MEASUREMENT OF ROAD SURFACE TEMPERATURE USING THERMAL MAPPING SYSTEM

Dukgeun Yun, Jaehong Park, Junggon Sung
Highway & Transportation Research Division, Korea Institute of Construction Technology
dkyun@kict.re.kr, jhpark@kict.re.kr, jgsung@kict.re.kr

ABSTRACT

According to the road accidents statistics of Korea, 33% of fatalities in 2011 occurred in winter. As many factors can be the causes of the accidents in winter season, road freezing is the most important factor among them. If a road manager has information or can predict the road surface condition or temperature, the accidents related with road surface freezing can be reduced.

In this study, a thermal mapping system was developed to measure road surface temperatures. And the road surface temperature (RST) and air temperature were measured along the various road sections such as normal road sections, bridges, tunnels and cut slope sections. As a result, although the RST in normal paved road sections was higher than air temperature during night time, the RST in bridges and cut slope sections was lower than air temperature. Moreover, the average RST in bridges and cut slope sections showed lower values than in normal paved road sections.

In this study, we suggest that significant attention is required in bridges and cut slope sections during winter.

1. INTRODUCTION

According to the road accidents statistics of Korea in 2006, 85.7% of the accidents occurred on dry surface, 12.4% on wet surface, 0.8% on icy surface and 0.4% on snow surface. However, considering death rates on various road surface conditions, it is known 4.2% of the death rates occurred on icy road, 3.9% on wet road, 2.8% on dry road and 1.2% on snowy road, which means that the wet and icy road conditions are more dangerous than a dry road condition. Especially wet roads would be more dangerous in winter because of easy change to icy roads.

The major factor to decide the state of water on road surfaces is a temperature. Even though road users or road managers are usually provided with air temperatures by weather forecast, the road surface temperature(RST) is more important in terms of the changes in the state of water on road surfaces. In order to realize and predict current road surface conditions in winter, it is important to obtain the information about RST.

Many countries operate the RWIS(Road Weather Information System) or MDSS(Maintenance Decision Support System) to predict road surface conditions and obtain the information to select appropriate road maintenance work in winter.

The FHWA of USA established the Clarus system in 2004 to reduce the impacts of adverse weather conditions for surface transportation users. The goal of the initiative was to create robust data assimilation, quality checking, and data dissemination systems that could provide near real-time atmospheric and pavement observations from the collective state's investments in road weather information systems, environmental sensor stations (ESS) as well as mobile observations from Automated Vehicle Location (AVL) equipped trucks. The objective of Clarus is to provide proper information to all transportation managers and users to alleviate the effects of adverse weather. (http://www.its.dot.gov/clarus/)

From the Clarus system, the road weather data can be collected through the ESS, and the collected data can be provided to the MDSS. The MDSS was developed to help highway maintenance agencies for the safety and mobility of travelling public. The MDSS is a computer-based, customizable tool that provides winter maintenance personnel with route-specific weather forecast information and treatment recommendations. The MDSS consists of 'Road Weather Forecast System' and 'Road Conditions & Treatment Module'. (http://www.ops.fhwa.dot.gov/weather/index.asp)

In MDSS, the RST can be predicted using the weather data from ESS and developed algorithms, and road managers can decide the follow-up maintenance works referring to the provided data from MDSS.

In some European countries, the RWIS is in operation in order to enhance the safety of road users and reduce maintenance cost.

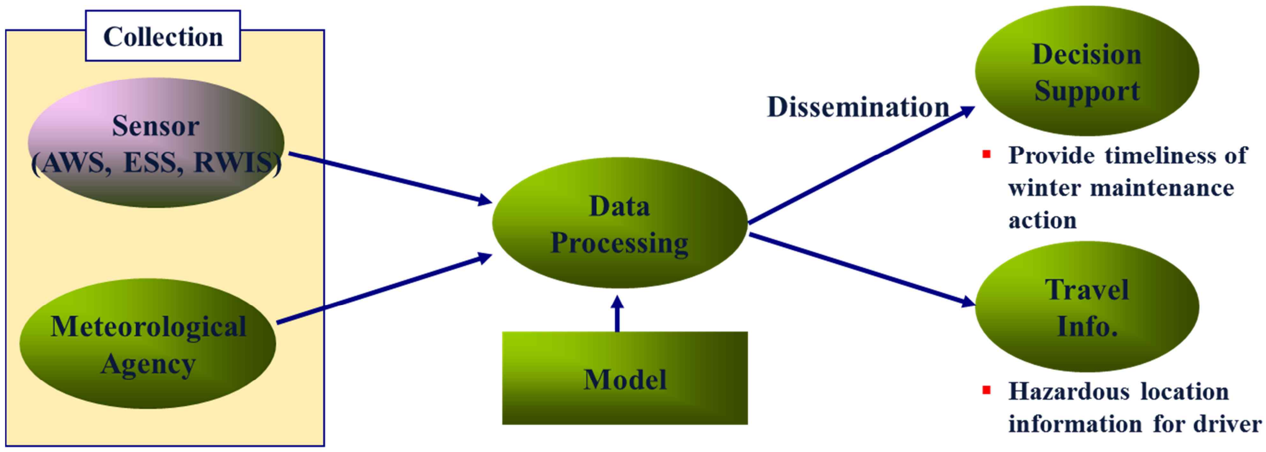


FIGURE 1. Conceptual Diagram of RWIS

As shown in Figure 1, an analysis algorithm is necessary for developing the model of RWIS. The basic model of RWIS is the road surface temperature prediction model(RSTPM), and each country has its own developed RSTPM.

However, because the RWS(Road Weather Station) cannot cover road sections, the results from the RSTPM are not the representative road section surface temperature but the spot RST, implying that if there is a shady area in a cut slope or bridge or tunnel, the temperature would be different from the RWS installed location.

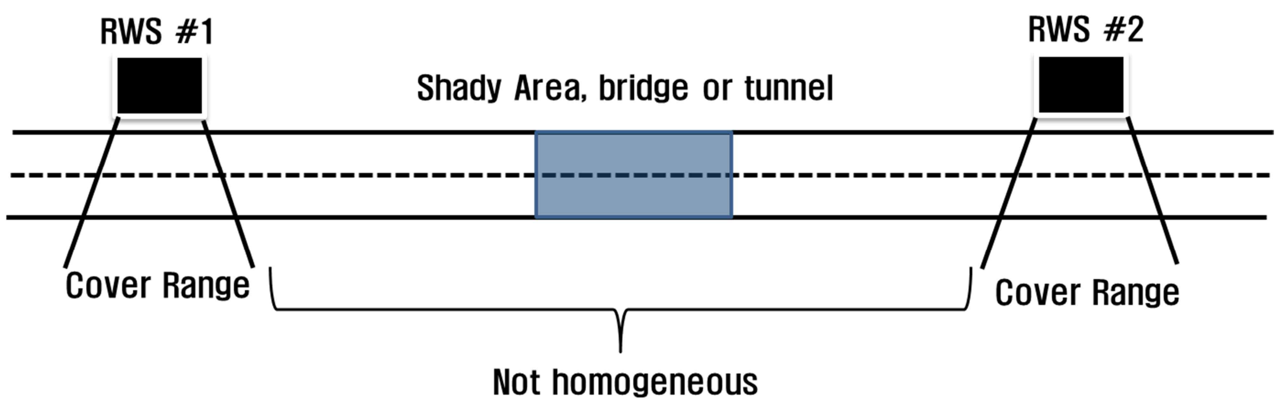


FIGURE 2. Coverage of RWS

Takahashi (2006) developed a road surface temperature prediction model and applied a RWIS to the model in Sapporo, Japan in which traffic volume was regarded as an independent variable.

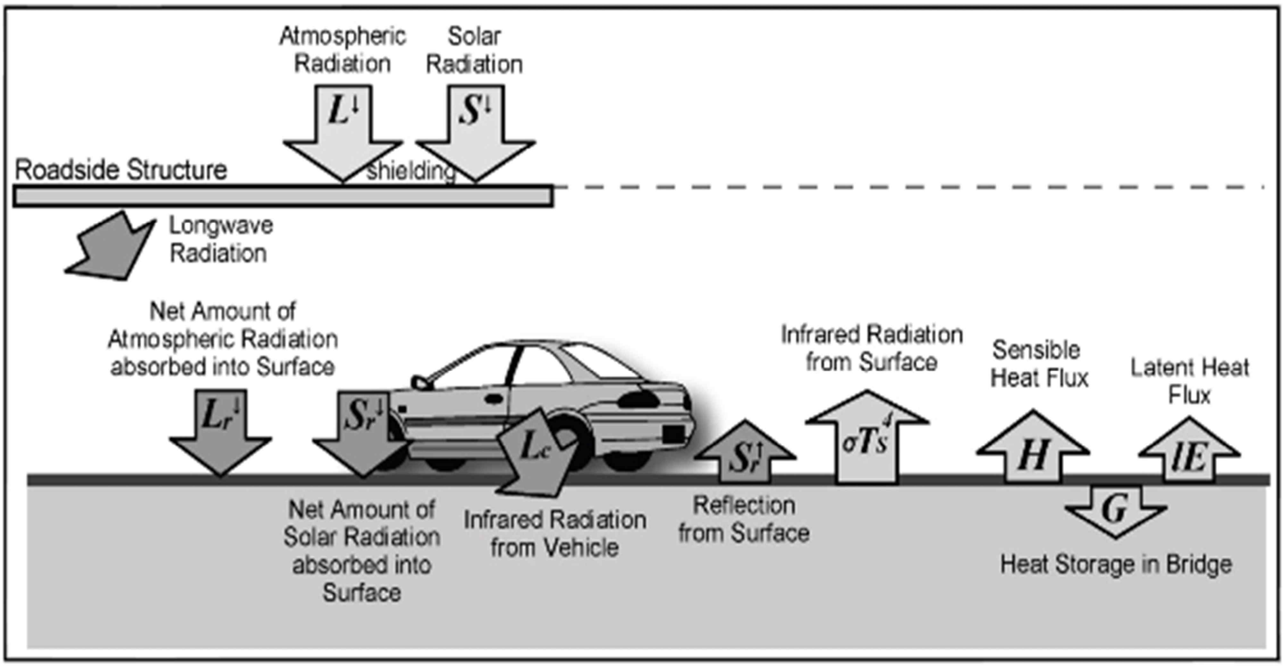


FIGURE 3.Road Surface Temperature Prediction Model(Takahashi, 2008)

According to Torbjörn Gustavsson(1999), the RWIS mobile temperature measurements, thermal mapping, has been used in applied road climatological studies since the mid-1970s. Lindqvist (1976) published an early report where methods for detecting road sections with a high frequency of ice formation were discussed. Other early works in this area are by Sugrue et al. (1983) and Thornes (1985). Thornes (1991) described the thermal mapping technique in great detail and also gave examples of how the temperature data varies according to weather as well as other important factors. The thermal mapping technique has also been used in a number of studies where the influence of different topographical objects was studied (e.g. Bogren & Gustavsson, 1989, 1991). An important development of the traditional mobile measurements was the inclusion of surface temperature detectors which could be used for road climatological studies. By use of infrared detectors the important factors influencing the local risk of road icing could be measured. Traditionally thermal mapping is used as a method to detect locations which differ in temperature compared to neutral areas; for example these could be areas where no gathering of cold air takes place. These locations are further compared with field observations and analyses of topographical maps to identify the most suitable locations for field stations in an RWIS. (Torbjörn Gustavsson, 1999)

If the tendency of RST can be measured along the road, the temperature of certain road section or location at which a RWS is not installed, could be calculated using reference location at which a RWS is installed. Therefore continuous thermal information is necessary to predict the road sectional temperature from the result of RSTPM which predicts the spot surface temperature.

In this study, a thermal mapping system was developed and the road surface temperature and air temperature data were collected in over 200km of expressway (motorway of Korea) during the night time using the developed system. After survey, the road sections were divided into a normal, bridge, tunnel and cut slope road sections and then the difference of temperature in each road section was verified.

2. THERMAL MAPPING SYSTEM AND DATA ACQUSITION

2.1. Composition of thermal mapping

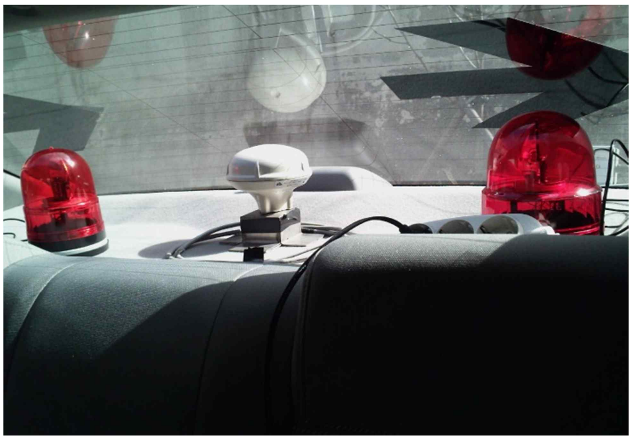
As mentioned above, consecutive RST is important information for estimating certain road section. Therefore in this study, the road surface temperature, air temperature and air humidity were measured using mobile equipments with temperature and humidity sensors, and then the measured results were plotted on the road map to understand overall pattern of RST along the road. In order to rapidly acquire RST, air temperature and humidity along the road, each sensor was installed on a mobile equipment. As the acquired data from the vehicle was plotted on the GIS based map to generate thermal map, the positional data also had to be collected as other collected data. Thus, a GPS sensor was also installed on the vehicle along with other sensors.
Table1 shows the composition and the characteristics of installed sensors for thermal mapping system developed in this study.

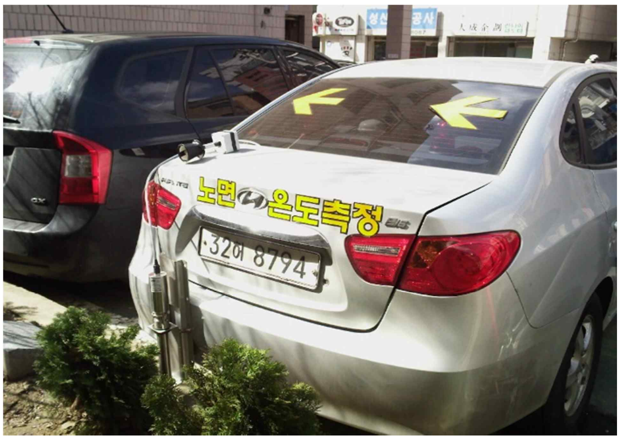
TABLE 1 Composition of Thermal Mapping System

Sensor	Category	Range
Air humidity sensor	Measurement Range	0%~100% RH
	Measurement Accuracy	±3% RH
Air temperature sensor	Measurement Range	-20℃~+80℃
	Measurement Accuracy	±0.3℃
Power supply	Input	8VDC~30VDC
Communication device	Output	4~20mA
Road Surface Temperature Sensor	Measurement Range	-25℃~+100℃
	Measurement Accuracy	±0.5℃
	Maximum stable range	<0.5℃
	Measurement Position from surface	40mm~1000mm
	Input Voltage	10VDC~32VDC
	Communication	CAN
GPS Sensor	Positional Accuracy	- 1.8m(Single GPS) - 0.7m(DGPS)
	Frequency	Max. 20Hz (0.05s)
	Power Supply	9VDC~24VDC
	Communication	RS-422

Figure4 shows the thermal mapping system and its installed sensors

(a) Road Surface Temperature Sensor (b) Air Temperature and Humidity Sensor





(c)GPS Sensor (d) Survey Vehicle

FIGURE4 Thermal Mapping System and Its Installed Sensors

2.2. Data Acquisition

The thermal mapping system was applied to approximately 220km of the expressway No. 50 (Young-dong expressway) of Korea to generate thermal map. The expressway No. 50 crosses the Korea peninsula from east to west and most of the road sections consist of mountainous area.

According to William z. Harrington et al.(1995) the pavement temperature is usually higher than the air temperature regardless of the materials of pavement during daytime. However, with the focus on maintenance in winter, the survey was conducted around midnight excluding the time zone of solar radiation in which the impact of solar heat, from 10:00PM March, 22 to 01:00AM March, 23, 2010 can be minimized. The thermal mapping system collected the data of the air temperature, road surface temperature and air humidity every 0.5 seconds over every 14m at 100km/h travel speed. Total collected data were 18,677 for each sensor.

Collected from the thermal mapping system, the data was plotted on the GIS map(Google earth) and Figure 5 shows the road surface thermal map for surveyed route expressway no.50. The blue dots represent lower temperatures whereas red dots do higher temperatures.

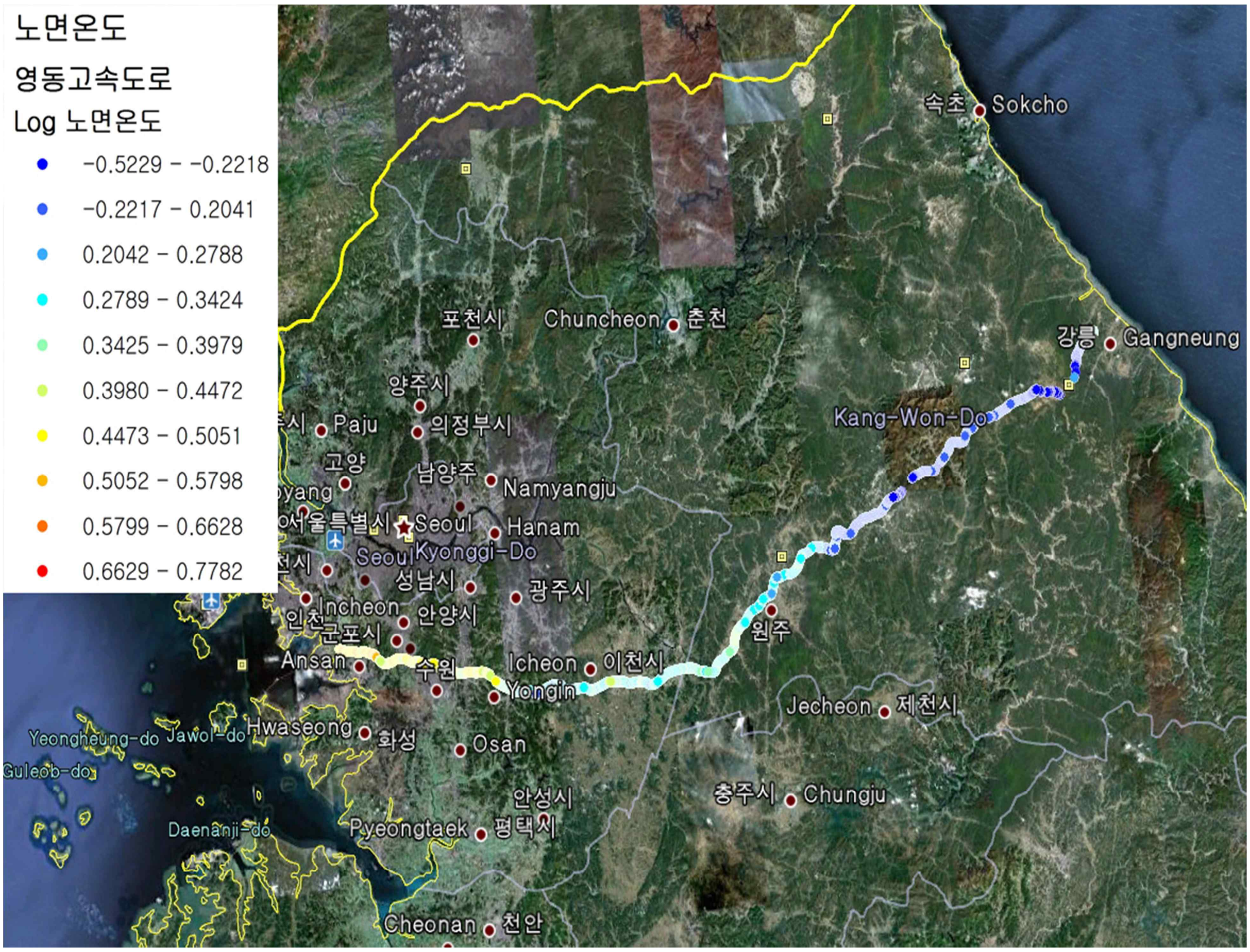


FIGURE 5. Thermal Map of Expressway no. 50

After weather data was collected, the surveyed road section was divided into a normal road section, bridge section (or over pass road section), tunnel section and cut slope section to compare corresponding characteristics.

3. ANALYSIS RESULTS

In order to analyse the RST characteristics along each road section, the following analysis was conducted.

(a) Comparison of measured air temperature with Automated Weather Station(AWS) from Meteorological Agency

(b) Comparison of RST for each road section

3.1. Comparison of measured air temperature with AWS

Since the weather forecast data is a representative value for certain area, the air temperatures from meteorological agencies are not consistent with the air temperatures in the road network above. In Korea, the highest resolution weather forecast (smallest weather area) is Digital forecast (Dong-Nae forecast) which covers 5kmX5km area. In order to compare the measured air temperature from the thermal mapping system to the air temperature from AWS, nearest AWS air temperatures were collected. As the air temperature from each AWS was assumed to cover 5kmX5km area, only the air temperature data of road within a radius of 5km from AWS was selected.

As the 13-AWSs were available in the surveyed road of this study, the averages of measured air temperatures and observed air temperature of AWS were compared, representing the results in Table 2.

TABLE 2.Comparison of Average Measured and Observed Air Temperature

No.	length of road(km)	Average Measured Air Temp. (A)	Observed Air Temp. of AWS (B)	(A)-(B)
1	8.4	2.6	0.7	1.9
2	7.9	2.7	1.6	1.1
4	10.3	2.7	1.4	1.3
5	10.3	2.7	0.6	2.1
6	10.8	2.0	-0.6	2.6
7	9.1	2.0	0.2	1.8
8	9.8	2.0	-0.1	2.1
9	3.1	1.9	0.5	1.4
10	10.3	2.1	0.5	1.6
11	2.9	1.8	1.5	0.3
12	4.9	1.7	-1.3	3.0
13	10.5	1.1	-0.6	1.7
14	9	1.2	-0.1	1.3

Table 2 shows that the measured air temperatures from thermal mapping are higher than the observed air temperatures. Generally the AWS is installed at open space or mountainous area and its area usually shows lower air temperature compared to other area. Moreover the air temperatures in road sections are higher than in soil sections because the pavement contains solar heat during daytime. The results in Table 2 also indicate that the measured air temperatures (i.e. road pavement area) are higher than the observed air temperatures of AWS (i.e. soil).

3.2. Comparison of RST for each road section

As mentioned above, the road section was divided into a normal, bridge (overpass), tunnel and cut slope section to compare the RST for each road section. The basic statistics such as average RST and air temperature for each section were compared and the results are shown in Table 3.

TABLE 3. Comparison of Average RST and Air Temperature

Classification	length(km)	Ave. RST	Ave. Air Tem.	Ave. of RST-Air Tem.
Normal	135	1.94	1.87	0.08
Bridge	20	1.55	1.88	-0.33
Cut slope	43	1.45	1.82	-0.37
Tunnel	15	2.41	1.28	1.13
Total	213			

From the comparison of average air temperatures as shown in Table 3, it was shown that the values of average air temperature for all road sections were almost similar except for the tunnel sections. However, with average RST being different, the average RST in bridge and cut slope road sections were lower than in normal and tunnel sections. Considering the difference between the average RST and air temperature, although RST of normal and tunnel sections were higher than air temperature, the RST of bridge and cut slope road sections were lower than air temperature, which means that the RST on normal paved road is higher than air temperature during night time. However the RST on bridge or cut slope section is relatively low compared to the value on normal paved road section because of less geothermal on bridge and less solar radiation on cut slope section due to shady areas during daytime.

Once the average RST for each road section was compared, an ANOVA test was conducted to identify the significant difference among each road section. The TukeyHSD, Duncan and Scheffe test were used for the ANOVA test. The results of ANOVA test on the RST of each road section are shown in Table 4.

TABLE 4. Results of ANOVA test of RST for Each Road Section

	classification	N	significant error = 0.05			
			Normal	Bridge	Tunnel	Cut Slope
Tukey HSD	Cut slope	3560	1.446			
	Bridge	1678		1.552		
	Normal	11266			1.935	
	Tunnel	1283				2.412
	Significant Error		1.000	1.000	.151	1.000
Duncan	Cut slope	3560	1.446			
	Bridge	1678		1.552		
	Normal	11266			1.935	
	Tunnel	1283				
	Significant Error		1.000	1.000	1.000	1.000
Scheffe	Cut slope	3560	1.446			
	Bridge	1678	1.552			
	Normal	11266		1.935		
	Tunnel	1283			2.412	
	Significant Error		.064	.268	1.000	

It is shown from Table 4 that the RST for each road section has significant difference and each of the normal, bridge, cut slope and tunnel road section has its own characteristics of surface temperature. Also, in Table 3, the RST in the bridge and cut slope road sections showed lower compared to the values in normal road section, which means that much attention is required in the bridge and cut slope road sections for road maintenance in winter.

4. CONCLUSIONS AND FURTHER STUDY

In this study, a thermal mapping system was developed and applied to the real-world roads to generate thermal map and analyse the difference of RST for road sectional characteristics such as normal paved road, bridge, cut slope road section. After the RST, air temperature and air humidity were acquired from the thermal mapping system, the RST for each road section was compared.
In conclusion, even though the RST was usually higher than air temperature in normal paved road sections, the RST was lower than in bridge and cut slope sections due to insufficient geothermal on bridge and solar radiation on cut slope. Also, the RST in bridge and cut slope showed relatively lower values compared to the values in normal paved roads and tunnel sections.

In this study, only one surveyed thermal mapping data was analysed. However if the thermal mapping system travels several times for certain road section and the acquired data accumulates, the RST for certain road section by the characteristics, such as normal paved road, bridge and cut slope road section, could be predicted

ACKNOWLEDGEMENT
This research was supported by a grant from an Inner research program titled “Study on the enhancement and result diffusion of road survey equipment for road information collection” funded by Korea Institute of Construction Technology,

REFERENCES

1. Korea Institute of Construction Technology(2010.12), “Study on RWIS Construction Plan of Expressway in Korea” final report
2. Muncy, S. G. (1993). Cold in-place recycling practices in North America. 5thEurobitume congress. Vol 1B, paper 4.39, pp 886-889
3. Naoto Takahashi, Roberto A. Tokunaga, Motoki Asano, Nobuyoshi Ishikawa(2008.5), R, Development and Operation of the Winter Maintenance Support System, SIRWEC, pp.1-11
4. Naoto Takahashi, Roberto A. Tokunaga, Motoki Asano and Nobuyoshi Ishikawa(2006.1) Toward Strategic Snow and Ice Control on Roads: Developing a Method for Surface-Icing Forecast with Applying a Heat Balance Model, TRB 85th annual meeting, No.06-2067, CD-ROM
5. Torbjörn Gustavsson. (1999) Thermal mapping – a technique for road climatological studies, Meteorol. Appl. 6, pp. 385-394
6. http://www.its.dot.gov/clarus/
7. http://www.ops.fhwa.dot.gov/weather/index.asp