EFFECTS OF WEATHER CONDITIONS ON FREE-FLOW SPEEDS

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Abstract: This study aims to identify problems in the current speed limitations applied to the national highway in Korea, in order to provide proper driving speed information to the introduction of the Road Weather Information System (RWIS). It is also designed to analyze basic data in order to provide proper speed information by national highway sections with consideration for environmental factors, such as weather conditions and slope degree, so that driver's safety can be secured to the maximum level. We compared traffic volume and driving speed of fine days and rainy days for 5km-long Daejeon-Gongju national highway section in order to figure out the impact of weather conditions on driving speeds. The analysis of variance (ANOVA) and the multiple comparison analysis based on the Tukey's HSD test will be utilized. We found that the driving speed distribution is not only influenced by weather conditions but also by inclination degree of roads.

Key Words: RWIS, weather conditions, ANOVA, multiple comparisons

1. INTRODUCTION

The traffic flow of multilane highway shows features of continuous traffic flow, on the condition that the section is long enough. Nevertheless, it is not as smooth as freeway due to a median barrier and roadsides frictions. The causes of roadsides frictions include 1) parking space, lane, intersections without traffic signal and left/right turns for driving into other regions, 2) cars on the opposite side on the multilane roads (excluding the case when there is a median), 3) visual distraction of drivers due to road landscape. Such the impact of friction factors on speed varies depending on land usage density and land usage types. If sidewalks and borders located close to roads, drivers tend to drive at the center of a lane, creating the effect of narrowing the lane width. (MOCT, 2000)

In general, passenger cars show diverse behavioral patterns on slopes. If it is 4～5%

inclination, most of drivers drive in the same manner as they do on flat roads. The 3% slope does not affect drivers at all when it comes to driving speed. It was known that the steeper the slop becomes, the lower the driving speed is. It was also pointed out by previous studies that on the descending inclination drivers tend to speed up (MOCT, 2000). However, these findings are based on analyzing data collected on fair days and only few researchers have addressed the volume-speed relationship in response to weather condition factors.

Meanwhile, the coverage survey has been conducted nationwide at 1,200 stations in the national highway in order to find out basic traffic flow data necessary to calculate the Annual Average Daily Traffic (AADT) in Korea. In addition, there are 400 continuous survey stations across the nation, where fixed traffic survey devices are installed to count and record the number of passing vehicles. For the continuous survey stations, the counting devices are installed at representative sections of the region centered around the divergence between expressway where tolls imposed and national highway where no tolls are charged, and the nodes between national highways. Geometric shape of roads, pavement conditions, electricity·telephone facility and other environmental factors are also taken into account in selecting continuous survey stations. The requirements to become a continuous survey section include: 1) the road before and after the continuous survey station be straight by more than 100m; 2) the installation of power supply and communication lines should be easy; 3) gas stations, bus stations and entry to villages should not be located nearby; 4) crossroads and traffic signals should not be located nearby; and 5) road surfaces should not be damaged and curved (KICT, 2001). Judging from the above requirements, we regard the road sections, which are not affected by a median barrier and roadsides and also not disturbed by excessive in-and-out vehicles movements, as homogeneous with the continuous sections. In general, the sections with the same road conditions show same traffic flow characteristics.

The speed limitations currently applied in Korea were formulated based on the road traffic laws and the road·structure designing standards. However, the limitations have not considered slope degrees and weather conditions including frozen roads, heavy snow, monsoon season and fog. The real-time provision of road conditions information and situation forests for major road sections by the Korea Meteorological Administration (KMA) are still in its infancy. However, the real-time road information provision is instrumental to satisfying socio-economic demands. Demand for a system that can offer road conditions forecasts for major road sections is very high.

To satisfy the demands of the user, first of all, the road weather observation system should be developed, which observes and monitors road surfaces and atmospheric conditions in real time. The road conditions information collected by this system should be provided to drivers, which will lead to preventing traffic accidents. This system reduces social costs when viewed from the national economic perspective.

Under the current limitations that the speed limitations is solely determined by geometric road structures, this study is geared toward conducting basic analyses by road section to the introduction of RWIS and thereby presenting objective data on the impact of weather conditions on driving speeds. RWIS is one of ITS application systems designed for driver's safety, effective road facilities operation and maintenance. It is highly expected that if the results of this study is seriously referred to and the proper speed limit information is provided to drivers and road administrators in accordance with weather conditions, it would dramatically reduce traffic accidents. The presentation of effective speed limit measures is sure to enhance road safety and finally improve social benefits.

Also, this study analyzed the implication of environmental factors for driving speeds on the national highway sections, which show features of the no traffic congestion flow.

2. THE SCOPE OF THE STUDY

2.1. Speed Limitations Standards

Table 1 shows design speeds by road type, which is widely used in Korea. The reason of defining design speeds lies in maintaining constant road shape and thereby keeping the same driving conditions within the design speed sections. This is the basic concept of roads designing (MOCT, 2000). According to designs speed, road geometric factors are determined. However, the vertical sectional grade shows different features depending on which car is driven. It does not economically make sense if we try to enable all types of cars to show design speed. Therefore, the value of vertical sectional grade should be determined in the way that does not reduce traffic volume handling capability and negatively affect safety by minimizing speed reduction within the acceptable range with economic efficiency. In Korea, with roads types and topographical conditions reflected, the vertical sectional grade values are classified as Table 1 below.

Table 1 Vertical Grades Criteria

Design Speed (Km/h)	Maximum Vertical Grades (%)							
	Freeway		Arterials		Collectors		Locals	
	Level	Mountainous	Level	Mountainous	Level	Mountainous	Level	Mountainous
120	3	4						
110	3	5						
100	3	5	3	6				
90	4	6	4	6				
80	4	6	4	7	6	9		
70			5	7	7	10		
60			5	8	7	10	7	13
50			5	8	7	10	7	14
40			6	9	7	11	7	15
30					7	12	8	16
20							8	16

Source: MOCT (2000)

These data, however, will be only valid for dry and fine weather. For driver's safety and effective road operation, environment factors should be considered in depth from various environmental perspectives in compiling this vertical sectional grades. As such, first of all, the features of speed distribution by road class should be studied. Based on the study results, the optimal information provision method should be provided with consideration for safety and networkability.

2.2 RWIS (Road Weather Information System)

As a constant monitoring system, RWIS provides drivers with real-time road weather information centered around bad weather-prone areas with an aim to boost safety of and communications with drivers. The related technologies can be divided into the observation area and the forecasting area. The domestic technology level in the observation area is still not sophisticated enough, as the Korea's technology regarding road surface observation sensors and data collection systems lags behind. The road weather observatories are also in their initial stage. They have been established mainly for planning and conducting experiments for ITS-related business. However, since the 1990s, the rising interest in the atmospheric science contributed to fostering a number of meteorological experts via domestic universities. Element technologies for surveying energy and moisture on the earth surface have been already developed. Automatic Meteorological System (AMS) observes the atmospheric status. Presently, it can be manufactured domestically and has been distributed to 1,000 organizations including the Korean Meteorological Administration (KMA), the Rural Development Administration, the meteorological related organizations and private organizations. When it comes to observatory data, the volume is huge enough to make climatological analysis. Yet, the road weather observatory is in the stage of experiment, so that RWIS has not been established yet.

Turning to the forecasting area, forecasting should be based on the numerical model. Without observatory data, forecasting is impossible. Since Korea does not have database on road weather observation information, accurate predictions of road surface conditions are almost impossible. The KMA provides road weather forecasts. They are produced via statistical application of broad area weather forecasts. As such, only the forecast for atmospheric conditions over highway sections has been available to date. As region-based atmospheric data, it has limits to be used for road features-based forecast. Therefore, it is necessary to develop a forecasting model by utilizing the road observation results.

On the other hand, in the forecasting field, the road weather information forecasting models reached the final stage of development supported by observatory systems, which were installed in the early 1990s. In particular, the road weather information support system has already been adopted by the industry, and many countries are using the support system as an ITS sub-module. Advanced countries have their own road weather forecast models developed and in operation. It is commonplace that they are able to provide road surface conditions forecasts in advance of 48～72 hours. The utilization of these observation information and forecasts is beneficial from a socio-economic aspect.

2.3 Related Literature

There are not many studies produced at home and abroad as well regarding flexible speed restriction measures tied to weather conditions. With this in mind, this study will only focus on researches on the impact of various weather conditions on driving speed. Choi (1999) analyzed the speed-traffic flow rate, the traffic flow rate-occupancy rate, capacity, critical speed, and critical occupancy rate, based on field research data collected from speed violation monitoring cameras installed on the Olympics Bridge in Korea. The findings are that the relation between speed and traffic flow rate on rainy days shows a similar pattern to that of fine days except the most outer lane. The service traffic flow rate is reduced by 10～20% in wet days compared with dry days.

On the other hand, Lamm et. al. (1990) made experiments on speed variation on curved highway when it is dry and wet as well. Ibrahaim. et. al. (1994) studied the impact of bad weather conditions on driving on highway. The findings were that 1) the driving speed was reduced by 2km/h in time of little rainfall; 2) the driving speed was reduced by 3km/h in time of little snow; 3) the driving speed was reduced by 5km/h～10km/h in time of heavy rainfall; 4) the driving speed was reduced by 38km/h～50km/h in time of heavy snow. They also stressed that along with bad weather conditions, the driving experience of drivers was also influential to speed change. According to the study of Brilon. et. al. (1996), weather conditions and darkness are relevant to speed variation. They said that when it is dark, the driving speed goes down by 5km/h. They also concluded that the wet 2-lane roads and the wet 3-lane roads see driving speed reduction by 9.5km/h and 12km/h respectively. May(1998) studied on road capacity reduction on highway. Bad weather conditions including snow, rain, fog and other factors lead to road capacity reduction according to her study.

Kyte. et. al (2000) studied the impact of environmental factors on free-flow speed. They focused their experiments on how the average speed is changed according to visibility, road surface conditions, rainfall, and wind speed. With reference to the previous study results as mentioned above, this study took a look at the impact of the environmental factors including weather conditions, inclination degree, and monitoring camera on driving speed by using the methods of variance analysis and multiple comparison method based on Tukey’s HSD test.

3. FRAMEWORK OF ANALYSIS

Data were collected in a total of four road sections. Three of them are points used for continuous survey, which are managed by MOCT. They include BanpoOncheon (40006), YuseongGab (40439) and BanpoBonggok (40446). The remaining area is Bakjeongja in Gongju city where vehicles were video recorded and their driving speeds were calculated later. As all the continuous survey stations indicate, such survey should take place where a certain degree of visibility is guaranteed; the influence of cross sections and traffic signal is minimal; and traffic jam rarely occurs. In order words, this study analyzed environmental factors and speed distribution patterns under the circumstance of no traffic congestion.

The reasons behind selecting the four test sections are that they are influenced by roadsides frictions to the minimal level, and share identical traffic flow features (including driver’s characteristics). These conditions are essential to analyze the traffic flow features on national highway and the impact of environmental factors on driving speed. As such, in order to minimize the interference of roadsides friction and maximize the usage of continuous survey data, the 5km-long section of the national highway No. 32 from Daejeon to Gongju was selected. In particular, the BanpoOncheon section (Nonsan-Gongju) is equipped with speed violation monitors of the National Policy Agency, which enabled comparison and analysis of speed distribution and its features. The features of selected observation places and their locations are displayed in Table 2.

Table 2. Features of Observing Points and Sample Quantity

Section	Direction	Lane No	Sight Distance	Grades (%)	Observation period	
					Clear	Rainy
BanpoOncheo (40006)	Nonsan-Gongj	2	Good	0	04.22-11.26	04.22-11.26
	Gongju-Nonsa			0	04.22-11.26	04.22-11.26
YuseongGab (40439)	Gongju-Daejeo	2	Good	-3.83	07.24-11.26	07.24-11.26
	Daejeon-Gongj			+3.83	07.24-11.26	07.24-11.26
BanpoBonggok (40446)	Gongju-Daejeo	2	Good	-2.76	05.08-11.26	05.08-11.26
	Daejeon-Gongj			+2.76	05.08-11.26	05.08-11.26
Bakjeongja	Gongju-Daejeo	2	Good	+5.64	09.30-01.12	10.18
	Daejeon-Gongj			-5.64	09.30-01.09	10.06-10.20

Note 1) Numbers in parentheses ( ) indicate the unique number given to each continuous survey station.
Note 2) the rainfall data unit: 1～10(mm/h)

As indicated in the Table 2, the BanpoOncheon section and the BanpoBonggok section are two lane road each direction. The median and the guardrail on the sidewalk are installed. That is why, drivers are not influenced by roadsides frictions. On the other hand, YuseongGab section and the Bakjeongja section are mountainous areas.

As for data selection for analysis, as the table above indicates, real-time data collected from continuous survey points on day time and night time were taken. Data for both directions were collected in time of clear days and rainy days. In order to collect rainfall data, the rainfall volume released by the Flood Control Centers at nearby Yuseong, Banpo and Hwedeok, were added and averaged. As a result, the data collected when rainfall volume is less than 10 mm per hour, were taken as valid. Theodolite was utilized to measure inclination degree of each section.

4. DATA ANALYSIS AND RESULTS

4.1. Analysis Methods

Based on the traffic volume and speed data for 5 minutes taken in time of clear day time, clear night time, fine day and rainy day at continuous survey points, this study classified traffic flow rate data and speed data. First of all, the speed distribution patterns at day time and night time were compared, we have no significant difference in speed unlike what were mentioned by other papers. What is to be noted here was that in the Bakjeongja section, which has steep descending inclination, the average night-time driving speed in a fine day is higher than the average day time driving speed. This finding is contrast to previous studies, but consistent with the speed results of the study of Oh et. al. (2002) regarding the high-speed expressway. It can be interpreted that on the highway scarcely influenced by outer lane frictions, drivers do not reduce speed on the descending inclination if there is no traffic congestion.

Furthermore, in almost all sections, the regression coefficient of the traffic volume-speed relations was close to zero (0). As mentioned before, it is because continuous survey points are installed at the best places for obtaining interregional traffic flow data. As such, they do not show the general features of the volume (Q)-speed (V) relationships. They rather show features of the no-traffic congestion flow. In this context, speed distribution pattern is formulated under no influence of traffic volume (traffic flow rate).

In order to find out traffic volume and speed distribution features on clean day and rainy day, this study adopted the SAS-based variance analysis method which displays whether there are any differences among average speeds of each observation point. Simply put, it is a very beneficial method to identify changes demonstrated by populations according to treatments and to figure out weather the changes, if any, have statistical significance.

There are three basic assumptions essential to conducting variance analysis. First, dependent variables should be quantity variables. Second, population is subject to a Normal distribution. Lastly, the variance of population among each group should be same. The 5km-long Daejeon-Gongju highway section, one of the selected study sections, is located on national highway No. 32, which is the shortest route between Daejeon and Gongju. Excluding the traffic volume getting into and out of the Donhak temple of Mt. Gyeryong, the characteristics of drivers are same. As pointed out in the previous paragraph, they have almost same environmental factors including the number of lanes, easy visibility, weather conditions and the level of roadsides frictions, thereby satisfying all conditions for variance analysis application.

4.2. Significance Test of Speed Difference based on ANOVA

The graphs below show frequency distribution and cumulative distribution of driving speed according to weather factors in time of clear days and rainy days. In almost all sections, the speed distribution in time of rainy days is more leaned toward left than in time of fine days. In other words, when it rains, driving speed is reduced. In particular, as indicated in Figure 4, the Bakjeongja section, which has a steep descending inclination, displays high-degree of difference in speed distribution.

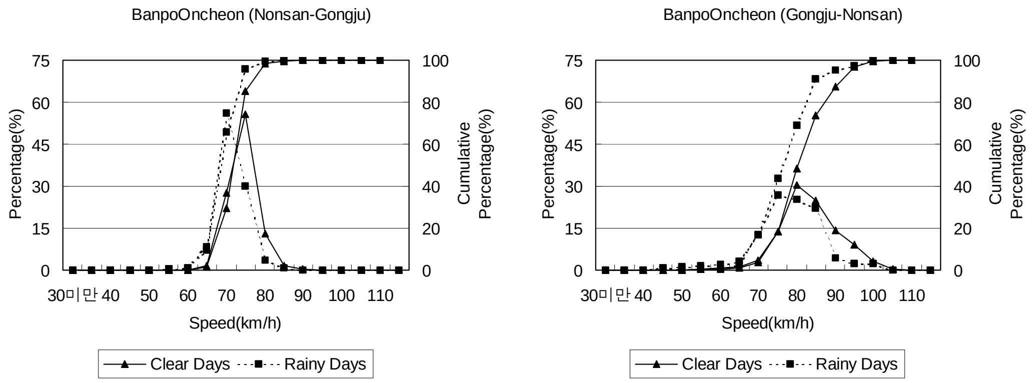

Figure 1 Speed distribution and Cumulative Percentage in 40006 (Clear vs. Rainy)

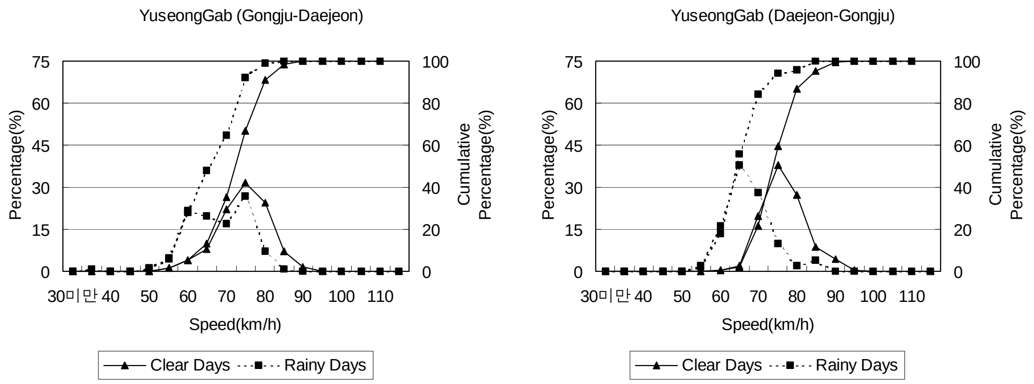

Figure 2 Speed distribution and Cumulative Percentage in 40439 (Clear vs. Rainy)

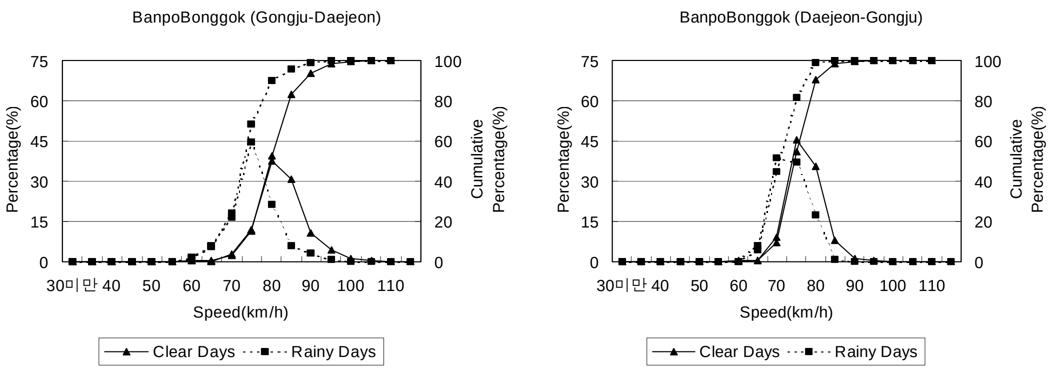

Figure 3 Speed distribution and Cumulative Percentage in 40446 (Clear vs. Rainy)

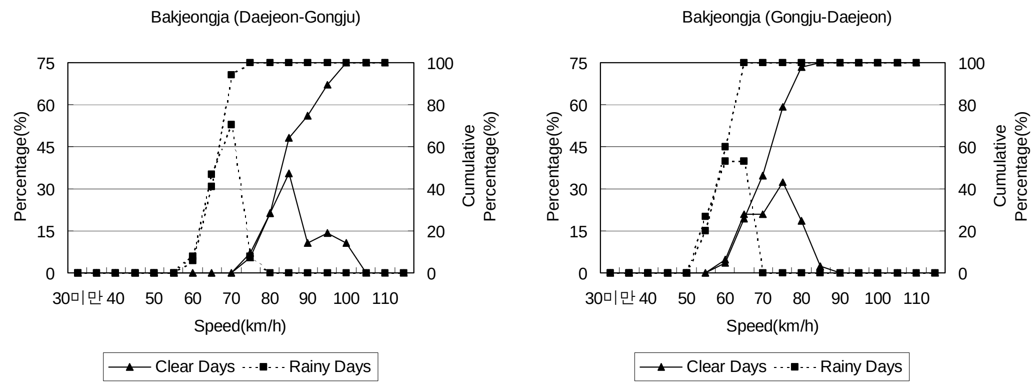

Figure 4 Speed distribution and Cumulative Percentage in Bakjeongja (Clear vs. Rainy)

ANOVA were conducted for each section by using traffic volume-speed data of sunny days and rainy days in order to figure out the impact of weather conditions on driving speeds. They were designed to show the influence of rain on driving speed by each direction of each section. When the distribution and variance data of fine days and rainy days are analyzed by each direction of all sections, it can be concluded as in Table 3. It indicates that all sections show statistical significance in the 1% significance level.

Table 3 Analysis of Variance according to Weather Conditions

Point	Direction	Observation No.		MST	MSE	F Value
		Clear	Rainy			
40006	Nonsan - Gongju	2238	306	2073.78	11.96	173.38*
	Gongju - Nonsan	1966	209	4180.95	54.65	76.50*
40439	Gongju - Daejeon	2050	111	4560.14	43.10	105.81*
	Daejeon - Gongju	644	50	4135.43	29.30	141.15*
40446	Gongju - Daejeon	2711	121	5674.00	34.90	162.59*
	Daejeon - Gongju	2551	121	1659.81	17.78	93.37*
Bakjeongja	Gongju - Daejeon	43	5	555.35	36.78	15.10*
	Daejeon - Gongju	28	17	3951.45	35.20	112.25*

Note1) The asterisk mark (*) refers to significance in the 1% significance level.
Note2) MST and MSE denote Treatment Mean Square and Error Mean Square, respectively.

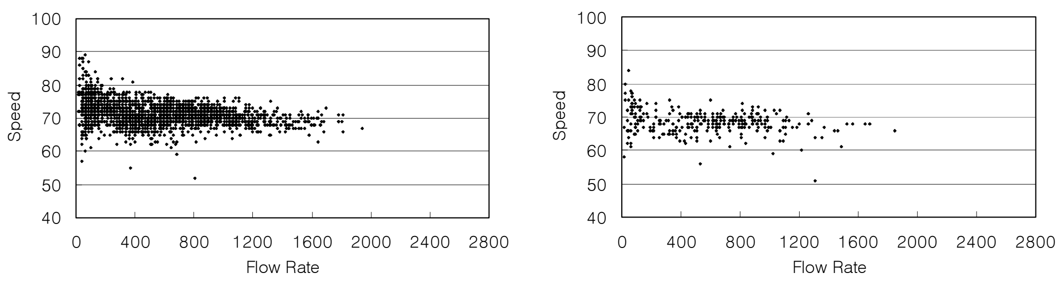

Figure 5 Speed-Flow Rate Distribution of 40006 (Nonsan-Gongju) (Clear vs. Rainy)

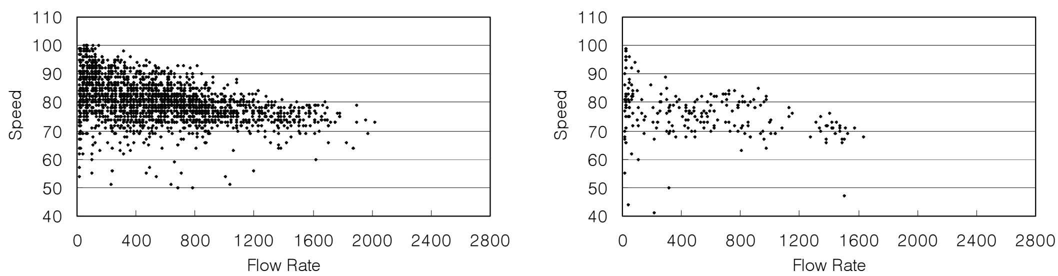

Figure 6 Speed-Flow Rate Distribution of 40006 (Gongju-Nonsan) (Clear vs. Rainy)

As Figure 5 and Figure 6 above indicate, the inclination degree of the speed-traffic flow rate graph in time of clear and rainy days is close to zero (weak negative) at the BonpoOncheon point (Nonsan-Gongju). The variance analysis result shows significant difference. Similarly, when looking at the BanpoOncheon point from Gongju to Nonsan, the inclination degree of the speed-traffic flow graph in time of clear and rainy days is almost zero. The variance analysis shows that there are significant differences in speed.

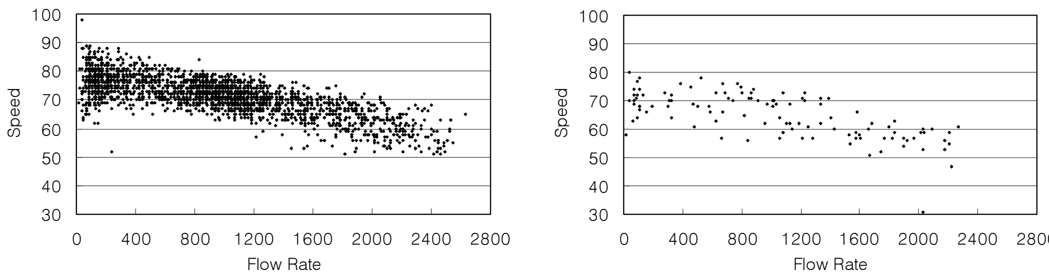

Figure 7 Speed-Flow Rate Distribution of 40439 (Gongju-Daejeon) (Clear vs. Rainy)

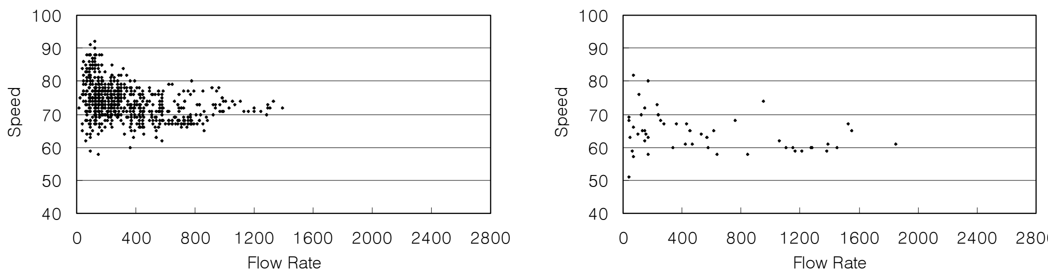

Figure 8 Speed-Flow Rate Distribution of 40439 (Daejeon-Gongju) (Clear vs. Rainy)

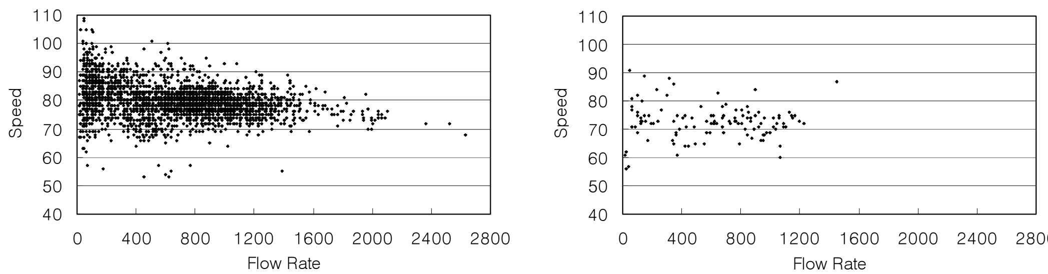

Figure 9 Speed-Flow Rate Distribution of 40446 (Gongju-Daejeon) (Clear vs. Rainy)

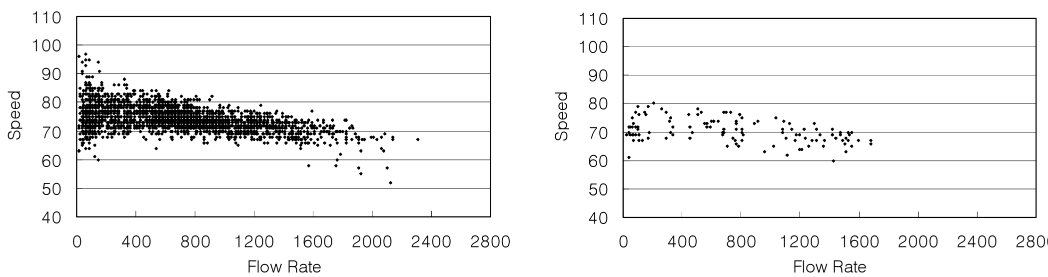

Figure 10 Speed-Flow Rate Distribution of 40446 (Daejeon-Gongju) (Clear vs. Rainy)

As the previous paragraph has just mentioned, this section is a flat from the both directions, so this section will be regarded as a standard section. The section from Nonsan to Gongju is where the reaction of drivers was shown, as speed violation monitoring cameras of the National Police Agency are installed at 70m ahead of the constant survey device. As for the distribution patterns, they are quite different between opposite directions of the section in spite of its flat conditions. In other words, the data are concentrated below the speed of 80km/h, legal speed limitation regardless of weather conditions. In addition, the speed reduction in time of rainfall happens less than other points.

As Figures 7～10 indicates, viewing the speed distributions of both directions, speed and traffic flow rate graphs are all showing negative inclination on sunny days and rainy days as well. Meanwhile, about 200m ahead of the survey points is a traffic signal located in the direction from Daejeon to Gongju (Upward inclination). As such, only the data which is not influenced by traffic signal was chosen and utilized for analysis. The distribution analysis displays that significant speed difference was caused by rain.

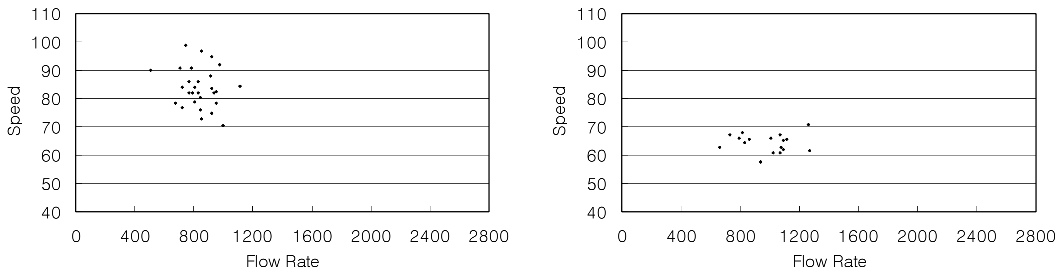

Figure 11 Speed-Flow Rate Distribution of Bakjeongja (Daejeon Gongju) (Clear vs. Rainy)

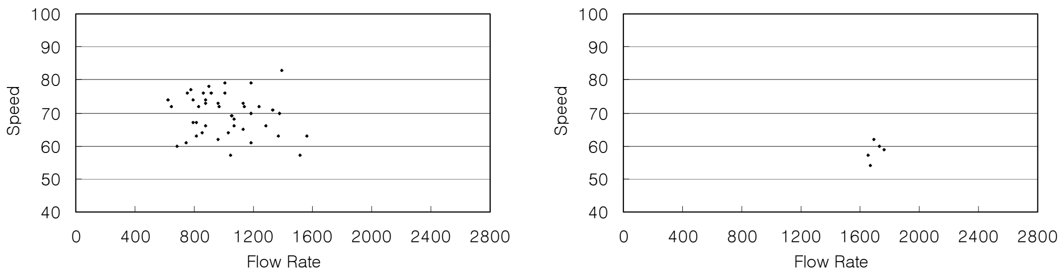

Figure 12 Speed-Flow Rate Distribution of Bakjeongja (Gongju Daejeon) (Clear vs. Rainy)

Figure 11 and 12 are about the Bakjeongja section in the direction from Daejeon to Gongju (downward inclination), where driving vehicles were manually video taped, as it is not equipped with devices for continuous survey. It was found that there is big difference in speed distribution between clear days and rainy days. Likewise, the variance analysis concluded that the ascending inclination of the Bakjeongja section shows significant speed distribution.

4.3. Multiple Comparison Based on Tukey's HSD Test

The variance analyses of the previous paragraphs indicate that speed reduction in each survey section occurred according to weather conditions. Assume that the F-test of variance analysis is rejected as a null hypothesis, and it is concluded that the average of levels are not same. In this case, in order to find out between which levels the difference exists, tests will be considered to find out average difference between two levels. In case of using 1% significance level in the test, it means that the maximum probability of rejecting Type 1 error or true null hypothesis is 0.01. Considering that tests of average difference are not independent, it is difficult to calculate accurate probability. However, in general, the higher the number of tests become, the more increasing the probability of rejecting true null hypothesis grows accordingly. In order to tackle this probability problem associated with the simultaneous usage of more than two average difference tests, the multiple comparison method was introduced, which is utilizing statistics.

Several methods have been suggested and in use for multiple comparison. One of them is the Honestly Significant Difference Test (HSD Test) proposed by Tukey in 1953. This method has been widely used since it was proven to have largest power and satisfy significance level alpha, even in cases where repeated measurement numbers are not same. The Tukey's HSD test calculates the values of average μ_i and μ_j as below.

$$HSD_{ij} = q_{p,n-p;1-\alpha}\sqrt{\frac{1}{2}\left(\frac{1}{n_i}+\frac{1}{n_j}\right)MSE} \tag{1}$$

In Formula (1), $q_{p,n-p;1-\alpha}$ is the value of $(1-\alpha)$ percentile of the standardized range distribution, which has parameter p and degree of freedom $n-p$. n_i and n_j are repeated measurement numbers on the i and j level. MSE is equal to mean squared error. If sample averages satisfy the below inequality (formula 2), hypothesis $H_0 : \mu_i = \mu_j$ will be rejected, and it can be concluded that μ_i and μ_j are different under the significance level α.

$$\left|\overline{\mu_i} - \overline{\mu_j}\right| > HSD_{ij} \tag{2}$$

If repeated measurement numbers same in all levels of formula (1) $(n_1 = n_2 = \cdots = n_p = r)$, HSD of the same values found in the average difference test, or

$$HSD = q_{p,n-p;1-\alpha}\sqrt{\frac{MSE}{r}} \tag{3}$$

can be utilized. If n_i is equal to n_j of two levels, n_i can replace r in the (3) above.

If the geometric structures of roads (No. of lanes, visibility, neighboring environments, etc.) show same features of the traffic flow, speed within the same section will have same distribution pattern. In fact, the four survey sections (8 directions) selected for this study have same environmental features except inclination degree. Therefore, the speed difference of each survey point, which was confirmed by variance analysis method, is found to be significant according to weather conditions. In this section, the multiple comparison method will be utilized to figure out the effects of weather conditions and inclination degrees on the traffic flow-speed distribution features on the 5km-long national highway section.

As a precondition to multiple comparison, the speed difference of 7 points excluding one point which is under influence of speed limit violation cameras, was looked at through variance analysis as below. The test was aimed to figure out whether there are any speed differences between survey points in time of clear day and rainy day respectively.

Table 4 Multiple Comparison (Clean Day) - 99% Confidence Level

Source	DF	Sum of Square	Mean Square	F Value	Pr>F
Model	6	129389.84	21564.97	610.52	<.0001
Error	9986	352729.63	35.32	-	-
Corrected Total	9992	482119.47	-	-	-

Table 5 Multiple Comparison (Rainy Day) - 99% Confidence Level

Source	DF	Sum of Square	Mean Square	F Value	Pr>F
Model	6	12869.16	2144.86	46.73	<.0001
Error	627	28777.07	45.90	-	-
Corrected Total	633	41646.23	-	-	-

Table 4 and 5 indicate that the seven survey points are showing significance of their speed difference in the 1% significance level. However, if the variance analysis concludes that each level shows difference, it needs to take a look at in which points the speed difference exist. For this analysis, the Tukey's HSD multiple comparison was utilized. The findings of the analysis are as below:

Table 6. Average Speed Difference between Study Points on Clean Days (Tukey's HSD Test)

Point	40006 (G-N)	40439 (D-G)	40439 (G-D)	Bakjeongja (D-G)	Bakjeongja (G-D)	40446 (D-G)	40446 (G-D)
40006 (G-N)	-	6.6516* (0.9318)	8.9398* (0.6479)	-3.4446 (3.9062)	10.877* (3.1639)	6.0848* (0.6159)	0.7441* (0.6080)
40439 (D-G)		-	2.2882* (0.9271)	-10.09* (3.9621)	4.2260* (3.2326)	-0.5668 (0.9051)	-5.9075* (0.0155)
40439 (G-D)			-	-12.38* (3.9050)	1.9378 (3.1625)	-2.8550* (0.6088)	-8.1957* (0.6007)
Bakjeongja (D-G)				-	14.322* (4.9839)	9.5294* (3.8999)	4.1888* (3.8986)
Bakjeongja (G-D)					-	-4.7928* (3.1561)	-10.1335* (3.1546)
40446 (D-G)						-	-5.3407* (0.5661)
40446 (G-D)							-

Note1) Asterisk (*) indicates that multiple comparison results in finding significant difference in the 1% level.
Note2) Numbers in the parentheses ( ) represent the HSD_{ij} values of formula (1).
Note3) G-N represents direction of vehicle flow from G to N where, G: Gongju, N: Naonsan, D: Daejeon

Table 7 Average Speed Difference among Survey Points on Rainy Days (Tukey's HSD Test)

Point	40006 (G-N)	40439 (D-G)	40439 (G-D)	Bakjeongja (D-G)	Bakjeongja (G-D)	40446 (D-G)	40446 (G-D)
40006 (G-N)	-	11.388* (3.6995)	10.8162* (2.7600)	11.178* (5.9267)	17.308* (10.634)	5.1709* (2.6844)	3.0387* (2.6844)
40439 (D-G)		-	-0.5719 (4.0024)	-0.2094 (6.5975)	5.9200 (11.022)	-6.2172* (3.9507)	-8.3494* (3.9507)
40439 (G-D)			-	0.3625 (6.1203)	6.4919 (10.743)	-5.6453* (3.0885)	-7.7775* (3.0885)
Bakjeongja (D-G)				-	6.1294 (11.955)	-6.0078 (6.0866)	-8.1400* (6.0866)
Bakjeongja (G-D)					-	-12.137* (10.724)	-14.2694* (10.7241)
40446 (D-G)						-	-2.1322 (3.0212)
40446 (G-D)							-

Note1) Asterisk (*) indicates that multiple comparison results in finding significant difference in the 1% level.
Note2) Numbers in the parentheses ( ) represent the HSD_{ij} values of formula (1).

In the table above, values of each line and column indicate difference between two sample averages. It also shows that the speed at BanpoOncheon (40006), which is flat, is significantly different from those of other three survey points, which have inclination to some degree, regardless of clear days or rainy days. In case of Bakjeongja (Daejeon-Gongju), which has steep descending inclination, the driving speed is higher than that of the flat survey point in case of clear days. However, in time of rainy days, drivers reduce speed to a large extent to prevent skidding on the downward slope.

Meanwhile, in time of rainy days, survey points which have a inclination (ascending and descending) do not show significant difference in driving speed between each other. It is mainly because unlike sunny days, drivers predict slippery road conditions so that they are extremely cautious in driving. Furthermore, in case of slight ascending or descending slopes, the driving speed is 6km/hr faster than steep upward slope. Yet, their speed does not show much difference from that of steep downward slope. The analysis above presents that the speed distribution in time of rainy days is closely related to inclination degrees. In the future, it seems necessary to investigate more survey data on speed distribution by various inclination degrees.

5**. CONCLUSIONS AND DISCUSSION**

This study adopted the variance analysis to verify whether differences are found in average speed of traffic flow between day time and night time of clean days, and between clean days and rainy days. As for analysis data, traffic data collected at continuous survey points run by the MOCT, and geometric condition data of another survey point where manual data survey took place, were mobilized. The study found that the all surveyed sections showed weak negative correlation between traffic volume and driving speed. The analysis of weather conditions data identified significant difference in speed distribution between fine days and rainy days. The current speed limitations of national highway are solely determined by roads type (group) and geometric design criteria. However, the findings of this study stress that not only weather conditions but also inclination degrees of roads affect driving speed distribution to a large degree, so that they should be taken into account.

In the place where speed limit violation cameras are installed, drivers abide by speed restriction rules. This camera-equipped place showed the less degree of speed reduction on rainy days compared with other survey points. As such, it can be said that drivers' speed distribution is affected by specific facilities installed on roads.

Meteorological organizations need to provide weather data exclusively collected by them, including atmospheric data, rainfall data, continuous traffic volume survey data, via the integration with ITS with an aim to satisfy a variety of demands of drivers. As this study pointed out, driving speed information provided should be reflected with weather conditions and inclination degrees. By the time when ITS currently under construction reaches its operation stage, it is expected that the current speed limit scheme will be turned into a more flexible system reflecting aspects of weather conditions and slope degree.

This paper tried to investigate the effect of rainfall, one of various direct environmental factors on driving speed. We know that further studies shall be carried out to observe and analyze other environmental factors such as road freezing, snowfall, wind speed and fog in order to secure more accurate data. Also tireless pursuit for devising measures should be made to promote integrated usage of all weather information exclusively collected by weather-related organizations for more accurate road weather information.

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