# MODELING AND DECISION SUPPORT SYSTEM TO DETERMINE WHEN TO IMPOSE SEASONAL LOAD RESTRICTION (SLR)

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## ABSTRACT
State Departments of Transportation (DOT) typically impose Seasonal Load Restrictions (SLR) by limiting travel of heavy trucks in certain roads to limit damage to the road. By applying commercial remote sensing and spatial information (CRS&SI) technology to monitor roadway surface conditions we will modify current procedures from manual collection to real time data transfer. A Decision Support System (DSS) application collects subsurface temperature data, and determines the depth of frost and thaw penetration. This assists State DOTs to control road damage by properly applying seasonal load restrictions, SLR, restricting heavy trucks for a period of time during spring thaw. The DSS will consist of a user-friendly graphical user interface (GUI), a data evaluation tool or SLR Interpolation (SLRI), a frost-thaw predictive model, and a centralized database storing new and historic data. Proper SLR timing minimizes road damage, maintenance costs, inconvenience to drivers, and fuel costs to the commercial vehicle industry.

Keywords: decision support system, seasonal load restrictions, frost-thaw predictive model, satellite data collection

## 1. INTRODUCTION
Sponsored by the United States Department of Transportation Research and Innovative Technology Administration (USDOT's RITA) a research team of scientists and engineers at the University of Massachusetts Dartmouth (UMassD) are collaborating with the United States Department of Agriculture (USDA) Forest Service (FS), the Maine Department of Transportation (MaineDOT), and the New Hampshire Department of Transportation (NHDOT), to develop a new experimental system that monitors subsurface roadway health conditions in real time during the critical spring thaw and recovery periods. Collected subsurface temperature data determines whether roads are vulnerable to damage by heavy vehicular traffic. State DOTs restrict heavy vehicles from using the roads by imposing seasonal load restrictions (SLR) during these short critical spring thaw periods. Currently, subsurface temperature data is collected manually at numerous roadside sites, and a tedious processing procedure occurs to determine the depth of frost and thaw penetration, as shown in figure 1. This research project will eliminate manual data collection and replace it with state-of-the-art commercial remote sensing and spatial information (CRS&SI) technology for real time data transfer via satellite. This project will be the first time State DOTs in New England use CRS&SI technologies to collect subsurface temperature data.

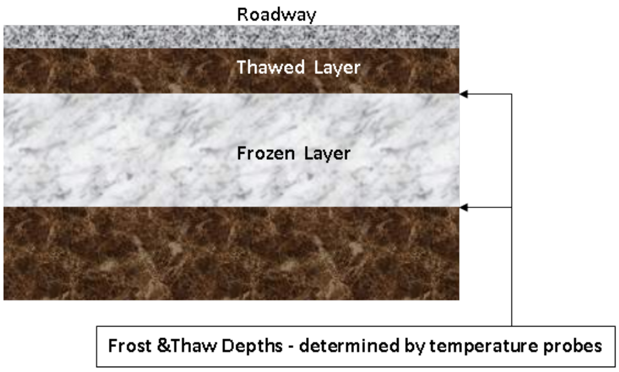


Figure 1: Frost/Thaw layers beneath the roadway during spring thaw.

A Decision Support System (DSS) will be placed on a server, connected to the data collection technologies and complemented by a project website. It will also contain data automated processing tools such as graphs and maps. Since the DSS will determine when to effectively impose SLRs, it will assist State DOTs in minimizing road damage and road maintenance costs. Additionally, it will prevent imposition of SLRs at inappropriate times, minimizing inconvenience to drivers and minimizing fuel costs to the commercial vehicle industry that often reroute deliveries. By using CRS&SI technology, State DOTs will also eliminate the manual collection of subsurface temperature data. Centralizing data will simplify its processing, thus making them less tedious. Also, since the data will be stored in a standard MySQL database the data can be easily accessed for future work. Although the DSS will primarily be used for monitoring, it is anticipated that State DOTs and the commercial vehicle industry will expand the DSS with other applications and use it for training.

## 2. PREVIOUS WORK

Although several state and federal agencies have been addressing the question of when to place and remove SLRs, historically load restrictions have either been based on a fixed date, year after year, or in some cases, visual determination after inspection of the roadside test site. Inspection and downloading of the subsurface temperature data accurately determines the frozen subsoil layer, and thus appropriate timing of SLR implementation. However, the labor-intensive inspection is difficult and sometimes impossible due to severe weather conditions at remote test sites. In addition, the mapping of the subsurface temperature data is currently a tedious process and has not been standardized.

Initial research in Minnesota (MN) indicates that no more than eight-weeks was required for pavement base and sub-grade layers to regain sufficient strength to support heavy truckloads. And this may even be shortened. Currently, MN currently suggests no more than eight weeks for the recommended duration of spring load restrictions for flexible pavements, and liberally allows shorter durations on a case by case basis [1,2]. Studies in MN have also suggested that an additional 1½ to 3 weeks is required for gravel-surfaced roads to regain adequate strength [3]. Studies in Canada have shown as long as five months are required for full recovery, while past USDA Forest Service (FS) studies have shown that allowing traffic to resume after five weeks will result in only limited damage [4]. Studies in the last few years on the application and removal of SLR have been conducted in parallel by Maine's Department of Transportation (Maine DOT), New Hampshire's Department of Transportation (NH DOT), and the FS. Detailed results are contained in technical reports [5,6,7,8] as well as published papers [9,10,11,12]. Conclusions from those studies suggest an urgent need for an automated, web-based system as well as an accurate prediction model to aid decision-makers in the process of applying and removing seasonal load restrictions.

Other models for predicting the depth of frost and thaw penetration based upon air freezing and thawing indices were originally developed at the Universities of Washington [13] and Waterloo, Canada [14]. These models have been used in their original form, and in slightly modified forms, by various transportation agencies in the United States and Canada. Input for these models is less cumbersome than EICM input and requires air temperature data only; however, as noted above, accurate sources of air temperature data are not always readily available in many of the remote areas where SLRs are critical.

In a collaborative effort, FS and NH DOT established nine test sites on several roads in central New Hampshire in the fall of 2006. Soil logs to a depth of about ten feet were obtained from borings at each test site during installation of instrumentation. Instrumentation was installed at the sites in 2007 and observations continued through the 2009 – 2010 winter and spring. Instruments at each site included a weather station, subsurface temperature recorders, water wells, frost tubes and subsurface moisture sensors. Falling Weight Deflectometer (FWD) tests were conducted in the late winter and early spring of 2007 – 2008 and 2008 – 2009. The FWD test provides useful data regarding structural changes in the pavement layers resulting from the seasonal variations in temperature and moisture.

In a similar study, Maine DOT established and monitored eight test sites during the 2006 – 2007 winter. Four of the sites contained frost tubes, but the other four sites contained no instrumentation. A soil boring was made at each of the test sites and layer thicknesses; grain-size distribution and initial soil moisture contents were obtained. FWD tests were conducted in the fall of 2006 and during March through May 2007 at the four sites containing frost tubes.

In this proposed project, critical quantitative data will not only be gathered in real time and assembled using (commercial remote sensing and spatial information (CRS&SI) technologies, but data processing will become automated. Specifically, SLRI output will display frost and thaw penetration plots used by State DOT personnel to determine subsurface frost layer location, thus determine when to impose the SLR.

## 3. GENERAL METHODOLOGY AND SERVICE

The system being built is to be composed of several distinct parts, including the integration of services, miscellaneous devices, creation of databases, configuration of appropriate server software and packages, custom data polling scripts, custom interpolation scripts, and a custom secure web application interface.

Overall, the system must support a generic and scalable storage database for a collection of states, establishments, evaluation sites, data loggers, sensors, and readings. We have narrowed data collection requirements to three distinct channels of data.

Firstly we have identified historical data, which must be imported from vast flat file archives into a universal database structure for the system.

Secondly we identified internet data which could be from one of multiple pre-existing sources. These sources could include the consumption of commercial weather APIs and/or the use of previously collected data from other University research of the past. For example, Plymouth State University of New Hampshire stores collected data from weather stations and subsurface sensors to CSV files available through a simple HTTP file web listing.

The third identified and primary data source for this project is satellite data, which ultimately is gotten from a CSV file as well. This data is however in a different format with specific fields and from a different provider.

The diagrams in Figure 2 and Figure 3 below show an overall synopsis of the network data flow for the primary target data channel (satellite data).

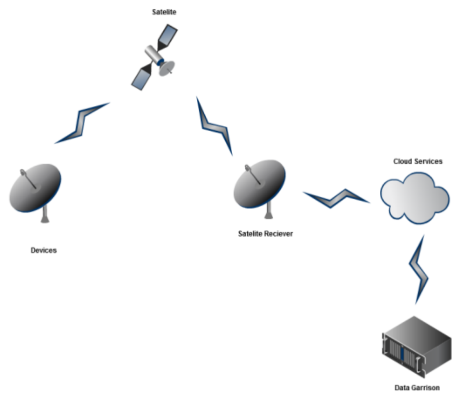


Figure 2: System design from satellite data collection perspective.

Satellite data is collected using in ground devices and sensors data logging hardware. The data logger stores readings locally and uses satellite communication to push data from the devices to a temporary storage solution with a third party provider, Data Garrison. This basic functionality is already available upon purchase of equipment from the provider with configuration.

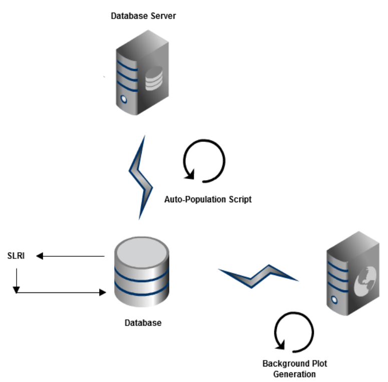


Figure 3: System design from internal data housekeeping and data plotting perspective.

Data stored permanently on our production servers from the auto-population scripts will be transferred to a database. The database will have scripts run on it in a nightly fashion which will execute and calculate the frost-thaw index.

Calculated values will be again stored in the database, in a separate table. With these calculated values, a plotting script will be run to create graphical interpretations of the data housed in the database. The data as well as their graphical representations will be made available via a web portal to users for interpretations, recommendations, and imposing seasonal load restrictions.

## 4. SYSTEM HARDWARE SETUP

Hardware devices required for data collection include temperature, moisture, depths, wind, and rain sensors installed at multiple sites across New England. These devices are to be installed both underground and above ground at sites handpicked by DOTs and researchers. The identification of appropriate sites and deployment of sensing hardware will collect metrics on the earth surface temperature, subsurface temperature, and assorted atmospheric readings. These devices, when purchased are configured to transmit data to a server of the satellite service provider and/or cloud service provider where data is made available at a subscribed interval from a hosted online server. In order to maintain these records, a local storage solution must be present. Local hardware also includes production and testing servers for data collection, maintenance, integration, and testing.

## 5. SYSTEM DATABASE DESIGN

The database is designed in a modular and scalable fashion to support both past, present, and future collected data, of which are all collected using different means and different flat files, and templates. Standardization of templates for the import of these flat files was needed, as well as analysis of the past (flat file) data contrasted with the future (data garrison, Plymouth State University, and other source locations and APIs) for consistency of data types, units, and fields. The storage of data shall be broken down into modular related storage components, represented as tables. States, establishments, sites, data loggers, sensors, sensor types, ports, readings, and reading types must all be accounted for when collecting and storing data in the database.

## 6. SYSTEM CUSTOM SCRIPTS

Scripts are run on both historic data and on remote data being collected. Data is collected from remote sites by scripts which are run on a nightly and hourly basis in order to import the data into DSS's database structure.

Currently the data stored at the various locations of retrieval are in separate formats, for example, data garrison stores data in simple CSV format which can be accessed via the internet based account. While other retrieval locations provide flat files, or web APIs to connect to.

A collection of auto population scripts will harvest the data from the provided satellite service and preexisting services to collect and store in the appropriate fitting database tables. This process of auto-population will occur at a set interval via a CRON job on production server based on the availability of data from sensors and on the remote service provider.

These scripts all perform SQL queries to extract certain data from the historic files and insert them in a relational fashion. Scripts connect to remote servers via HTTP protocol and use CURL requests to receive, CSV, XML or JSON notation responses from interactions with remote web services and storing into the database in a standardized fashion.

By doing this we allow all similar data to be grouped and sorted by other scripts run locally, and opening the better possibilities for future work and scalability within the project.

Other major scripts in the project include an SLRI script which will interpolate collected data. Generation of charts, graphs and tables will be created by scripts and displayed via the web application. Another script will tie in with a predictive model for estimated frost and thaw depths at a given site. Theses scripts will be added to the system as a CRON job and will be able to make a prediction based off of the daily readings. This predictive model will be supplied by the Civil Engineering department at UMassD.

Programming languages used for the various scripts include Perl, Python, PHP, and BASH shell scripting languages.

## 7. WEB APPLICATION

A secure, user login protected web application will be supplied displaying all collection sites and collected data in chart, graph, and table fashion. User interface to the data collected shall be worked on based on the needs of the end users and delivered via a custom internet web portal application.

The web application is developed using MVC architecture via the Code Igniter PHP framework. Users are able to securely signup, register, and view collection sites and data collected based on user account level, affiliated establishment and sites.

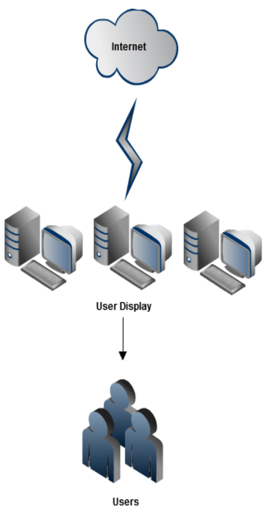


Figure 4: System design from end user perspective.

## 8. REQUIREMENTS AND DEPENDENCIES

In order to start development on the system as a whole and for the various components integrated into the system we do have a set of requirements for development driven by the Civil Engineering department at UMassD, experts in manual SLR applications, and strong backgrounds with the formulas used for calculations. Many of the requirements also come with dependencies on outside resources, current and previous researchers, and other various components being created within the project as well. Some of such dependencies include hardware, software, and the availability of data.

Since the system is modular certain components could be developed independently of each other. Data population scripts from preexisting sources such as Plymouth State University could be created with little need for additional resources on top of the already created services. Other providers such as the primary source of satellite data does require equipment to be present, tested, and integrated with the service provider Data Garrison. Other data sources including external weather data from online APIs, historic data compilation and normalization has its dependencies on various entities, departments and individuals as well.

### 8.1. Historical Data

Requirements for the normalization of historic data and import into the system were created based on observed shared requirements between integrated system, creating a generalized import format and also aiding in the database structure development. The Civil Engineering department at UMassD have supplied recent years worth of historical data in the normalized format for import into the data base for key sites identified for historic and future collection and prediction and validation.

### 8.2. Auto Populated Data

Each of the auto population scripts from various sources, with their own individual requirements and dependencies shall be developed and tested individually and integrated into the system to interact with the production database and server. The requirements for which data each of the scripts should be collecting are closely related. Since the collection of similar data is needed from multiple sources, the required fields for each auto population source have been obtained and verified with the prediction models and SLRI script to be run on the auto populated data base off of requirements set for the same equations on historic data.

### 8.3. SLRI and Prediction Scripts

The SLRI and prediction scripts each are also created independently, however to be run in production mode, they have dependencies on the auto population scripts having been working and collecting data from various sources. This data collected by the auto population scripts will serve as an input to the SLRI and prediction algorithms.

### 8.4. Graphical Plot Generation

Graphical plots are generated based on the output of the SLRI and prediction model algorithms as well as the auto populated data collected. These graphical plots will be generated, and updated daily to provide the latest visual representation of the frost thaw index to users of the site. The graphical plot generation script has dependencies on the above mentioned scripts. Requirements for the plots generated are defined by previously generated plots created via the manual collection and Microsoft Excel generated plot techniques used to date.

### 8.5. Secure Web Application

The web application is another component which can also be created semi-independently of the above mentioned auto populate scripts, SLRI, or prediction scripts. The basic operation of the secured web application can be created, however the display of data and plots requires the majority of the previously mentioned scripts to be in place and working before serving data to the users of the system. By using the stored data from the individual scripts and the generated plots from the plot generation scripts, the web application will serve the data and plots to the users for viewing, interpretation, imposing SLR, and future research.

## 9. FUTURE WORK

Future expansions to the system created can come in the form of web services, additional research, and user end applications. The hardware system itself is expandable in many ways due to its modular nature. Additional data can be collected through added hardware and software extensions. Also, since the design of the database is in a modular and scalable fashion, additional data related to various components interacting in the system can ultimately be added in future work for more robust data collection or more advanced prediction models. Additions of other state departments and use by multiple state DOTs for the prediction of seasonal load restrictions on highways and public ways is completely possible due to the web application implemented in this project. Multiple sources and source affiliations can be added for tracking and recording the collected data from the satellite and internet site sensors making this project expand across state borders. There is use for the analysis and calculations performed on the data that can be applied in multiple applications for both DOTs and trucking industries.

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