in West Seaside Freeway are 6.2 and 6.0%, respectively (6.7 and 6.3% at Seoicheon Tollgate, and 10.6% and 9.8% at Yongin Tollgate). This consistent pattern implies that respondents in both surveys are uncertain as to their detour-making behaviour and actually this pattern is not unexpected in applying the stated preference analysis. Nonetheless, the discrepancies are not too serious, and it is trusted that the research results can be applied.

6 Findings and conclusion

Proper VMS placements on freeways are pivotal to the success of FTMS because this device provides freeway motorists with real-time traffic information and directly influences motorists' decision-making behaviour in detours. The research attempts to determine major influential variables for making detours by investigating motorist preferences. The following findings are reported:

- Additional travel time delay is the most influential variable in determining motorist detour-making.
- More than 70% of freeway motorists recognise adjacent national roads as their detour routes and both AADT and the distance to the entering point of the detour path are dominating factors for their detour decision-making. With AADT increase, freeways are easy to experience traffic congestions, and this condition may explain why AADT significantly influences motorists' detours.
- Compared with the detour ratios provided by the stated preference survey, the revealed preference values are slightly lower for all locations.

These research findings should be useful for cost-effective placement of VMS on freeways and it is recommended that the results be tested by practicing engineers in the ITS sector.

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