Strategies for Ensuring Optimal Guidance in Decision Support Systems for Winter Maintenance Operations

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ABSTRACT

Maximizing roadway safety, mobility and efficiency, while minimizing maintenance-related costs, is the common goal of winter maintenance engineers around the globe. The ability to achieve this goal is fundamentally grounded in the decision-making process carried out by such engineers. The inability to make accurate decisions in an effective, efficient manner can result in less than desirable roadway level of service and in some cases, the loss of life. This paper discusses the concept of a decision support system for winter maintenance operations, a concept that has been gaining increasingly widespread support as a way to address the difficulties associated with the winter maintenance decision-making process. Moreover, some of the challenges associated with providing accurate guidance are discussed.

A winter maintenance decision support system, in the context of this discussion, is an interactive, automated system. It should be capable of providing winter maintenance personnel with objective guidance regarding options on how to treat networks and routes, especially when hazardous road weather conditions are imminent or exist. The system automates the procedure of obtaining, synthesizing, and applying road weather data and information in the decision-making process. Guidance provided by the system can include information regarding treatment timing, rate, location, and type. Optionally, an end user can interact with the system to ascertain the consequences of action or inaction.

Although decision support applications have shown some success, it is clear that not all systems will fully capture the potential of the concept. There are essential elements and aspects that should be considered, some of which are discussed herein. Of particular importance is the need to properly assess and predict the road weather conditions along corridors of interest. A comprehensive decision support system will not solve all of the challenges related to winter road weather management. However, it has the capacity to enable winter maintenance engineers to make consistently better decisions regarding how to plan for and respond to adverse road weather conditions during the winter season.

Keywords: weather, winter maintenance, Decision Support System, road weather.

1. INTRODUCTION

Technological advancements have resulted in the proliferation of highly advanced strategies for collecting, transmitting, and communicating data and information. These innovations have propelled the majority of transportation sectors forward in terms of facilitating improved operational decision making. It is generally recognized that better decisions translate into improved operations, with the potential to reduce costs and increase safety and mobility. However, some have argued that the amounts of data and information that are the result of technological advancements, while beneficial at many levels, may in fact jeopardize some decision makers' ability to effectively arrive at critical decisions that directly impact operations. The basis of this claim is grounded in the notion that decision makers can easily become mired in the process of analyzing and interpreting data in an effort to glean what is most important. One segment where this is clearly a concern is the winter maintenance segment of the roadway transportation sector.

Winter maintenance activities account for considerable operational costs and can have significant implications on road network safety. Winter maintenance engineers' decisions are directly linked to their ability to garner an understanding of the current road weather conditions throughout a network and how these conditions will change over time. Over the last two decades, the winter maintenance community has experienced an onslaught of data, information, tools, and procedures designed to make the process of addressing adverse winter weather conditions easier. Novel road weather instrumentation, enhanced forecast models, high resolution cameras, radars, satellites, and semi-mobile and mobile platforms have all contributed to the arsenal of data and information that winter maintenance engineers have to assess and predict the state of the roadway. Although the availability of ample observation and forecast data have aided engineers, the process of making critical decisions concerning road treatment (timing, types, rates, and location) continues to be taxing.

Other aspects that can be stumbling blocks in the winter maintenance decision making process are the collection and interpretation of meteorological data. The expanded number of datasets available to the winter maintenance community has elevated the need for key decision makers to increase their capacity to analyze and properly decipher disparate weather and road condition data. Some in the community have meteorological training and are skilled in analyzing and applying road weather data and information to operations; however, the majority of maintenance engineers have little or no meteorological training, and the process of evaluating large amounts of road weather data can be daunting. In extreme cases, data misinterpretation can lead to poor decisions, reducing roadway level of service and jeopardizing the safety of the traveling public.

In recent years, the concept of decision support systems has been gaining traction as a viable means of providing assistance to winter maintenance personnel regarding how to treat roadways prior to and during adverse weather. A decision support system, if properly designed, can provide several advantages including the ability to process a large number of data inputs, regardless of their complexity. While the idea of a decision support system can take on multiple meanings, this discussion defines a decision support system as an information system that uses dynamic and static inputs, decision models, and human experience in an interactive modeling process to produce objective, repeatable guidance. In the case of winter maintenance operations, such a system delivers recommendations regarding roadway treatment strategies under disparate weather and road conditions.

The United States Federal Highway Administration (FHWA) introduced a prototype decision support system for winter maintenance in 2002 in an effort to prove the concept [1]. It is safe to say that this prototype system stimulated the development and deployment of similar decision support systems by private sector companies and academic institutions in North America. What has become evident is that no two decision support systems are equal when it comes to applicability and performance, particularly as they pertain to winter maintenance operations. This paper discusses the essential components of decision support systems for winter maintenance, as well as elements that separate superior applications from those less able to deliver the desired benefits.

2. DECISION SUPPORT SYSTEM STRUCTURE

In order for a decision support system to fully meet the needs and requirements of winter maintenance engineers, it should include some fundamental components, as this will enable the system to be optimized for operations. Fig. 1 illustrates the key features that should be considered when developing and deploying a decision support system (DSS) in support of winter maintenance operations. Note that the elements outlined in the figure can also be used to construct decision support systems for other transportation sectors and modes.

The components identified in Fig. 1 are used to replicate the steps a decision maker must go through when formulating a treatment strategy, including data ingest, data processing and analysis, inference, and data and information dissemination. Within a DSS, each one of these features is critical to the success of the overall application:

1. **Data Ingest** encompasses the acquisition of data that aides in diagnosing and predicting road weather conditions. These data can be dynamic (e.g., temperature observation) or static (e.g., road composition). They may come from instruments and platforms owned and operated by a road authority or from ancillary sources.

2. **Data Processing and Analysis** includes the execution of additional routines, algorithms, or models in an attempt to gain more detail about the current and projected weather and road conditions (e.g., running a road model).

3. **The Inference Step (Decision Model)** is the point at which the understanding developed concerning the current and forecast road weather conditions is coupled with decision logic regarding winter maintenance treatment strategies to ascertain what type(s) of action, if needed, should be recommended.

4. **The Dissemination of Data and Information** is comprised of multiple delivery methods used to put vital information into the hands of the decision maker (e.g., web interfaces, handheld devices, etc.). More importantly, the process of dissemination includes how information is conveyed to the end users. In other words, the methods used to communicate highly-complex data and information in an intuitive manner in order to ensure effectiveness across a wide range of end users.

5. **Consultation** does not refer to a physical part of a DSS; it refers to a service that provides an added level of support (human interface opportunity) in connection with a DSS. For instance, an end user may want further explanation regarding the guidance being supplied by the DSS.

Fig. 1. Diagram of essential elements for a winter maintenance decision support system.

While most DSSs may contain some or all of these higher-level components, not all applications will deliver the required level of performance, as the specific approaches employed within each discrete component are what dictate a DSS's ability to meet and/or exceed the expectations of the end user. The following sections describe in more detail the required attributes that are necessary for the successful development and deployment of a winter maintenance DSS. Due to manuscript limitations, the primary focus of this discussion is on data inputs and data dissemination. In no way is this to detract from the importance of the other elements found in Fig. 1, since all are critical in the development and deployment of robust, operative winter maintenance DSS applications.

2.1. Input Data

One of the primary benefits of a DSS is its ability to serve as a single repository of data and information, with critical items being available to the end user at the click of a button. A DSS relies on both external sources and internal processes for the static and dynamic data used to drive the application. Generally speaking, these data can be classified into three different categories: observed, forecast, and authority-specific (Fig. 2). Within each of these categories, the amount, quality, and types of data can vary considerably from one DSS to the next. Moreover, how the data are used in internal DSS processing can substantially influence a DSS's capacity to provide accurate, timely information and guidance to decision makers. It is important for decision support systems to take full advantage of all available, high-quality data in order to provide optimum guidance. While the specifics surrounding how these data should be leveraged in a DSS is beyond the scope of this paper, an attempt is made to touch on some of the more salient, notable strategies and attributes.

2.1.1. Forecast Data

Even though a DSS can include a number of different inputs, it is without question that the most important datasets are the atmospheric and road condition forecasts, as these form the foundation for the treatment recommendations issued by the system. However, note that these datasets can be optimized through the use of other categorical data. In the end, a DSS is only as good as the forecasts that drive it.

Forecasts used in DSSs must be able to provide specific information along a road authority's routes of interest; they cannot be broad, ill-defined regional predictions. Furthermore, the forecasts should have sufficient lead-times to support both tactical and strategic aspects of winter maintenance operations (e.g., out to 48 or 72 hours). Finally, in order for a DSS to support round-the-clock operations, the forecasts used in a DSS should update every three hours or less. Frequent updates can benefit from recent observations and new model runs, depending on the forecast methodology employed.

The obvious choice for atmospheric forecasts is Numerical Weather Prediction (NWP) models. Mesoscale models are capable of providing forecasts at lead-times, resolutions, and update rates that benefit the winter maintenance community. Nevertheless, it is important that the forecasts originating from numerical models are tuned appropriately for use in a DSS. Typically, this tuning process is based on using real-time observations from the roadway(s) for which the forecast is being provided, which denotes the importance of having a dense, well-maintained road weather observation network. It has been shown that the inclusion of real-time observations in data assimilation schemes and post-processing techniques can significantly improve forecasts [2,3]. The importance of accurate atmospheric forecasts cannot be overstated, as these forecasts directly aid in road condition forecasts over the same period.

In terms of forecasting road conditions, one-dimensional energy and mass balance models have shown promise in DSS applications [4]. There are several open-source road models available for use by the road weather community [5,6]. Meteorological centers and private sector companies have also made investments in the development of proprietary road models. While all of these models are based on the same principles, there are inherent differences that result in differing levels of performance, and it is these performance characteristics that will impact the efficacy of a DSS. The authors make no attempt herein to suggest which specific model(s) might be best for DSS applications – accuracy should be the prime objective of any system – instead, the focus is on how a model should be applied.

As suggested above, a road model is only capable of supplying a forecast at a single point. A forecast point usually coincides with an Environmental Sensor Station (ESS), and data from this station can be used to initialize the model, a process which all models should follow to ensure forecast accuracy. ESS data can also be used in post-processing routines that are aimed at improving the output of a road model.

Single-point forecasts have been used to infer the conditions across a larger portion of roadway; however, it is recognized that this is not the most favorable practice, since the road temperatures and conditions can change considerably over short distances. In recent years, the technique of running a model at closely spaced intervals along a road has grown in popularity. This approach can also be problematic, as the majority of forecast points are not collocated with an ESS. Without proper initialization (i.e., using actual observations from an ESS), the accuracy of forecasts at non-observing sites can suffer. Although there may be some merit in this approach, used alone it does not provide the level of accuracy needed to optimize a DSS.

Thermal Mapping is a well-established technique for accurately determining the road temperatures between observing sites. A high-resolution infrared thermometer is used to assess the spatial variation of road surface temperatures under differing nighttime regimes. Once a road network has been mapped, relatively warm and cold sections of the network can be easily identified using the retrieved thermal signatures. Thermal maps can also be combined with road temperature forecasts valid at ESS sites to gain an understanding of how the road temperature throughout a network will evolve overnight. Thermal mapping does have its limitations. As a general rule, it can only be used at night, during non-precipitation situations. Regardless of these limitations, thermal mapping is a proven, highly-accurate method for diagnosing and predicting road temperatures across a network, not just at a single point along the roadway [7].

In order for a DSS to supply accurate guidance as it pertains to road forecasts, the authors recommend some combination of techniques. By fusing forecast data from multiple techniques, it is possible to generate superior forecasts suitable for a decision support system.

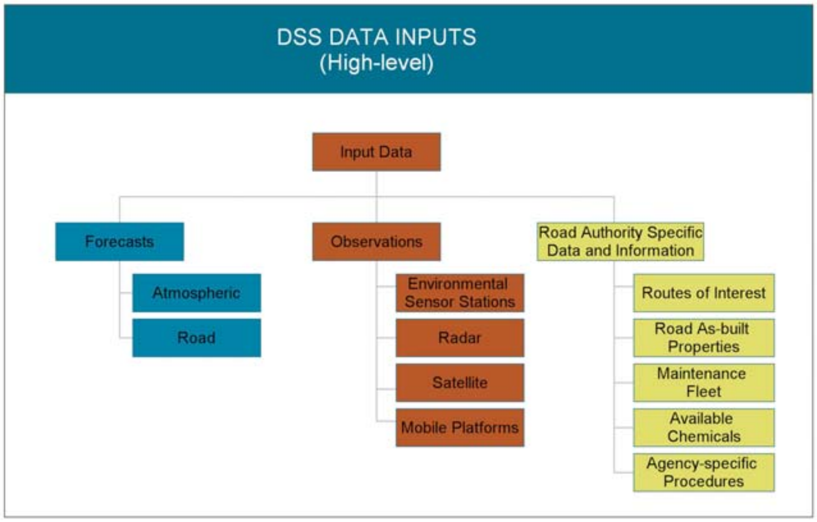

Fig. 2. Input data for a winter maintenance decision support system.

2.1.2. Environmental Observations

Observations are another cornerstone in the framework of a winter maintenance DSS. The right observations are able to provide maintenance engineers with a picture of the past and current road weather conditions. This is important in terms of knowing how to tactically respond to current and imminent adverse weather and road conditions. When observations are included in various DSS processing steps (not just visualization), the benefits of a DSS can be more fully realized. As previously noted, any attempt to provide treatment recommendation guidance without using strategically placed sensing platforms is not advised. Using real-time observations such as those from ESSs can enable accurate assessment of the roadway network, proper initialization and post-processing of weather and road forecasts, and better-quality output from supplemental DSS processing routines (e.g., event characterization). The effective use of observations will culminate in a more tailored, accurate winter maintenance DSS.

ESS platforms are undoubtedly the most important sources of real-time data for road weather DSSs. Not only do these data support more precise, timely assessments and predictions of road weather conditions, but they allow a DSS to be tuned to better meet the needs and requirements of road authorities. Most times, careful consideration is undertaken when deploying an ESS network. Accordingly, the observations from these platforms are positioned to capture traits of the road network that are of most interest to the road authority. The advent and deployment of enhanced sensing technologies (e.g., non-intrusive sensors) has led to unparalleled observations of road state, along with friction-related measurements. DSS applications designed to support winter maintenance operations should have the capacity to integrate and leverage this relatively new class of ESS observations.

By and large, a DSS will typically draw on stationary ESS platforms in an effort to provide diagnostic and prognostic weather-related information regarding a roadway network; however, the availability of observations from mobile platforms (e.g., maintenance and patrol vehicles) is on the rise. The various types of observations originating from mobile platforms are also rapidly growing. Conventional atmospheric and road condition data can be augmented by using mobile observations, increasing the ability to garner additional insight into the road weather conditions between stationary observing platforms. Recent developments in mobile surface state sensors can also play a significant part in forecast model verification along specific routes. Some mobile observations can also be used to determine the treatments that have taken place in a road network. Since this information is important in the DSS treatment recommendation process, every effort should be made to incorporate these observations in a DSS.

Fig. 2 also suggests that a DSS should include radar and satellite data. Again, these data are sources of tactical information, and they support the viewpoint of constructing a DSS to be the principal repository of data and information for winter maintenance. Radar and satellite data allow an end user to track an event and get an added sense of how their road network will be impacted in the very near-term. Products within these categories can deliver information on precipitation, type, and intensity, along with other parameters that influence road conditions (e.g., cloud cover).

The importance of data sharing between departments (e.g., maintenance, traffic management, etc.) has become a high priority in recent times. As these interdepartmental relationships grow, data sharing amongst departments will also increase. This will present additional opportunities for DSS developers and users to obtain ancillary datasets that can contribute to a winter maintenance DSS. Examples include added camera imagery, traffic flow data, accident/incident locations, road closures, etc. A DSS must be positioned to take full advantage of these new datasets.

2.1.3. Road Authority Data

In order for a DSS to make recommendations that are suitable for a road authority's winter maintenance operations, it must have some level of "understanding" concerning the authority's resources, road network, and operational practices. This aspect of a DSS speaks to the need to develop a software framework that is modular and configurable, since each road authority will have a somewhat different approach to winter maintenance operations.

When establishing the road condition forecasts points within a DSS, it is necessary to obtain information regarding the as-built properties of the roadway (i.e., road material type, thickness, etc.) for which the forecasts are being produced. It is also important to understand and account for other site-specific characteristics such as site elevation, surrounding obstructions, and the observations available at the forecast site. Identifying and including these metadata in the configuration file of the road model will help to refine the road forecasts, which are ultimately used in the treatment recommendation decision logic.

The road authority will also need to supply resource information (human and material), as this information will need to be integrated into a DSS's decision logic configuration files. For example, a DSS should be adequately configured to provide guidance that is specific to an authority's operations. To do this, the system should be set for the types and amounts of chemical used by that particular authority. Furthermore, it may also be necessary to include other data such as how long it takes to treat discrete road segments; this improves the recommendation process. In the end, the amount of data collected from a road authority is dependent on the complexity of the decision logic used within the system. Regardless, this data collection task must be a very collaborative effort between the DSS supplier and the road authority.

2.2. Supplemental Data Processing and Decision Models

The importance of obtaining and/or producing the proper data inputs for a DSS is evident from the preceding discussion, as the timeliness and quality of these data can dramatically impact the performance of the system. Nonetheless, a DSS's performance is also based in part on effectively exploiting input data through internal processes and procedures, some of which have already been touched on. These supplemental processing routines and algorithms are instrumental in constructing event timelines and characteristics, which are required in the decision model that is ultimately responsible for providing treatment guidance to the decision maker. In designing a complete DSS solution, supplemental processing can further enhance the performance and capabilities of a DSS by delivering additional data and information for use in the decision model or elsewhere in the system.

The decision model(s) used in winter maintenance DSSs can take on several forms depending on the market or particular client for which the application is intended. This reinforces the modular DSS development approach supported by the authors. One acceptable methodology is to design the logic based on industry best practices [8]. In many cases, these act as a good starting point and can be modified accordingly. Another approach is to integrate logic that captures the actual eutectic properties of chemicals used to treat roadway surfaces. By using real-time observations and forecast information, as well as previous treatment actions, the chemical effectiveness can be tracked and estimated. Once more, this points to the need for strategically distributed road weather observations and advanced road weather forecast capabilities.

Whilst treatment recommendations are at the core of a DSS, there are a number of other potential products that should be considered. For instance, a DSS can provide added benefit to winter maintenance practitioners if its overall functionality includes other items such as alerting. Alerting can cover a wide range of possibilities, with both real-time and forecast data being central inputs. Some examples that have already taken hold in the winter maintenance realm include notifications of frozen precipitation, high winds, and forecasts of below freezing road temperatures. A DSS that is flexible can be configured to include those elements and products that are of most interest to the road authority being served.

2.3. Data and Information Dissemination

The most accurate forecasts, most comprehensive set of observations, and finest treatment guidance are of no use if these data and information are not communicated to maintenance personnel in an intuitive, easily-accessible manner. It is safe to say that most DSS end users will not have an in-depth understanding of the inner workings of the application, nor will they desire this level of familiarity. What will be demanded is the ability to quickly ascertain whether their network is or will be impacted by hazardous road weather conditions and what actions need to be taken, if any. Therefore, the amount of interpretation required by an end user must be kept to a minimum, and the methods used to disseminate and convey data and information must adhere to the dimensions of usability. As demonstrated in Table 1, these dimensions can be expressed using the 5 Es [9].

Table 1. The five dimensions of usability (the 5 Es) that should be an innate part of decision support systems [9].

CHARACTERISTIC	USABILITY DESCRIPTION
Effective	A DSS should allow winter maintenance practitioners to fully achieve their goals and objectives, with an acceptable level of accuracy.
Efficient	The application should enable users to meet their goals and objectives in a timely fashion, maintaining the desired level of accuracy.
Engaging	A DSS should employ an interesting, appealing interface.
Error tolerant	A DSS should be designed in a way that errors are minimized and error recovery is supported.
Easy to learn	A DSS should promote rapid, trouble-free adoption and high-level use, but should also enable more complex analysis and investigation.

A comprehensive DSS will enable winter maintenance engineers to access the data and information most critical to their operation via a number of different means. The conventional method that applications such as DSSs currently rely on is a Graphical User Interface (GUI) that is delivered as a web application (i.e., accessed through a web browser). With the advances in technology, the methods by which to retrieve data are rapidly expanding. Within the domain of winter maintenance, road authority staff can expect to interact with a DSS when they are away from a central office or maintenance facility. Road weather information and guidance can be acquired through in-vehicle systems; furthermore, handheld devices can act as a conduit to a DSS. Each one of the above mediums can facilitate two-way interactions with a DSS — a user can receive and send information. Regardless of whether one or all of these methods are offered, the DSS and associated user interface(s) need to account for the five dimensions of usability.

In order to claim any level of success, a DSS shall be effective in supporting a winter maintenance decision maker's goal of ensuring an adequate level of service while minimizing related costs. Note that this may not be gauged solely by the treatment recommendations provided by the DSS, but it may be measured by the quantity and quality of support provided by the system as a whole. For instance, if designed appropriately, a DSS can also provide forecasts of weather and road conditions, specific alerts, and access to real-time data. The combination of all of these elements together, including treatment recommendations, will determine whether a DSS is successful in meeting the needs and requirements of the decision maker.

Efficiency is a fundamental feature of a winning DSS. A DSS that does not help to accelerate the decision-making process is less than desirable. The winter maintenance DSS concept alone, when executed correctly, will increase efficiency, as it will allow a decision maker access to a significant number of critical datasets in a single location. The efficiencies that are inherent in the DSS concept can be quickly extinguished, however, if the implementation acts to cloud a decision maker's judgment or hinder the decision process. Examples of this include a DSS that has a layout that is clunky and cumbersome, leaving the end user to unnecessarily spend time looking for much needed data or information. Moreover, a DSS that takes too long to process data can be counter productive to the decision making process. In most cases, this is the result of poor software design.

Today's technological world has cultivated a population base that demands instant gratification; likewise, users of technology expect a pleasurable experience, whether the application or device they are interacting with is for work or play. The winter maintenance community is no different. A winter maintenance DSS must be engaging. Its interface and functionality are in some sense competing with user experiences provided by mainstream entities like Google and Apple. In the end, winter maintenance engineers must have a DSS experience that will be stimulating enough that they will continue using the application.

A DSS's design should be such that it minimizes user errors. For example, the interface should essentially guide decision makers through the proper steps that will allow them to get the information they need, as well as input data required by the system. User actions that result in errors or potential errors should be easily reversible in a well-designed DSS (e.g., incorrect treatment entered into the system).

Finally, a DSS has to be easy to learn. While some initial training may be required, it should not entail days of classroom time and in-depth study of volumes of literature. Novice users should be able to realize tangible benefits in a very short period of time, but the application should also permit more seasoned users to delve deeper into the system and what it offers. This aspect of usability is the most challenging in terms of a winter maintenance DSS, since the potential users in the winter maintenance community are quite diverse in terms of their experience with and acceptance of advanced technologies.

3. SUMMARY

An attempt has been made in this paper to briefly highlight some of the more important elements of a winter maintenance decision support system. As the concept of decision support systems for winter maintenance operations continues to gain broader backing, it is important to recognize those elements of a DSS that are necessary for a high-quality system. At a top level, a winter maintenance DSS should leverage the following: accurate, timely road weather observations and forecasts, supplemental data processing, tailored decision logic, and data dissemination techniques that incorporate the five dimensions of usability. When designed properly, a winter maintenance DSS has the capacity to deliver effective guidance to road authorities regarding hazardous winter weather events, potentially improving roadway level of service and safety while reducing operational costs.

5. REFERENCES

[1] Petty, K. and Mahoney W., 2008. *The U.S. Federal Highway Administration winter road Maintenance Decision Support System (MDSS): Recent Enhancements and Refinements.* 14th International Road Weather Conference, Prague, Czech Republic.

[2] Liu, Y., Vandenberghe F., Low-Nam S., Warner T. and Swerdlin S., 2004: *Observation-quality estimation and its application in the NCAR/ATEC real-time FDDA and forecast (RTFDDA) system*. 16th Conference on Numerical Weather Prediction, Seattle, Washington.

[3] Myers, W., Brown B. G., and Pocernich M., 2006. *Consensus Probabilistic Forecasting*. 18th Conference on Probability and Statistics in the Atmospheric Sciences, Atlanta, GA. American Meteorological Society.

[4] Linden, S. and Petty K. R. 2008. *The Use of METRo (Model of the Environment and Temperature of the Roads) in Roadway Operation Decision Support Systems.* Preprints, 24th Conference on Interactive Information and Processing Systems, New Orleans, LA. American Meteorological Society.

[5] Crevier, L. and Delage Y. 2001. *METRo: A New Model for Road-Condition Forecasting in Canada.* Journal of Applied Meteorology. 40: 2026 - 2037.

[6] Frankenstein, S. and Koenig G., 2004: *Fast All-season Soil Strength (FASST).* U.S. Army Corps of Engineers, Washington, D.C., Available from the National Technical Information Service (NTIS), Springfield, VA., pp 106.

[7] Shao, J., Lister P. J., Hart G. D., and Pearson H. B., 1996. *Thermal mapping: reliability and repeatability*. Meteorological Applications. 3: 325 – 330.

[8] Federal Highway Administration, 1996. *Manual of Practice for an Effective Anti-icing Program: A Guide for Highway Winter Maintenance Personnel*. Publication No. FHWA-RD-95-202. FHWA, Department of Transportation.

[9] Quesenbery, W., 2004. *Balancing the 5Es: Usability*. Cutter IT Journal. 17: 4 - 11.