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Use of Road Weather Information System (RWIS) as Assistive Tool for Effective Winter Road Maintenance – Technical and Contractual Interactions

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ABSTRACT

Winter highway operation and maintenance in the northern periphery is a challenge, a broad and complex area. Understanding about this area and its effect on winter traffic performance is far from complete. During the last forty years since Swedish Transport Administration (former Swedish National Road Administration) began attempting of the use of Road Weather Information System - RWIS on the Swedish road network, the repair and maintenance methods of this assistive tool has dramatically changed. Changing of the methods have been due to the progress and development of the technology within this area i.e. from simple stations that could be connected via telephone network for icy road warning to a more sophisticated and modern internet based technology. The main objective of this study was to investigate and find the importance and effectiveness of using weather data collected from RWIS by road agencies as an assistive tool for effective performance of winter road maintenance, and how these tools are currently maintained without influencing the delay of winter road maintenance. The study also attempts to find possible interactions between technical and contractual issues that may affect winter road maintenance. The method of the study was partly based on a theoretical study by reviewing some internationally published articles and reports in this area and furthermore a domestic questionnaire survey, an international benchmarking and a follow-up study within a selected region in Sweden. The results of the study reveal that even if the weather stations are normally placed on roads where the risk of icy roads is greatest, there are indirect factors which influence the planned maintenance of these tools which subsequenly cause delay of winter road maintenance.

Keywords: *RWIS, Winter road maintenance, Winter maintenance tools, Contract, Road maintenance contract, RWIS Maintenance*

1. INTRODUCTION

In many countries, winter conditions cause disruption of road traffic. The magnitude of this varies with geographical location, altitude and other climatologic factors, such as whether the climate is inland or maritime [9]. The winter maintenance of roads is strongly influenced by climate conditions and topography. In addition to these natural considerations, road managers also need to take into account the general preparedness of road users to deal with difficult weather driving conditions when drawing up their winter plan [12].

Winter operation of the roads is a task that involves seemingly simple tasks and duties. This includes moving the snow, which impedes the traffic and to ensure that there is no slipperiness.

Road users expect that the entire road network must be accessible, feasible and safe even in the winter. One of the difficulties of winter operation of traffic surfaces is that weather predictions for the coming winter season are difficult to make. Those who are responsible for winter operation must have good knowledge about how different weather conditions can cause traffic problems [9]. In this context, the term *Road Weather Information System (RWIS)* which is based on meteorological stations installed on roads, is usually used to describe a system of sensors connected together to provide real time, accurate and site-specific road surface conditions and weather data [6].

According to Zwahlen *et al*, (2007) RWIS are essentially weather stations that are located adjacent to the roads at selected locations that report the usual weather data.

Weather stations are thus a number of various types of sensors that make it possible to obtain information on e.g. road surface temperature, air temperature, air humidity, type and amount of precipitation and wind direction and speed [14].

RWIS is thus a basic tool and source in planning and performance of winter road maintenance. It is also important to realize that RWIS is only an assistive system in order to make the right decisions at the right time for

efficient winter maintenance. Appropriate use of weather data, collected from weather stations contribute to more effective winter road maintenance. It also creates conditions for a positive development of traffic in the transport system and keeps operation and maintenance costs at a reasonable level in winter. Performing winter maintenance tasks with high quality depends on just-in-time repair and maintenance of the system. On time maintenance of the system in addition contributes to reducing car accidents during winter and a lot of money will be saved through more effective organisation of road maintenance.

The primary objectives of this study are to investigate and find the importance and effectiveness of using weather data collected from RWIS for winter road maintenance as an assistive technology. The study aims further to find out whether the road and transport administrations take the active use of weather data collected by these tools in consideration in their current winter maintenance contract as an important issue or not. Finding the way the clients demand, encourage or recommend the contractors using the data from RWIS in their maintenance planning is another purpose of the study. The study also aims to investigate and identify the way these tools are repaired and maintained by the road administrations and agencies. The purpose of the study is further to identify factors that affect Just-in-time maintenance of these tools which subsequently influence winter road maintenance and traffic disruptions and delays as a consequence. The study finally attempts to find possible interactions between technical and contractual issues that may affect winter road maintenance.

This study is based on four individual investigations connected to RWIS i.e. a literature survey, a case study, a questionnaire survey across Sweden and an international benchmarking by sending an electronic questionnaire to some Road Administrations in the countries that have almost similar winter road conditions as Sweden.

The study was conducted by a literature review by searching in different databases to locate literature from a variety of fields of inquiry. The keywords RWIS, winter road maintenance, maintenance of RWIS, and winter maintenance tools were used to search for the most appropriate subject noun in the databases.

Through combination of the keywords the search process generated many possible references. Although the literature search resulted in many hits, but criteria for selection of literature was that those would be published between 2000 and 2012, describe the methods which are currently used and describe methods which are based on experiences from the use of RWIS in winter road maintenance. After a perusal of the abstracts, it was found that there were a few references that were in the criteria for selection. These were then included in this study. Additional materials were also collected from Swedish Transport Administration (STA), other Swedish authorities, and a number of municipalities concerning their current technical and contractual materials which dealt with RWIS.

After completing the literature review of previous investigations and identifying the technical and contractual issues concerning RWIS, an electronic questionnaire survey was performed nationwide to gain insights into the Swedish authorities' and contracting companies' experiences in this field.

The survey was followed by an observation survey within a selected region in Sweden a so-called case study.

The final phase of the study was to perform an international benchmarking in order to gain international insights into other countries' experiences on RWIS.

2. TECHNICAL ASPECTS IN SITING OF RWIS

Weather stations are generally located along a road network after a careful climate/thermal mapping i.e. they are located in places vid risk for early slippery conditions. Proper siting is essential if the weather station is to provide the data necessary to estimate weather data in a consistent and reliable manner [5]. Siting of weather stations can vary from neutral locations in open flat areas to extreme environments in road cuttings. In addition to thermal mapping, knowledge of the regional climate and experiences of local maintenance personnel are also used as a common method [7].

The observations at each weather station are also affected by local surroundings [7] i.e. a station hidden from view behind an obstacle will not accurately represent the weather data thus they should be isolated from large obstacles [5].

According to White *et al*, (2006) a poorly selected place can result in incorrect output, service difficulties or even damage from passing traffic.

According to the results of a field study performed by Gustavsson *et al*, (2002), the locations of weather stations and sensors are such factors that influence the quality of temperature measurements. Thus it is necessary to take the importance of these factors into consideration when installing weather stations in order to give winter road maintenance staff accurate weather data.

Sensors installed in weather stations frequently have an in-built test function to alert the users that a problem has arisen [21], but some function errors are not detected and registered by the system e.g. humidity sensor shows 100% humidity when it is 60% in reality or a temperature sensor shows +10 C˚ when it is -3 C˚ in reality. The system only

detects errors when the sensors do not provide any measurement value at all.

3. RWIS MAINTENANCE ASPECTS

A weather station, like any other piece of equipment, requires regular maintenance if it is to perform its assigned task correctly. Some of the more important maintenance chores can and should be performed by local maintenance personnel since they have access to the station on a regular basis. Local maintenance personnel can help keep the weather stations functioning by performing some simple routine maintenance chores. The power supply of the weather station may also require some routine maintenance. A rechargeable battery can be supplied serving as a backup when the power supply fails. Technical maintenance should be performed anytime the routine maintenance reveals a problem. Technical maintenance is an essential aspect of operating a weather station. The use of weather stations represents a significant advance in the field of winter road maintenance management. To obtain the best and most reliable results from a weather station, the station must be properly sited and properly maintained [5].

4. USE OF RWIS IN SWEDEN

Sweden as a Nordic Country with its special climate has very tough winters. During the winter, road conditions may vary completely between different regions and from snow to ice, slush, wet or dry pavement across the country. According to a Swedish definition winter road condition is when there is ice, snow, slush or frost on any part of the road.

In 1972, STA (former Swedish National Road Administration, SNRA) started installing and using simple weather stations on the Swedish road network as a warning system for icy roads. This was the beginning of the current modern Swedish road weather information system [4]. In 2007, the system comprised 720 field stations but during the recent years the 60 more field stations have been installed within Swedish road network. Since February 2012 the system comprised approximately 780 field stations and more than 200 road cameras for purpose of monitoring road conditions during winter. The system has approximately 1000 users and even more. The system provides an early warning signal when conditions become critical. The information is given in real time, which enables road managers to take action before the first icy spots have even been formed [13]. The system works in such a way that the data from the 780 field stations, three satellites and twenty one weather radar stations are processed in a central computer. This input is also processed in prognosis models that present road surface temperatures forecasts.

Weather prognoses are updated and will be sent by Swedish Metrological and Hydrological Institute (SMHI). All information is processed and transmitted to all system users through the regular network. The task of these approximately 780 weather stations located along the Swedish road network are to collect weather information and distribute to users via a central computing environment for the collection and presentation of the weather situation. Users are mainly operating contractors in charge of winter maintenance i.e. responsible winter road maintenance contractors receive the real time data as help in planning their actions. The earlier contractors know the type of required measure then the more accesible and safer road for road users. The information is not only used for road maintenance but also it is used for traffic information, tracking costs for winter operations, surfacing, research and development (STA, 2012). Figure 1 shows the Swedish RWIS map.

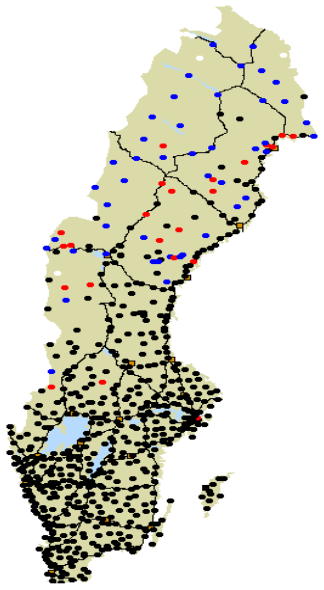

Figure 1. Density and location of RWIS network in Sweden (Source: STA)

5. USE OF RWIS WORLDWIDE

Today RWIS is commonly used in several countries in Europe and North America.

According to Laurinavicius *et al*, (2011) the number of installed weather stations in different countries depends on some basic factors such as financial situation, road network density, traffic volume and the density of population in the concerned countries. The system is developed and expanded regularly depending on the expansion of the road network in each country.

In 2002, the U.S. Federal Highway Administration published a so-called RWIS standard that described three categories of standards being considered for RWIS applications. These standards were; siting standards,

calibration standards, and communication standards. The term "standard" used in the publication was in order to simplify the presentation of the material that referred to guidelines, recommended procedures, protocols, and other practices that formalized some of the processes involved in deploying and maintaining RWIS sensors.

The U.S. Department Of Transportations (DOT) encouraged road agencies to use the above named standards as a starting point to learn about RWIS standards and to consider how they might use these standards to reinforce their own RWIS operations. Today, the use of this system is the current practice in several states in USA, the Baltic countries and in countries like Australia, Denmark, Finland, Germany, Japan, Norway, the Netherlands, New Zeeland and the United Kingdom.

Lithuania started using RWIS as late as 1999 by installing 20 weather stations across its road network [10]. The importance and effectiveness of using RWIS in winter road maintenance can be realized when it is seen that Lithuania as one of the youngest countries in the northern periphery has rapidly developed its road weather information system from 20 to 88 weather stations (current number of weather stations was obtained after request from Lithuanian Road Administration in June 2012).

After several years of using RWIS as an effective tool for winter road maintenance and realizing the importance of the system in early planning of the winter actions by several road/transport administrations and agencies around the world, they experienced that

- the system has had a large cost benefit because the action can be applied before the occurrence of serious traffic accidents or disasters
- the system has been stable enough because of the high percentage of availability to measurement data
- the system gives the ability to be proactive, which means that contractors can be warned before the weather changes
- the system gives the ability to automatic output data to variable speed signs which has the added benefit that drivers/motorists accept variable speed signs more readily than regular speed signs
- The meteorological offices can get input for their predictions

The use of RWIS as an important assistive technology can also provide decision support to road administrations, road agencies and contractors. It can also contribute to weather forecasts that are more accurate.

6. DOMESTIC INVESTIGATION

6.1 Questionnaire Survey in Sweden

During the last 20 years the winter operation and maintenance of the Swedish road network has been performed by public procurement and contracting through competitive bidding.

In 2010, in order to find out how the contracts were designed and how satisfied the parties had been with the contracts, a comprehensive electronic questionnaire survey was performed. An individual section of the survey dealt with RWIS. The main purpose of the RWIS-survey was to find out if the importance of an active use of weather data from RWIS was specified in the current winter maintenance contract and further how the Swedish weather stations were repaired and maintained on a contractual basis and possible technical and contractual improvement of the system. A number of clients and contractors across Sweden, within five geographic regions i.e. northern, middle, eastern, western and southern regions who had been working with winter maintenance issues were selected to respond questions concerning RWIS. This section of the survey consisted of six questions with multiple answers. All the selected companies which were both public and private had activities in winter road operation and maintenance. 41 persons from 18 Swedish companies were selected and received the questionnaire. The selected persons were both experienced and involved in the winter road maintenance in several cities within the respective regions across Sweden.

6.2 Data Collection, Response Rate and Analysis

The time between sending the questionnaire and the response was estimated to be two weeks i.e. between 27th of May and 10th of June 2010. After the deadline, the questionnaire was responded by only 23 participants. The response time was extended in an additional week by sending a reminder to those who had missed or forgotten the deadline of the survey i.e. two weeks after the circular. There was no further response after the second round. Each person in the survey had received an identifying code to ensure participants' anonymity and to address the survey completely confidential. Data collection was also performed electronically. All the received responses were saved automatically for later analysis i.e. after the second deadline. After the second deadline, the analysis of all responses was conducted by using a software program.

- Number of sent questionnaires 41 (100%)
- Rate of responses 23 (56%)

The following table shows how the respondents were distributed between the main groups.

Table 1. Response rate

Organisations	Sent	Response	Response (%)
State authorities	23	12	52.2
Private sector	12	8	34.8
County councils	2	2	8.7
Municipalities	4	1	4.3
Total	**41**	**23**	**100**

6.3 Selected Results

When asking if the respondents were familiar with the RWIS as an assistive tool for collecting weather data, a clear majority of the respondents (84.2%) were aware of the RWIS i.e. the majority of the respondents recognised it as a concept, as figure 2 shows.

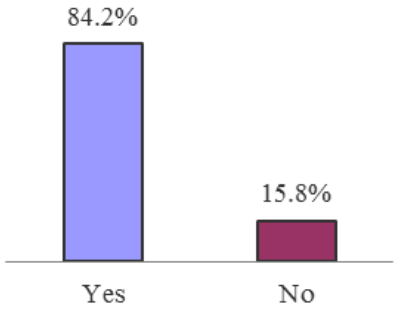

Figure 2. Awareness of the participants with RWIS

Possible specification or recommendation of an active use of weather data collected from web-based weather stations by the current maintenance contract was asked.

As figure 3 shows, although most of the contracts specified and recommended an active use of weather data collected from web-based weather stations (68.4%) across Sweden, there were even some contracts which did not mention it at all, that the use of such these data was an asset in winter road maintenance (26.3%) and the rest of the respondents did not know if there were such these recommendations or specifications in the current winter maintenance contract or not.

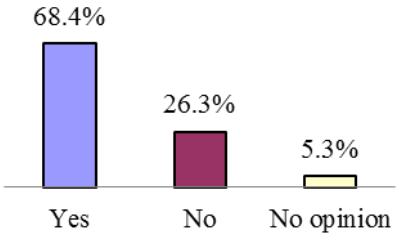

Figure 3. Use of weather data from RWIS specified in the current maintenance contract

Concerning, if the participants had any knowledge about *the number of* the installed weather stations in their geographic regions, more than half of those who worked with winter maintenance were not aware of *the number of* weather stations within their geographic regions (52.6%). Only 42.1% knew about the number of RWIS and 5.3% had no idea about it even they work with this issue according to figure 4.

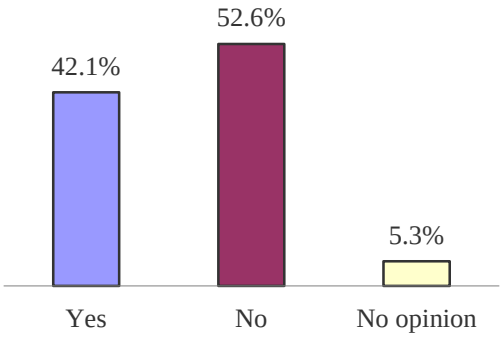

Figure 4. Respondents´ knowledge about the number of regionally installed weather stations

Every respondent left different number which was clearly uncertain and differed from each other as the table 2 shows.

Table 2. Respond to the number of RWIS given by both clients and Contractors

Region	Client (*no.*)	Contractor (*no.*)
Eastern	100	3
		4
		12
		9
Western	No opinion	No opinion
Northern	108	No opinion
Southern	55	No opinion
Middle	80	No opinion

By responding to the question if the winter operation managers believed that the weather stations could provide sufficient information for preparedness and stand by operation, as figure 5 shows, only 33.3% believed that the weather stations could provide sufficient information for preparedness work and about 33.3% had no opinion if RWIS could give enough information. The people who experienced that RWIS did not give such information for preparedness work (33.3%) stated that RWIS were only a little part of the information system. Both the clients and contractors had access to weather radar and weather forecasts from Swedish Meteorological and Hydrological Institute (SMHI) otherwise they could not manage to perform the winter maintenance of Swedish road network.

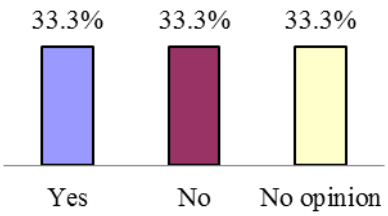

Figure 5. Response rate to sufficiency of the outcome of the weather stations

Some operational staff claimed in this connection that they had to complement the weather data from the weather stations by consultation of contracted meteorologists and using own experience, assessment and judgment because the outcome of the weather stations did not match the reality.

Concerning the need of additional weather stations to be installed (figure 6) in the regions, 16.7% of the operational staff believed that it was needed to install additional weather stations in their regions because of the insufficient results from weather stations.

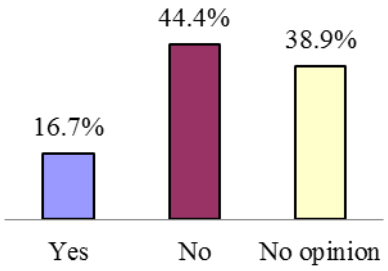

Figure 6. Response to more RWIS to be installed

Concerning the way that the system was being repaired and maintained i.e. if the current winter maintenance contract covered the repair and maintenance of RWIS, all the participants responded that repair and maintenance of RWIS was performed by an own contract apart from their current performance contract and by other contractors.

7. REPAIR AND MAINTENANCE OF RWIS IN SWEDEN

When in July 2010, the results of the domestic questionnaire survey identified that the repair and maintenance of the meteorological stations would be performed by another contract apart from the current road maintenance contract, in order to find out if repair and maintenance of the system was performed according to the contract or not and further identify possible obstacles for maintaining these tools that contractors may meet on the field, an observation study, a so-called follow-up study was planned.

As STA has divided Sweden in six main regions, and approximately 120 meteorological stations are located in the STA´s eastern region which is almost a high density in relation to the size of the region, then this region was selected for observation and follow-up during winter season 2010-2011.

7.1 Follow-up Study

As the winter period in Sweden in average begins 1th of October and ends 30th of April, the planned observation was started on October within the eastern region of the STA which covers five counties (figure 7). The reason to the selection of this region was almost a high density of inhabitants, a high traffic volume during winter season and the density of the installed weather stations. The follow-up study was accomplished in April 2011. Maintenance of the road weather stations in the eastern region included preventive and corrective maintenance of road weather equipment along the road network in the region. The main goal with the maintenance of the system was to keep a high availability to weather data from the RWIS with a minimum of 96% during October and April so that the winter road operation contractors should have access to at least 96% of the outcomes from the system. The maintenance performance procedure according to the contract was in general as described in section 7.1 and 2.

7.2 Preventive Maintenance

- The preventive maintenance of the weather stations would be performed by inspecting of them once a month during the winter on those roads which would be salted and twice during the whole winter on the other roads i.e. the roads which would not be salted
- The inspection should comprise function control of all the sensors and components and calibration of air humidity sensors
- If there was any camera installed at the measuring stations, the function of camera should be controlled and should be cleaned if necessary. Repair or replacement of components should also be performed if necessary. This should be performed after call-off by the RWIS-manager

7.3 Corrective Maintenance

- All the occurred errors were registered in a so-called *error code list*
- Every morning during winter, both the RWIS-service contractor and RWIS-manager received the error code list showing the errors that occurred on the weather stations the day before
- All the occurred errors on the stations would be eliminated according to the error code list by the RWIS-service contractor in consultation with RWIS-manager within an agreed period according to the contract, normally within 24 hours

Figure 7. The STA´s eastern region relative to the rest of Sweden

7.4 Selected Results

During the winter period 2010-2011, *nominally* the availability to the measurement data was 98.7% which had exceeded 96% availability. It meant that the functionality of the system was very high and all the inspection remarks and errors were measured and eliminated from the *error code list* but there were some indirect obstacles that influenced maintenance activities. When the service staff was in the field for monthly routine inspection and control of the RWIS, they found and realized that some weather stations were inaccessible due to inappropriate location. As figures 8.1 and 8.2 show, it was too difficult for the service personnel to get a service place near to the stations to perform routine inspection and possible maintenance activities. In such cases the contractors omitted the inspection and left the place only because of the inaccessibility to reach weather stations to perform the necessary services if needed and left the place and reported "no action" because of inaccessibility of the stations or without any comments.

In order to find out if the other regions had similar problems during winter, some RWIS-managers and winter road maintenance contractors in the northern, southern, and middle regions were contacted and were asked if there were inaccessible weather stations in their region too, and in what way such these obstacles influenced the road maintenance during winter. The personal contacts revealed that in some cases the same contractor performed both winter maintenance measures and had responsibility for repair and maintenance of RWIS according to entirely separate contracts. The study also revealed that the biggest problem the clients met was the lack of sufficient trained staff in RWIS area at the contracting companies. On the other hand the contractors that were responsible to perform both winter road measures and maintenance of weather stations claimed that the weather maps had been too complicated to interpret by maintenance personnel because of the lack of computer skills. The contractors also stated that partly the wrong location of a number of weather stations and partly inaccessibility of some other stations that had errors gave inaccurate weather data that subsequently affected the winter maintenance. As a consequence, the payment of the invoices was delayed by the client that affected the contractor´s scheduled maintenance work.

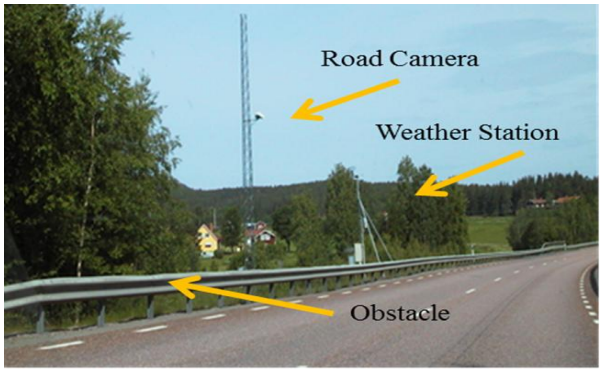

Figure 8.1 Typical obstacles around a weather station located with road 83 in Gävleborg county, Sweden (Source: STA)

Figure 8.2 Typical obstacles around a weather station located with Öresund Bridge between Sweden and Denmark (Source: MeteoGroup, www.vinterhalka.se)

8. INTERNATIONAL INVESTIGATION AND BENCHMARKING

With respect to the outcome of the domestic survey and the follow-up study, and believing that an interaction among Road Administrations in different countries, the comparison of work methods and learning from each other can contribute to improving and developing of the way to repair and maintenance of such tools in Sweden, made an international investigation and benchmarking in winter issues essential, regardless of performing the services in similar or different manner. The main objective of this international benchmarking was to focus on international experiences, to collect information from countries that have similar winter road conditions as Sweden. The aim of the study was further to investigate the current maintenance contract forms and agreements in the field of winter maintenance of roads in the other countries. Furthermore the study aimed to identify both problems and possible paths to improve the winter maintenance contracts in Sweden by comparing the results of the international investigation with the results obtained from an earlier accomplished survey in Sweden. Twelve countries which have almost similar winter road conditions were selected. The selection of the countries and the contact with the selected countries´ Road and Transport Administrations were made in cooperation with the department of international affairs at the Swedish Transport Administration (STA).

8.1 Questionnaire Survey

An electronic questionnaire that was targeted to winter maintenance contract in cold climate was designed and sent to the contact persons at the Road and Transport Administrations in the selected countries. The survey was conducted during May and July 2012. The questionnaire was distributed to the selected countries´ Road and Transport Administrations on May 19th 2012 but most of the selected countries did not respond to the questionnaire by the demanding deadline of ten days. After two reminders only seven countries responded to the questionnaire. The response rate after two reminders was 58% (7 road agencies) which was acceptable for this type of investigation. The request for information appears in the following table.

Table 3. Request for information

Countries where a questionnaire was sent	Countries that responded the questionnaire
Canada *(Ontario)*	Canada *(Ontario)*
Finland	Finland
Norway	Norway
Iceland	Iceland
Denmark	Denmark
Estonia	Estonia
Lithuania	Lithuania
Latvia	-
England	-
Austria	-
Japan	-
USA *(Washington DC)*	-

Similar to the domestic questionnaire survey, an individual section of the survey dealt with RWIS. This section of the survey consisted of three questions with open-ended answers.

8.2 Selected Results

Concerning active use of weather data from RWIS according to the current contract, four of seven respondents stated that the current contract did not specify or recommend an active use of weather data for planning of winter measures. Only Ontario Ministry of Transportation in Canada and Lithuanian Road Administration specified active use of RWIS in their contract (figure 9).

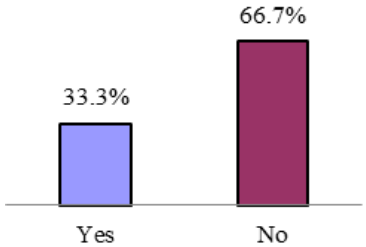

Figure 9. Response to active use of RWIS according to the contract

Concerning the number of installed weather stations in participating countries in the survey, the totally installed RWIS across the responding countries, appears in figure 10.

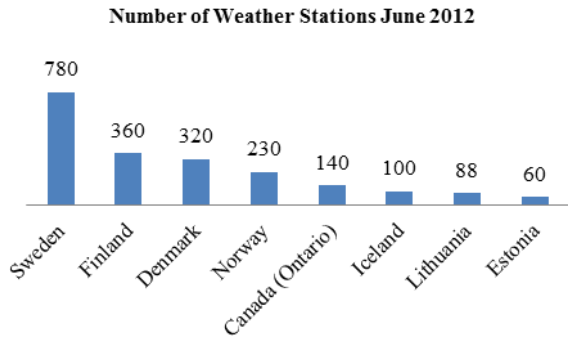

Figure 10. The number of RWIS according to the responds from the international survey in June 2012

The repair and maintenance of the RWIS has a separate contract in five of the six responding countries. Only in Finland repair and maintenance of RWIS is covered by the current maintenance contract (table 4).

Table 4. RWIS maintenance contract in selected countries

Country	Contract form
Finland	Part of current contract
Canada	Separate contract
Iceland	Separate contract
Denmark	Separate contract
Estonia	Separate contract
Lithuania	Separate contract

Only in Finland the winter road maintenance and the repair and maintenance of RWIS are performed according to a joint contract with a satisfactory result (figure 11).

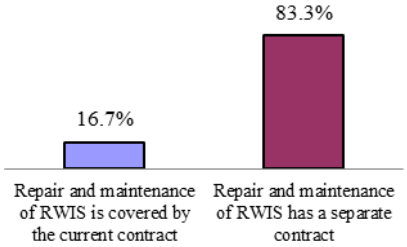

Figure 11. Response on repair and maintenance of RWIS in current contract

9. CONCLUSION AND RECOMMENDATIONS

From the study undertaken the following conclusion can be drawn. RWIS is used by most countries as a very effective tool during the winter. During recent years, the system has been developed into an important assistive tool in winter highway maintenance, where it can be useful in predicting when and where it will be slippery. Although most of the contracts specify and recommend an active use of weather data collected from weather stations, the study shows that not only in Sweden but also in the other participating countries in the survey, there are even some contracts which do not mention it at all.

The study also shows that more than half of those who work with winter maintenance in Sweden are not aware of the number of weather stations within their geographic region. The study shows further, information from weather stations is not sufficient and operational staff complements the information from the weather stations with information from other sources like contracted meteorologists. In addition, they use their own experiences, assessment and judgment because the outcome of the weather stations does not match reality and the number of weather stations is not enough with respect to the size of the country and improperly sited of some weather stations. Although both the contractors and clients were working with winter road maintenance issues, they should have known the number of RWIS within their own geographical region, because the operating contractors have to use weather data for planning of winter measures.

As mentioned in the introductory sections of the article, there are 780 installed RWIS in Sweden and STA has officially published the number of the weather stations and all the contractors have access to them. Generally, the weather stations are placed on roads where the risk of icy roads is greatest i.e. RWIS are located where the optimum weather data can be obtained. According to the result of the observations in the eastern region there are some stations that are inaccesible due to practical obstacles and wrong locations. The obstacles limit the maintenance performance specially when the service should be performed during the winter in the cold weather that subsequently influence winter road maintenance and increase maintenance costs. The study also reveals that the payment for performed work is often delayed i.e. the client pays the invoice for performed work almost late which affects continous maintenace work.

When service staff is not able to inspect a number of meteorological stations because of the inaccessibility to reach the stations, it will be difficult to know which one of the stations is out of order or which component needs to be replaced. An out of service station with functional errors directly influences the accuracy of the outcomes by the system even if the minium rate of accessibility to the weather data must be 96% as a goal e.g. the outcomes of 100 stations is the same as 120 stations when 20 of them are out of function. It means that because of the already high comlexity of the system, the accuracy of the outcome will be questionable when one of them is out of servic.
The study preliminary suggests some pointers to improvment of the system both technically and contractually.

- Number of RWIS stations should be increased, and some of those that are improperly located should be moved. Correct location of the stations contributes to more preventive maintenance than corrective maintenance that subsequently contributes to efficient winter maintenance and keeps maintenance costs in a reasonable level.

- The complexity of the monitored weather maps should be reduced to a simpler version in order to create a better work environment to the service personnel with less computer skills.

- The interval for maintenance of the RWIS should be reduced during winter season so that the accuracy of the weather data will be more reliable for operational staff

- Because some errors are not detected and regestered by the system on the error code list, therefore it is important that users notify RWIS-managers as soon as possible when such errors are met by the contractors while using the system. This will be possible only through a close cooperation between the clients and contractors

- A structured approach should be established between RWIS organizations and users of the system

- Conditions for a joint contract for both winter road maintenance and repair and maintenance of RWIS need to be investigated and tested as a pilot-test in a region somewhere in Sweden and then the results of the pilot-test will be analyzed and evaluated, if the modell will be applicable or not

- An improved collaboration modell, a so-called partnering in the contract between client and contractor shuold be developed and tested in order to find out if there are any advantages and/or disadvantages with partnering in contract.

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REFERENCES

[1] Abdi, A. (2012a). Winter Road Maintenance on Contractual Basis: an International Benchmarking, manuscript for research report, Royal Institute of Technology – KTH, Stockholm, Sweden.

[2] Abdi, A. (2011). Technical and Contractual Aspects in Winter Highway and Railway Operation and Maintenance: a Survey of Current Technical Systems and Contract Forms in Sweden, Licentiate thesis, Royal Institute of Technology – KTH, Stockholm, Sweden.

[3] Aurora program, (1998). Review of the Institutional Issues relating to Road Weather Information System (RWIS), final report, Eagan, Minnesota, USA.

[4] Axelson L. (2000). Development and Use of Swedish Road Weather Information System, Swedish National Road Administration, Borlänge, Sweden.

[5] Brown, P., Russell, B. (2009/2010). Siting and Maintenance of Weather Stations, Arizona cooperative extension & the University of Arizona, College of Agriculture and Life Sciences, Tucson, Arizona, USA.

[6] Canadian Strategic Highway Research Program [C-SHRP] (2000). Anti-icing and RWIS technology in Canada, C-SHRP technical brief # 20, Canada.

[7] Eriksson, M., Norrman, J. (2001). Analysis of station locations in a road weather information system, International Journal of Climatology, Meteorol. Appl. 8, 437-448 (2001).

[8] Gustavsson, T. Borgen, J. (2002). Measurement of Road Climatological Variables, University of Gothenburg, Gothenburg, Sweden.

[9] Johansson, A. (2000). Winter Operation: Roads, Streets, Railways and Airfields, Chalmers University of Technology, Gothenburg, Sweden.

[10] Laurinavicius, A., Jukneviciute-Zilinskiene, L. (2011). Eleven years of RWIS operation in Lithuania: possibilities for the use of data collected, Vilnius Technical University, Vilnius, Lithuania.

[11] Ljungberg, M. (2002). Expert system for preventive salting operations on winter roads, licentiate thesis, Royal Institute of Technology – KTH, Stockholm, Sweden.

[12] Norem, H. (2001). Winter Maintenance Practice in the Northern Periphery, RODEX SUB PROJECT B PHASE I, Trondheim, Norway.

[13] Swedish National Road Administration's education centre, (2009). Basic Training in RWIS, Course Document, Borlänge, Sweden.

[14] Swedish National Road Administration's education centre, (2009) Fundamental of Winter Road Maintenance, Revised Course Document, Uppsala, Sweden.

[15] Swedish National Road Administration, (2006). General Description of RWIS, Borlänge, Sweden.

[16] Swedish National Road Administration, (2007). Road Weather Information System, Borlänge, Sweden.

[17] Swedish Transport Administration, (2011). Road Weather Information Systems, order no. 100353, Borlänge, Sweden.

[18] Swedish Transport Administration, (2010). The Road to Excellence: an International Benchmarking Project between National Road Administrations, Borlänge, Sweden.

[19] U.S. Department of Transportation, (2002). An Introduction to Standards for Road Weather Information Systems (RWIS), Washington, USA.

[20] Venäläinen, A., Kangas, M. (2003). Estimation of Winter Road Maintenance Costs Using Climate Data, International journal of climatology, Meteorol. Appl. 10, 69-73 (2003).

[21] White, S. P., Thornes, J. E., Chapman, L. (2006). A Guide to Road Weather Information Systems, version 2, University of Birmingham, UK.

[22] World Road Association – PIARC Technical Committee 3.4 Winter Maintenance, (2006). Snow and Ice Data book, edition 2006.

[23] Zwahlen, H. T., Mitchell, G. F., Russ, A. (2007). Evaluating RWIS and Brine Pretreatment for Snow and Ice Removal, Government Engineering, USA.

