

## 노면온도와 기상조건과의 상관관계에 관한 연구

양충현<sup>1\*</sup> · 김진국<sup>2</sup>

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# Investigation the relationship between road surface temperature and weather conditions using a vehicle attached sensors

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### [요 약]

동절기 도로는 운전자에게 매우 위험한 주행환경을 제공한다. 일반적으로 습하거나 눈이 많이 오는 날씨에는 건조한 도로에 비해 마찰계수가 감소한다. 이는 겨울철 교통사고의 발생 가능성을 높이는 결과로 이어진다. 따라서 안전하고 효율적인 동절기 도로주행환경을 제공하기 위해서는 노면온도에 대한 정확한 정보를 수집하는 것이 매우 중요하다. 본 연구에서는 이동식 노면온도 측정시스템을 이용하여 도로의 노면온도, 대기온도, 대기습도, 차량의 주변온도 및 GPS 데이터를 수집하였다. 수집된 데이터의 전처리 과정을 통해 분석을 위한 DB를 구축하고 두 가지 통계적 테스트를 통해 노면온도와 기상조건 간의 상관관계를 파악하였다. 분석결과는 향후 노면 온도를 예측하는 데 필요한 기초자료로 활용될 수 있을 것이다.

### [Abstract]

Winter roads often lead to inferior conditions to drivers. The freezing and thawing cycle leads to a decreased friction coefficient in wet or snowy weather when compared to dry roads. This leads to an increase in possibility of traffic accidents during the winter. Therefore, collecting accurate information on road surface temperature is crucial to provide a safe and efficient winter road environment. This study collects surface temperature, atmospheric temperature, humidity, vehicular ambient temperature, and GPS data through a thermal mapping system. The collected data is transformed into a database format that can be analyzed, and the correlation between the road surface temperatures is identified using two statistical tests. These can provide great insights of necessary parameters for forecasting the road surface temperature by statistical results.

**색인어** : 차량 외기온도, 이동식 노면온도 측정시스템, 노면온도, 통계분석, 도로 유지관리

**Key word** : Vehicular ambient temperature, Thermal mapping system, Road surface temperature, Statistical test, Road maintenance

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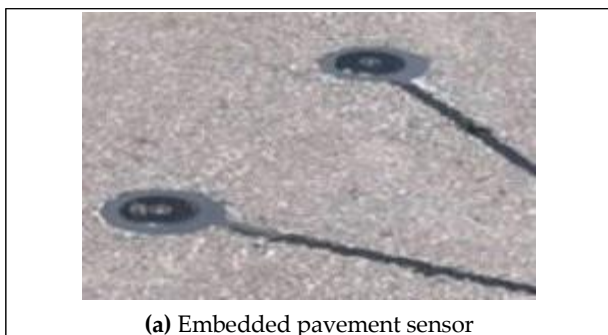
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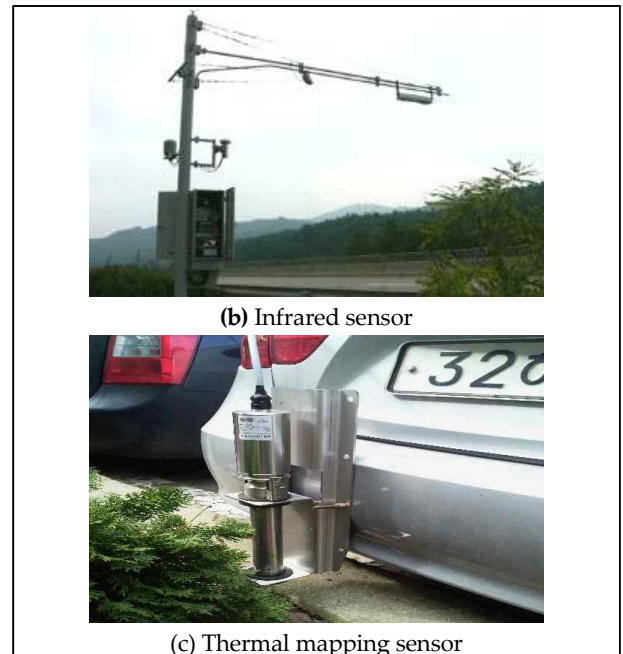
## I. Introduction

A road surface can immediately freeze after rain during the winter[1]. For example, when it rains, air temperature generally decreases, and thus wet roads tend to be freezing. In addition, snow cover on the road can repeatedly cause freezing and thawing due to changes in temperature. The road surface friction coefficient changes according to road surface condition. When road surface becomes wet or freezing, the road surface friction coefficient tends to be lower than dry condition of road surface[2]. Furthermore, the road surface temperature at night differs by more than 10°C compared with daytime during the winter season[3, 4]. The freezing and thawing cycle decreases the friction coefficient in wet or snowy conditions when compared to dry roads. Freezing rain, which occurs frequently during the winter season, can decrease the level of traffic safety. According to the U.S. Federal Highway Administration, 1,836 deaths and 136,309 injuries per year were caused by icing or snowfall on the road during the winter[5]. In addition, traffic accidents during the winter season are about 19% higher and the number of people injured by traffic accidents is about 13% higher when compared to other seasons[6]. Importantly, freezing rain during the winter forms unstable traffic flow[7]. Therefore, collecting accurate information on road surface temperature is crucial to provide a safe and efficient winter road environment.

The road surface temperature can be measured using a road weather information system (RWIS) or a thermal mapping system (TMS)[8]. There are two sensors used in a RWIS: an embedded pavement sensor and infrared sensor installed on the road shoulder. A RWIS can only collect road surface temperature data for a single point on the road. On the other hand, a TMS can be equipped on a vehicle, and collect road surface temperature data over entire road sections while driving[9]. Typically, the variables affecting road surface temperature are roadside temperature, atmospheric temperature, and humidity. Of these, the roadside temperature is defined as the atmospheric temperature between 9m and 14m above the road surface[3].



(a) Embedded pavement sensor



(b) Infrared sensor

(c) Thermal mapping sensor

그림 1. 노면온도 수집 센서의 종류

Fig. 1. Three types of sensor

In this study, temperature sensors were attached to the front and rear of the survey vehicle. The roadside temperature was assumed to be the same as the temperature collected from the vehicular ambient temperature sensor. They were attached to both the front and back of the survey vehicle because the location of them differs between vehicle manufacturers.

This study collected surface temperature, atmospheric temperature, humidity, vehicular ambient temperature, and GPS data through a TMS. The collected data was transformed into a database format for analysis, and the correlation between the road surface temperatures was identified using two statistical tests.

## II. Materials and Methods

### 2-1 Literature Review

The survey vehicle, equipped with a TMS, repeatedly drove the same route over the same time under different weather conditions in the winter and collected data for surface temperature, atmospheric temperature, humidity, vehicular ambient temperature, and GPS. A thermal map was constructed based on the road surface temperature information from the collected data. To increase the reliability of the thermal map, mathematical filtering methods were used[10].

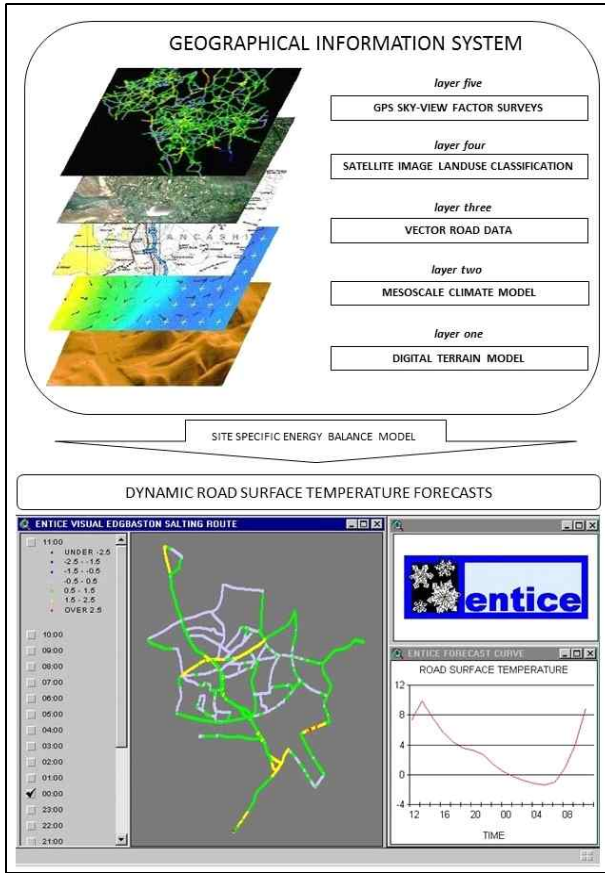


그림 2. 노면결빙 예측 시스템  
 Fig. 2. Road Ice Prediction (University of BIRMINGHAM)

A TMS is typically used to measure the lowest road surface temperature under various weather conditions. The road surface temperature was measured using the TMS for more than 100,000 km of the roads and airports in the United States, Canada, Europe, and Japan[11, 12]. The TMS measurement is mainly conducted by the highway agencies. To maximize the spraying of snowplows, a TMS is used to identify the optimal paths, locations, and numbers of snow removal vehicles. Therefore, predicting the freezing of the road surface is highly crucial.

According to the study using a TMS in Korea, the road topography and local climatic factors or topographical factors such as tunnels and bridges can affect the road surface temperature[13]. A road surface temperature model based on the RWIS was developed, and its predicted values were compared with the actual road surface temperature collected from the TMS. In 2010, Korea Expressway Corporation implemented a TMS for the freeway[14]. This TMS showed lower consistency of collecting data. However, it is meaningful that it was the first attempt to build a freeway TMS in Korea and utilize it for winter road operation[15].

In Northern Denmark, a TMS was used to verify the performance of the Danish road weather model[16]. Previous research associated with TMSs has suggested that thermal mapping is a very useful tool for studying road weather, but it is necessary to define error rates and limitations. The Danish study confirms this[16]. Another study asserted that the data accuracy collected by TMSs was influenced by many systematic random errors[17]. It was found that the temperature difference in road surface of about 1.5°C occurs in each lane, which directly affects the traffic heat fluxes. Teconer, a Finnish private company, developed the Road Condition Monitor that collects real-time information on road conditions in winter. For this purpose, TMSs were installed in 148 vehicles of the Finnish road management organization[18]. In the US, TMS equipment was installed and utilized in several states. Minneapolis, Minnesota has built a thermal map around its airport and utilized it well. In the UK, a GIS model combined with TMS was used to predict the road surface temperature in the West Midlands, and it was confirmed that the accuracy of prediction accounts for about 74% of spatial accuracy[19, 20].



그림 3. 미국 Minneapolis 공항의 노면온도 표출 Map  
 Fig. 3. Thermal map in Minneapolis airport in U.S



그림 4. 핀란드의 노면온도 표출 Map  
 Fig. 4. Thermal map in Finland

Overall, TMSs are not only useful for current road surface temperature measurement and information collection for an entire road section, but also provide essential information for road surface prediction[21]. However, In Korea, the guidelines for the utilization of TMS, policy decision making based on TMS, and studies for predicting road surface temperature have not fully matured when compared to other countries.

**2-2 Data Collection**

**1) Thermal Mapping System (TMS)**

A TMS was installed on the survey vehicle to collect road surface temperature, vehicular ambient temperature (front and rear of the vehicle), atmospheric temperature, and humidity data. Figure 6 shows the TMS installed in the survey vehicle maintained by Korea Institute of Civil Engineering and Building Technology (KICT).

The KICT TMS consists of a power supply, a communication device for data transmission, an air temperature and humidity sensor, a road surface temperature sensor (using a non-contact infrared camera), and a GPS sensor combined with a computer and various software for displaying and storing data (see Figure 6). The data processing procedure and detailed specification of the TMS are presented in Figure 7 and Table 1, respectively.



그림 5. TMS를 설치한 조사차량  
Fig. 5. TMS installed in the survey vehicle



그림 6. 자료수집을 위한 센서들의 설치 위치  
Fig. 6. Location of each sensor on the survey vehicle

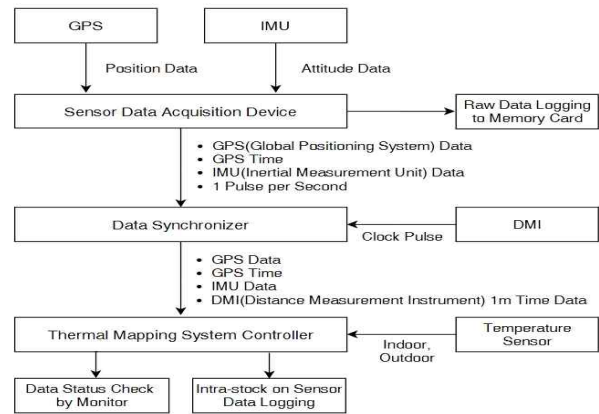


그림 7. 전체 시스템 개념도  
Fig. 7. Conceptual diagram of the overall system.

표 1. 센서들의 상세 스펙  
Table 1. Key sensor specifications

Division		Contents
Relative humidity sensor	Measuring range	0%~100% RH
	Measuring accuracy	±3% RH
	Relative humidity hysteresis	±1% RH
	Sensor element	HMI1500LF (Capacitive Type)
Air temperature sensor	Measuring range	-20 °C ~ +80 °C
	Measuring accuracy	± 0.3 °C
	Sensor element	PT-100 Ω (RTD Type)
Power supply	Operating voltage	8 VDC ~ 30 VDC
Communication device	Output data	4 ~ 20 mA
Road surface temperature sensor	Measuring range	-25 °C ~ +100 °C
	Measuring accuracy	± 0.5 °C
	Maximum stability range	< 0.5 °C
	Measuring point position (ground spacing)	40 mm ~ 1000 mm
	Operating voltage	10 VDC ~ 32 VDC
GPS	Output data	CAN Communication
	Measuring range	·Positional accuracy: 1.8m ·Satellite-based error information: 1.2m ·DGPS: 0.7m
	Measuring accuracy	20 Hz (0.05s)
	Operating voltage	9 VDC~24 VDC
	Output data	RS-422
Vehicular ambient temperature sensor	Size	H 70×W 25×D 13 (mm)
	Power	5 V, 50 mW
	Data logger	Up to 1sec interval
	Measuring range	·Temperature : -40 °C ~ +80 °C ·Humidity : 5% ~ 95% H
	Precision	·Temperature : ±0.3 °C ·Humidity : ±2.0% RH
Resolution	·Temperature : 0.01 °C ·Humidity : 0.04% RH	

### 2) Study area

For this study, the 37.03km-section of Seoul outer-ring road was selected as the study area because it includes various road geometries and is known to experience frequent snowfall and road icing in winter. In particular, the study area includes tunnel and bridge sections that can directly or indirectly affect road surface freezing. The study area was classified into three types: normal section, bridge section, and tunnel section that affect the road surface temperature (see Figures 8 and 9).

The road surface temperature is the lowest just before sunrise. In this study, the data collection time was from 05:00 to 06:00. Data collection was performed during the same time intervals for the same survey interval every day.

### 3) Data Processing

Table 2 shows the attribute data, data format, and time period of each sensor included in the TMS.



그림 8. 다양한 기하구조 조건을 갖춘 현장조사 구간  
 Fig. 8. Various road geometric conditions

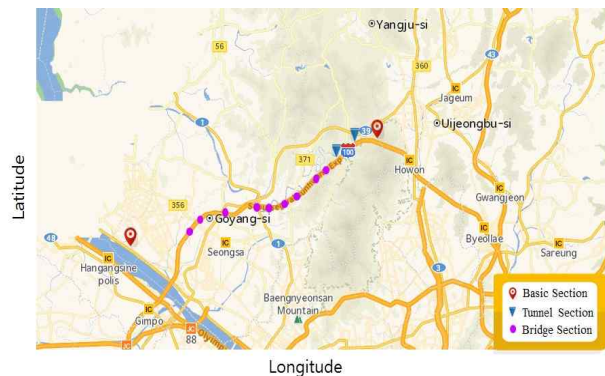


그림 9. 데이터 수집을 위한 현장조사 구간  
 Fig. 9. Roadway section for data collection

As shown in Table 2, the data collection cycle needs to be equalized because the GPS time is acquired at 1s intervals, the road surface temperature at 1s intervals, and the vehicular ambient temperature at 0.125 s intervals. In addition, it is necessary to convert GPS time to GPS coordinates. Therefore, a pre-processing procedure for the data collected through a TMS is required; this procedure is presented in Figure 10. The number of collected surface temperature datapoints is 4,665 in 2016 and 3,187 in 2017. The collected data was processed and converted into a database in a form that can be analyzed as follows (see Table 3).

표 2. 수집 데이터의 형식 및 포맷  
 Table 2. Data type, format, and collection time

Sensor	Data type	Format	Collection Time
GPS	latitude, longitude, H-Eil, SDHoriz, SDHeight, Veast, Vnorth, Vup, sol, roll, pitch, heading	text	1 sec
TMS	front and rear ambient temperature	csv	0.125 sec
	road surface temperature, relative humidity, air temperature	json	1 sec

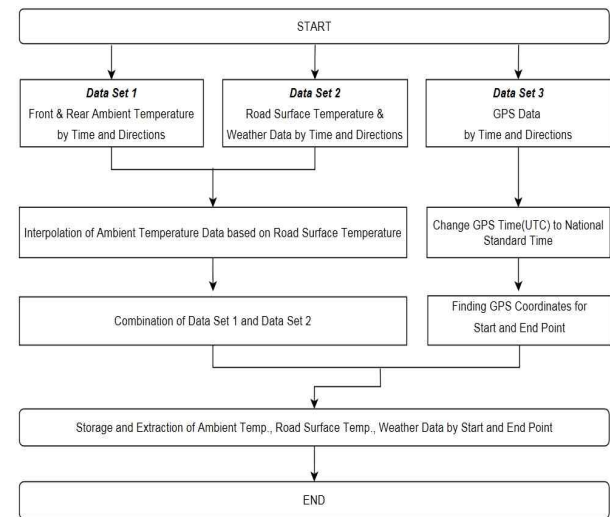


그림 10. 수집 데이터의 전처리 과정  
 Fig. 10. Pre-processing for aggregating the collected data

표 3. 수집 데이터의 전처리 결과 (예시)

Table 3. Example of final database by pre-processing

Date, Time	Air temperature (°C)	Relative humidity (%)	Road surface temperature (°C)	Ambient temperature (°C)		Road type
				Rear	Front	
2017-01-24 16:49:35	-0.33	34.57	0.4	-1.89	8.61	basic
2017-01-24 16:49:36	-0.33	34.57	0.4	-1.88	8.62	basic
2017-01-24 16:49:37	-0.33	34.75	0.2	-1.87	8.63	basic
2017-01-24 16:49:38	-0.34	34.38	0.2	-1.86	8.64	basic
2017-01-24 16:49:39	-0.34	34.78	0.2	-1.85	8.65	bridge
2017-01-24 16:49:40	-0.34	35.01	0.2	-1.84	8.66	bridge
2017-01-24 16:49:41	-0.35	34.46	0.6	-1.83	8.67	bridge

### III. Results

The Pearson's correlation coefficient was used to statistically evaluate the correlation between data collected through the TMS. This method is frequently used in the fields of traffic engineering and traffic safety and has the advantage of quantitatively analyzing the relationships of data[22]. This method, however, does not explain the causal relationship but only the degree of association between the two variables. The Pearson correlation coefficient is given by

$$R_{xy} = \frac{S_{xy}}{S_x \times S_y} \tag{1}$$

Where  $R_{xy}$  represents the correlation coefficient between variables x and y; and  $S_{xy}$  are the standard deviation of variables x and y; and indicates the covariance of variables x and y. If the correlation ( $R_{xy}$ ) is between 0 and 1, it can be considered that there is a positive correlation, and if  $R_{xy}$  is between -1 and 0, it can be determined that there is a negative correlation; if  $R_{xy}$  is equal to 0, it can be regarded as no correlation between two variables. Pearson's correlation coefficients of the front and rear of vehicular ambient temperature, the atmospheric humidity, and temperature were calculated based on the road surface temperature. The results are shown in Figure 11.

As shown in Figure 12, all the results of the Pearson correlation coefficients are positive, indicating a positive correlation between the road surface temperature and the variables that we considered. Humidity is associated with the presence or absence of weather precipitation. Because the temperature is lower during the day when it is raining, the relationship between humidity and road surface temperature can be expected to be negative. However, since there were no rainy days during the data collection and the correlation coefficient had

a value close to 0, that relationship cannot be decided. When taking the absolute values of the four correlation variables, the rear outside temperature is seen to have the greatest influence on the road surface temperature followed by air temperature and vehicular ambient (front) temperature. It is noteworthy that the correlation coefficient between vehicular ambient (front) temperature and the road surface temperature is relatively low compared to the correlation coefficient between the atmospheric temperature and the road surface temperature. This is likely because vehicular ambient (front) temperature can be affected by the heat of the vehicle's engine.

The statistical hypothesis test was also performed on the mean values of the front and rear of vehicular ambient temperature and road surface temperature for each road section to analyze the relationship between the road section, the road surface temperature, and the front and rear of vehicular ambient temperature.

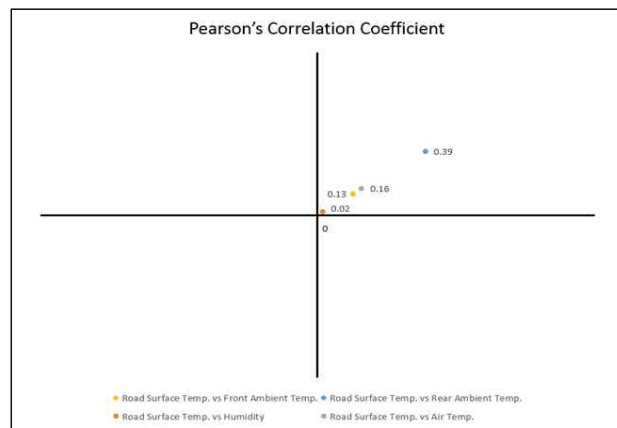


그림 11. 피어슨 상관관계 분석 결과

Fig. 11. Results of Pearson's correlation coefficient analysis

표 4. 가설검정 (도로구간별 차량의 전방, 후방 외기온도, 노면온도)

Table 4. Statistical hypothesis between the front and rear ambient temperature and road surface temperature by roadway sections

Hypothesis	Null hypothesis (H0)	Alternative hypothesis (H1)
1st	$H_0: \mu_{basic} \leq \mu_{bridge}$	$H_1: \mu_{basic} > \mu_{bridge}$
2nd	$H_0: \mu_{bridge} \leq \mu_{tunnel}$	$H_1: \mu_{bridge} > \mu_{tunnel}$
3rd	$H_0: \mu_{basic} \leq \mu_{tunnel}$	$H_1: \mu_{basic} > \mu_{tunnel}$

Table 5 shows the results of the second and third hypothesis tests conducted on the road surface temperature. It is statistically verified that the road surface temperature of the tunnel section is lower than the road surface temperature of the other sections. On the other hand, vehicular ambient temperature of the front and rear of the vehicle showed a similar temperature. As mentioned above, the bridge section cannot see temperature difference when compared to the tunnel section, and the same conclusion can be made based on the results of the hypothesis test.

However, it can be confirmed that the road surface temperature of the bridge section is lower than that of the normal section for some dates while the front and rear outside temperature of the vehicle are high. Therefore, the road surface temperature can be different depending on the type of road section.

#### IV. Discussion and Conclusions

Information on the change in road surface temperature in winter is very important not only for road agencies but also for general drivers. More precisely, information about the road surface condition such as dry, wet, and slushy is ultimately essential rather than the road surface temperature. We should know, however, that the road surface conditions are mainly dependent upon its temperature. In Europe and the United States, many studies on road surface temperature have been conducted, and currently the data associated with road surface temperature is collected, processed through various methods, and implemented in highway maintenance. In Korea, however, research on road surface temperature has not been active yet. In this study, we analyzed the statistical relationship of various data (road surface temperature, outside temperature of the vehicle, atmospheric temperature, and humidity) collected through a TMS. These can be considered necessary parameters for forecasting the road surface temperature.

There is a limit to generalizing the results of this study, but it is

meaningful that we have tried basic research in the field of road weather using a TMS which is intended for operation by central or local government, or corporations in Korea. To elaborate on and rationalize the information on road surface temperature change patterns for the main arterial roads in the future, it is necessary to apply TMSs on different types of roads. In doing so, it will be possible to improve the operational efficiency of TMSs, to establish practical measures to improve snow removal operation, and to prepare preemptive measures against snow and black ice, which seriously threatens traffic safety in the winter season.

표 5. 가설검증 결과

Table 5. Hypothesis test results

Type	Date	Direction	1st	2nd	3rd
			Basic vs. Bridge	Bridge vs. Tunnel	Basic vs. Tunnel
Road surface temp.	20170227	upstream	1*	1	1
	20170227	downstream	0**	1	1
	20170302	upstream	1	1	1
	20170302	downstream	0	1	1
	20170302	upstream	0	1	1
	20170303	upstream	1	1	1
	20170303	downstream	0	1	1
	20170306	upstream	0	1	1
	20170306	downstream	0	1	1
Front ambient temp.	20170308	upstream	1	1	1
	20170227	upstream	0	0	0
	20170227	downstream	0	0	0
	20170302	upstream	1	0	0
	20170302	downstream	0	0	0
	20170302	upstream	0	0	0
	20170303	upstream	1	0	1
	20170303	downstream	0	0	0
	20170306	upstream	1	0	0
Rear ambient temp.	20170306	downstream	0	0	0
	20170308	upstream	1	0	1
	20170227	upstream	1	1	1
	20170227	downstream	0	1	0
	20170302	upstream	1	0	1
	20170302	downstream	0	0	0
	20170302	upstream	0	1	0
	20170303	upstream	1	1	1
	20170303	downstream	0	1	1
	20170306	upstream	0	0	0
	20170306	downstream	1	1	1
	20170308	upstream	1	1	1

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