TP 14362E

ITS for Variable Load Restrictions

Prepared for
Transport Canada

by
IBI Group

March 2005

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Mara Bullock
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NOTICES

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Transport Canada does not endorse products or manufacturers. Trade or manufacturers' names appear in this report only because they are essential to its objectives.

Since some of the accepted measures in the industry are imperial, metric measures are not always used in this report.

This project is part of Canada's Intelligent Transportation Systems (ITS) R&D Plan, *Innovation Through Partnership*, funded by the ITS Office of Transport Canada under the Strategic Highway Infrastructure Program (SHIP).

The Transportation Development Centre of Transport Canada served as technical authority of this project.

Project Team

Mara Bullock, Project Leader
Brian Delsey, Software Designer
Russell Brownlee, Engineer
Susan Tighe, Pavement Expert

Un sommaire français se trouve avant la table des matières

Transport Canada Transports Canada

PUBLICATION DATA FORM

1. Transport Canada Publication No. TP 14362E	2. Project No.	3. Recipient's Catalogue No.
4. Title and Subtitle ITS for Variable Load Restrictions		5. Publication Date March 2005
		6. Performing Organization Document No.
7. Author(s) Mara Bullock		8. Transport Canada File No. 2450-GP013
9. Performing Organization Name and Address IBI Group 230 Richmond Street West, 5th Floor Toronto, Ontario Canada M5V 1V6		10. PWGSC File No. 052ss-T8663-030015
		11. PWGSC or Transport Canada Contract No. T8663-03-0015/007/SS
12. Sponsoring Agency Name and Address ITS Office – Transport Canada Place de Ville, Tower C, Floor 27 330 Sparks Street Ottawa, Ontario Canada K1A 0N5		13. Type of Publication and Period Covered Final
		14. Project Officer Pierre Bolduc

15. Supplementary Notes (Funding programs, titles of related publications, etc.)

This project is part of Canada's Intelligent Transportation Systems (ITS) R&D Plan, *Innovation Through Partnership*, funded by the ITS Office of Transport Canada under the Strategic Highway Infrastructure Program (SHIP). The Transportation Development Centre of Transport Canada served as technical authority for this project.

16. Abstract

This report reviews the planning, design, and operations and maintenance data requirements for asphalt pavements. Methods for determining when to implement and lift spring load restrictions (SLR) and winter weight premiums (WWP) are reviewed, and recommendations are made on how intelligent transportation systems (ITS), including field equipment and central software systems, can be used to quantitatively assist transportation agencies in making these determinations. Details on the types of field sensors that can meet the data collection requirements and a Road Condition Watch software requirements specification are incorporated. Recommendations are described for a basic system and an advanced system, which take into account current best practices and research that is under way to study SLR.

17. Key Words Spring load restriction, SLR, winter weight premium, WWP, intelligent transportation system, ITS, data collection, best practices, asphalt pavement	18. Distribution Statement Limited number of copies available from the Transportation Development Centre

19. Security Classification (of this publication) Unclassified	20. Security Classification (of this page) Unclassified	21. Declassification (date) —	22. No. of Pages xxxiv, 68, apps	23. Price Shipping/ Handling

CDT/TDC 79-005
Rev. 96

Canada

Transports Canada | Transport Canada

FORMULE DE DONNÉES POUR PUBLICATION

1. N° de la publication de Transports Canada
TP 14362E

2. N° de l'étude

3. N° de catalogue du destinataire

4. Titre et sous-titre
ITS for Variable Load Restrictions

5. Date de la publication
Mars 2005

6. N° de document de l'organisme exécutant

7. Auteur(s)
Mara Bullock

8. N° de dossier - Transports Canada
2450-GP013

9. Nom et adresse de l'organisme exécutant
Groupe IBI
230 Richmond Street West, 5th Floor
Toronto, Ontario
Canada M5V 1V6

10. N° de dossier - TPSGC
052ss-T8663-030015

11. N° de contrat - TPSGC ou Transports Canada
T8663-03-0015/007/SS

12. Nom et adresse de l'organisme parrain
Bureau STI – Transports Canada
Place de Ville, Tour C, 27e étage
330, rue Sparks
Ottawa, Ontario
Canada K1A 0N5

13. Genre de publication et période visée
Final

14. Agent de projet
Pierre Bolduc

15. Remarques additionnelles (programmes de financement, titres de publications connexes, etc.)

Ce projet fait partie du Plan de R&D du Canada sur les systèmes de transports intelligents STI), *Innover par l'établissement de partenariats*, financé par le Bureau des STI ainsi que par Transports Canada dans le cadre du programme stratégique d'infrastructures routières (PSIR). Le Centre de développement des transports de Transports Canada a agi comme responsable technique pour ce projet.

16. Résumé

Le rapport passe en revue les données nécessaires à la planification, la conception, l'exploitation et l'entretien de chaussées en asphalte. Il examine ensuite les méthodes utilisées par les administrations routières pour déterminer quand appliquer et quand lever les restrictions de charges printanières (RCP) et les primes de poids hivernales (PPH), et formule des recommandations concernant l'aide quantitative que les systèmes de transports intelligents (STI), y compris l'appareillage sur le terrain et les systèmes centraux, peuvent apporter aux administrations dans la détermination de ces dates. On y trouve des détails sur les types de capteurs à utiliser pour colliger les données *in situ*, ainsi qu'un dossier de spécifications d'un logiciel de surveillance de l'état de la chaussée. Il comporte enfin des recommandations pour la conception d'un système de base et d'un système évolué, qui tiennent compte des meilleures pratiques en vigueur et de la recherche en cours concernant les RCP.

17. Mots clés
Restriction de charge printanière, RCP, prime de poids hivernale, PPH, système de transport intelligent, STI, collecte de données, meilleures pratiques, chaussée en asphalte

18. Diffusion
Le Centre de développement des transports dispose d'un nombre limité d'exemplaires.

19. Classification de sécurité (de cette publication)	20. Classification de sécurité (de cette page)	21. Déclassification (date)	22. Nombre de pages	23. Prix
Non classifiée	Non classifiée	—	xxxiv, 68, ann.	Port et manutention

ACKNOWLEDGEMENTS

We would like to thank Ray Van Cauwenberghe and other staff from Manitoba Transportation and Government Services (MTGS) for spending 2 days outlining their SLR/WWP process.

We would also like to thank Pierre Bolduc from the Transportation Development Centre of Transport Canada for his project management support and guidance, as well as all of the members from the Technical Steering Committee for their insight and guidance, including:

Ray Van Cauwenberghe – Manitoba Transportation and Government Services

Steve Goodman – City of Ottawa

Fritz Prophète – Ministère des Transports du Québec

Mario Ouellet – Meteorological Services of Canada

Tess Sliwinski – ITS Office of Transport Canada

Sarah Wells – Transportation Association of Canada

Paul Delannoy – Meteorological Services of Canada

Allan Bradley – Forest Engineering Research Institute of Canada

Denis Paquette – Environment Canada

Denis Saint-Laurent – Ministère des Transports du Québec

Madeleine T. Betts – ITS Office of Transport Canada

EXECUTIVE SUMMARY

Introduction

Intelligent Transportation Systems (ITS) include the application of technology to address transportation issues. The objective of this project was to examine whether there is a role for ITS in the implementation and lifting of Spring Load Restrictions (SLR) and Winter Weight Premiums (WWP). In addition, the scope was expanded to look at how ITS can assist with data provision for pavement planning, design, and operations and maintenance.

The current asset value of Canada's roads and pavements is in the order of $150 billion, encompassing the national, provincial and municipal road network. Protecting this investment is of critical importance to the movement of goods and the mobility of people. The two biggest sources of deterioration are the environment and traffic loading. It is a major challenge to design a pavement that will withstand very low temperatures in the winter and high temperatures in the summer. In addition to resisting environmental effects, the pavements must be able to withstand the effects of heavily loaded trucks, which are an important source of revenue to our national economy.

Pavements are especially vulnerable to deterioration throughout the spring thaw. During this time of year, as the thaw progresses, the pavement structure becomes weak due to saturation and differential thaw. Damage can occur not only in the surface asphalt layer but also in the base, sub-base and subgrade layers, depending on the degree of saturation and the degree of thawing. Consequently, the pavements will exhibit signs of premature deterioration due to permanent structural damage. This damage can be limited to cracking or it can be more severe, resulting in a full failure that requires immediate repair. Thus it is critical that SLR be applied to those pavements not structurally designed for spring thaw weakening. This includes much of the secondary highway system.

The effects of frost action and thaw weakening can be both costly and disruptive for transportation agencies and their users. Load restrictions have become a common practice for many transportation agencies in Canada, in an attempt to limit damage to the pavement structure. SLR and WWP reduce pavement distress caused by trucks travelling on the weakened structure. This is used as an alternative to designing and constructing a pavement that is capable of carrying the normal legal loads at any time of the year.

A market scan summarized the various methods for determining start and stop dates for restrictions. Canadian transportation agencies use a number of quantitative and qualitative approaches, including specified calendar dates, visual observations, air temperature measurements, subsurface temperature measurements and deflection testing. The actual types of restrictions include load limits for certain axle configurations, complete restriction, reduced speed limits and various combinations of the three. Canadian transportation agencies reported that there is pressure from the trucking agencies to reduce the duration of the restrictions; however, they continue to have concerns relating to managing their asset. A quantitative approach presents an opportunity to manage these concerns.

This report summarizes the data needs for pavement planning, design, and operations and maintenance. It also illustrates how ITS can assist in the provision of data for SLR and WWP as well as other pavement life-cycle requirements.

Data Requirements

Data requirements for the planning, design, and operations and maintenance for asphalt pavements for Canadian best practices were collected. These requirements were then consolidated into three data groupings:

- Road Structure
- Traffic
- Environmental

Table 1 provides an overall list of each of the data types required for the planning, design, operations and maintenance, and traveller information function, and groups the requirements into Road Structure, Traffic or Environmental requirements.

It is clear from the lists that there is a lot of duplication between the planning, design, and operations and maintenance functions. Therefore, collection of data to support the imposition and lifting of SLR and WWP will have benefits for the planning and design functions as well.

Table 1: Data Requirements for Planning, Design, and Operations and Maintenance Functions

	Road Structure	Traffic	Environmental
Planning	Deflection/strength (historic) Strength of weakest structure (i.e., bridge) Pavement age Distress data (surface defects, cracking, rut depth) Material properties for subgrade, sub-base, base, asphalt Roughness	Characterizations of traffic loads: volume, % commercial, axle weight, # of axles, axle spacing, total weight, vehicle classification, vehicle height, vehicle width, vehicle length, speed, occupancy	Frost depth (historic) Daily temperatures (min/max/mean) Precipitation (max, day)
Design	Deflection/strength Pavement age Material properties for subgrade, sub-base, base, asphalt Stress/strain Relative elevation of pavement structure (up or down)	Characterizations of traffic loads: volume, % commercial, axle weight, # of axles, axle spacing, total weight, vehicle classification, vehicle height, vehicle width, vehicle length, speed, occupancy	Pavement temperature (hourly, daily average, max/min daily, average 7 day max/min) Air temperature (hourly, daily average, max/min daily, average 7 day max/min) Precipitation (hourly) Wind speed (hourly)

	Road Structure	Traffic	Environmental
	Moisture content in subgrade, sub-base and base Consolidation settlement		% Sunshine (hourly or W/m^2) Relative humidity (hourly) Frost depth (yearly historic and max) Freeze/thaw cycle Thaw progression Solar radiation
Operations & Maintenance	Deflection/strength Stress/strain Material properties for subgrade, sub-base, base, asphalt Pavement thickness Capillary action Relative elevation of pavement structure (up or down) Moisture content in subgrade, sub-base and base Distress data (surface defects, cracking, rut depth) Roughness Water level table Salinity Recovery period (lag time) Saturation	Characterizations of traffic loads: volume, % commercial, axle weight, # of axles, axle spacing, total weight, vehicle classification, vehicle height, vehicle width, vehicle length, speed, occupancy	Pavement Temperature (hourly, daily average, max/min daily, average 7 day max/min) Air Temperature (hourly, daily average, max/min daily, average 7 day max/min) Precipitation (hourly) Frost depth (daily max/min) Thaw depth (daily max/min) Freeze/thaw cycle Thaw progression Thaw index Solar radiation (current and predictive) Forecast min/max daily air temperatures (5 days in advance)

In addition, data required to disseminate SLR and WWP information to trucking and other agencies were also collected. Data requirements for Information Dissemination included:

- Roads that have SLR or WWP;
- Date of imposition;
- Date of lifting;
- Revised legal load limit; and
- Fax/e-mail addresses for trucking association representative.

Canadian ITS Architecture

The ITS Architecture for Canada provides a unified framework for integration to guide the coordinated deployment of ITS programs within the public and private sectors. It offers a starting point from which stakeholders can work together to achieve compatibility among ITS elements to ensure unified ITS deployment for a given region. It is for this reason that it is important that the architecture defined for the use of ITS for Variable Load Restrictions, be based on, and remain compliant with, the ITS Architecture for Canada.

The User Services and Market Packages that are applicable for this project are included in Table 2. The definitions include the full architecture definition, which helps to illustrate how ITS for SLR and WWP can fit into a larger ITS context.

Table 2 summarizes the interrelationship between the User Services and the Market Packages.

Table 2: Applicable User Service and Market Packages

User Service Bundle	User Service	User Sub-Service	Market Package
1 Traveller Information Services	1.1 Traveller Information	1.1.1 Broadcast Traveller Information	Road Weather Information System (ATMS18)
			Roadway and Weather Data Fusion (ATMS21)
			Environmental Information Dissemination (ATMS22)
			Variable Speed Limit and Enforcement (ATMS27)
		1.1.2 Interactive Traveller Information	Road Weather Information System (ATMS18)
			Roadway and Weather Data Fusion (ATMS 21)
			Environmental Information Dissemination (ATMS22)
			Variable Speed Limit and Enforcement (ATMS27)
2 Traffic Management Services	2.4 Environmental Conditions Management	2.4.1 Roadway Environmental Sensing	Roadway Environmental Sensing (ATMS20)
		2.4.3 Road Weather Information System	Road Weather Information System (ATMS18)
			Roadway Environmental Sensing (ATMS20)
		2.4.4 Vehicle-Based Sensing	Virtual TMC and Vehicle-Based Sensing (ATMS12)
	2.5 Operations and Maintenance	2.5.1 Infrastructure Maintenance Management	Roadway Environmental Sensing (ATMS20)
	2.6 Automated Dynamic Warning and Enforcement	2.6.1 Dynamic Roadway Warning	Dynamic Roadway Warning (ATMS26)
5 Commercial Vehicle Operations	5.1 Commercial Vehicle Electronic Clearance	5.1.1 Electronic Clearance	Variable Speed Limit and Enforcement (ATMS27)
			Electronic Clearance (CVO03)
		5.1.3 Weigh-In-Motion (WIM)	Variable Speed Limit and Enforcement (ATMS27)
			Weigh-In-Motion (WIM) (CVO06)
	5.4 Commercial Vehicle Administrative Processes	5.4.1 Commercial Vehicle Administrative Processes	Commercial Vehicle Administrative Processes (CVO04)
8 Information Warehousing Services	8.1 Weather and Environmental Data Management	8.1.1 Roadway and Weather Data Fusion	Roadway and Weather Data Fusion (ATMS21)
		8.1.2 Environmental Information Dissemination	Environmental Information Dissemination (ATMS22)
		8.1.3 Roadway Meso and Micro Prediction	Roadway Micro-Prediction (ATMS23)

System Concept

A system concept was developed to address the data requirements, data analysis and information dissemination requirements for an SLR and WWP system. Two quantitative approaches were developed: a basic system that uses algorithms that are currently being used across Canada and an advanced system that reflects current research completed in Quebec. The system concept includes the definition of the system functionality, the hardware required to deliver the functionality and the software requirements necessary to meet the functionality. The system concept was outlined within the context of the Canadian ITS Architecture and a preliminary cost prepared for a basic and an advanced system.

System Functionality

Data Collection

The data will be collected in real time and aggregated into configurable resolutions ranging from 5 minutes to 24 hours. The identification of minimums and maximums will also be possible. All raw data will be stored by the system.

This data may be collected by a number of different types of equipment, depending on the preferences of the transportation agency and availability of technology.

Algorithms

An analysis of existing algorithms that are currently used internationally to determine when to implement and lift SLR and WWP was completed. Algorithms were suggested for SLR and WWP implementation and lifting for the basic and advanced systems and included algorithms to provide advance warning of upcoming implementations.

Information Dissemination

Transportation agencies across Canada use a diverse set of tools to disseminate information to commercial agencies. Integration of the data into a GIS-based central system will assist with electronic dissemination through the various technologies employed by these agencies, including:

- Web site;
- E-mail;
- 511;
- Fax polling service; and
- Interactive Voice Response.

The system will generate responses for the various dissemination devices using the information stored in the central computer. These responses will be developed using predefined templates and will be approved by the users prior to dissemination.

Field Components

The data that is required to run the algorithms can be delivered by a variety of equipment. Therefore, wherever possible, agencies can make use of their existing infrastructure or their hardware preferences. For example, if there are existing Remote Weather Information Systems (RWIS) or planned RWIS deployments, these sites could be augmented with additional sensors to meet all of the requirements. Alternatively, if an agency has frost probes in place, it may wish to add additional equipment at that location.

The system will also include other checks and balances, using more traditional approaches, to ensure that data is valid. For example, as there is a correlation between pavement temperature and strain, the system will also include a check and backup for the strain measurements. A table will be configured in the system, based on laboratory results, that correlates pavement temperature to strain.

All equipment will be installed in accordance with the equipment manufacturer's recommendations.

There are two alternatives for how the field data can be processed: field data can be sent to the central system for processing or can be processed locally through field controllers that generate alarms and aggregate data for transmission to the central system. The choice of field or central processing is often driven by communication requirements and infrastructure availability. Regardless of where the data processing for each site is performed, there will always be a central processing function to store, archive and visually display information from all of the sites in a central location.

If the final design architecture identifies a need for distributed processing, then some sort of Advanced Field Controller (AFC) would be deployed that comprises the necessary communication interfaces to consolidate the various sensor devices and perform local processing of data. Software specific to this application would be developed in conjunction with the central software requirements. The AFC will be a rugged, industrial PC custom designed to support the necessary hardware interfaces and that will run the software application. It is generally preferred that a centralized system be used, where all of the data will be sent to the central system for processing.

National Transportation Communications for ITS Protocol (NTCIP) standards will be used wherever possible for communication to field devices.

Central Components

The central system components will comprise the necessary software and hardware elements to collect, analyze and disseminate the SLR and WWP information. The software will be developed to poll each of the AFCs or field device controllers for information (either processed or raw, depending on where the processing is completed) and to display the information graphically on a GIS-based map. The alarms that are generated for warning or for SLR implementation and lifting and WWP implementation and lifting will be graphically displayed here for review and acceptance by a user. The central system will also generate the information for dissemination through e-mail and facsimile and to external systems that may deploy other technologies such as interactive voice and 511. This will allow data to be graphically disseminated, which will be helpful for users to illustrate where there are restrictions in place.

Data will be stored and archived for use by the planning and design departments.

The software requirements of an SLR/WWP automated monitoring system will be referred to as the "Roadway Conditions Watch" application or RCWatch for short.

The full set of RCWatch requirements are outlined in the Software Requirements Specification (SRS). The SRS describes the software components of RCWatch that provide the roadway condition monitoring and notification functions for a centralized operations centre. Depending on physical implementation and the capabilities of off-the-shelf field equipment, RCWatch will comprise software that runs on one or more centrally located computers and may additionally include software running on a distributed network of field controllers.

The principal function of the software is to collect and analyze surface and sub-surface data to identify periods for which to implement SLR and WWP.

The primary business process supported by RCWatch is the collection and analysis of surface and sub-surface data for a defined roadway network for the purpose of determining the appropriate periods during which the SLR and WWP programs are to be implemented.

RCWatch will aid operating agencies by automating the process of roadway condition monitoring and the dissemination of these conditions to various other departments and external agencies as required. An overview of RCWatch software is provided in Figure 1.

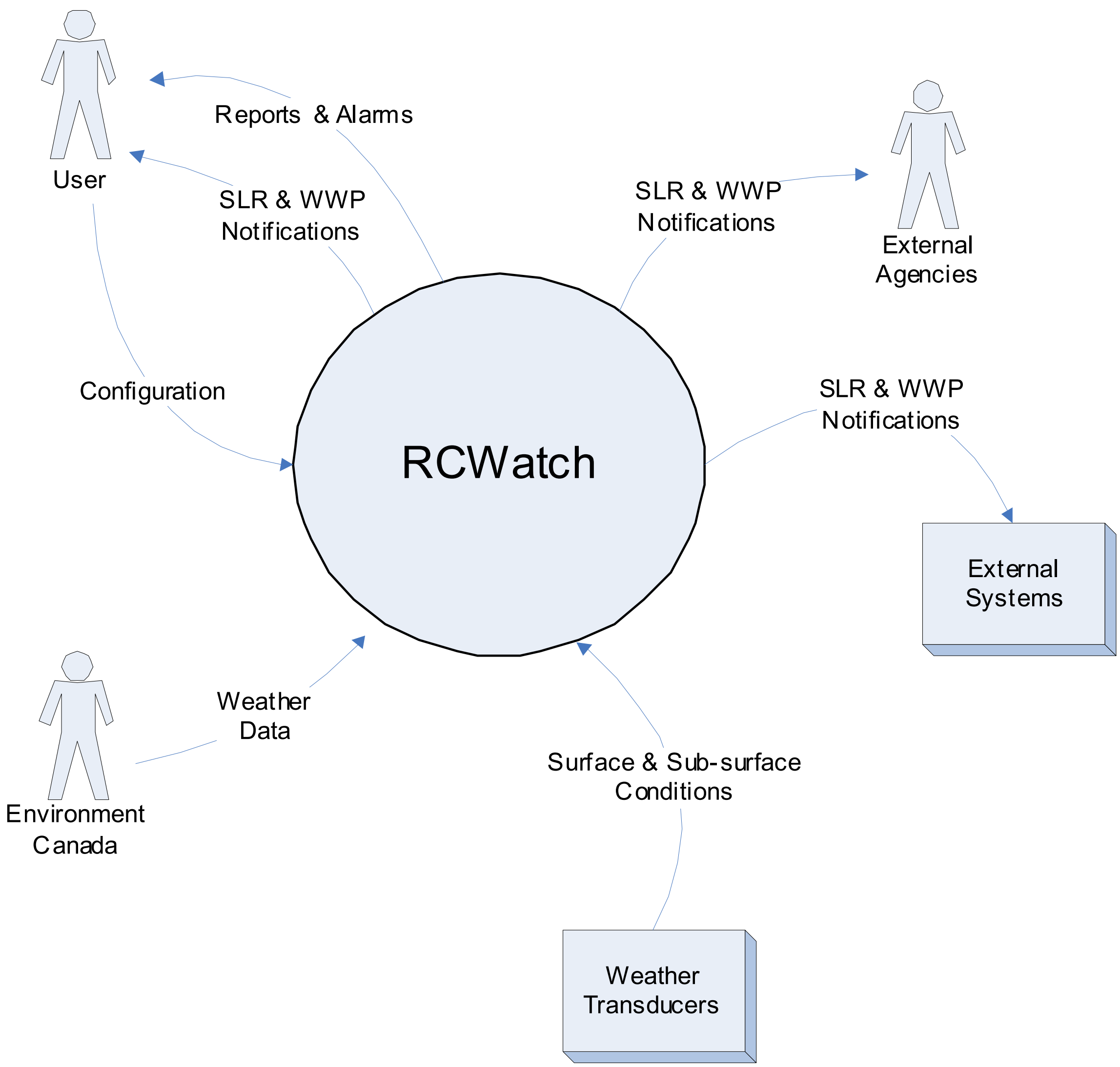

Figure 1: RCWatch Context Diagram

ITS Architecture

The system concept can be described by the following Physical Architecture (Figure 2) as defined by the Canadian ITS Architecture.

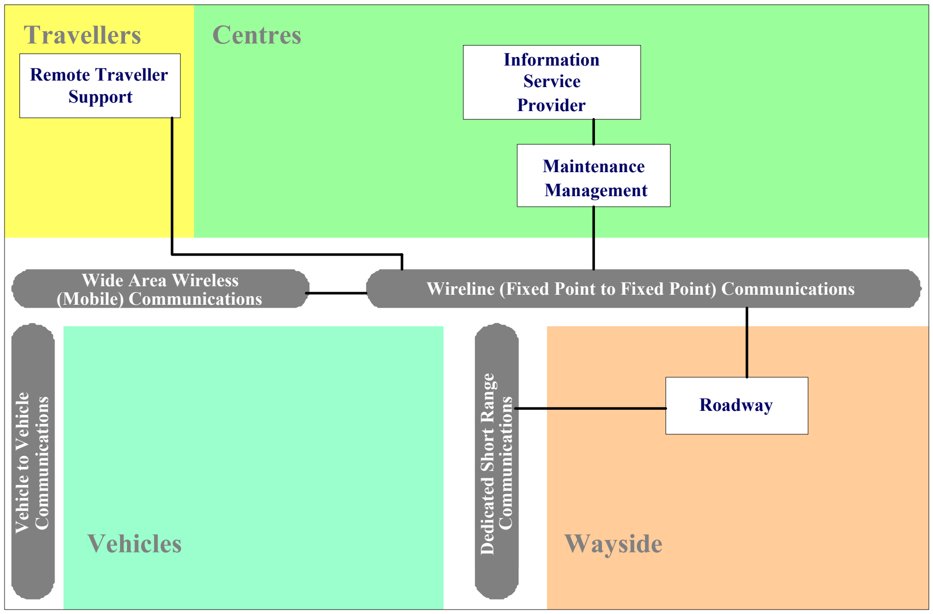

Figure 2: ITS Physical Architecture

The Physical Architecture has been constructed using the “sausage diagram” and shows the physical location of the ITS components and the communications medium used to connect them. For this system concept, there is no interaction with the vehicles. The schematic included in Figure 3 includes a few more details about the particular functions.

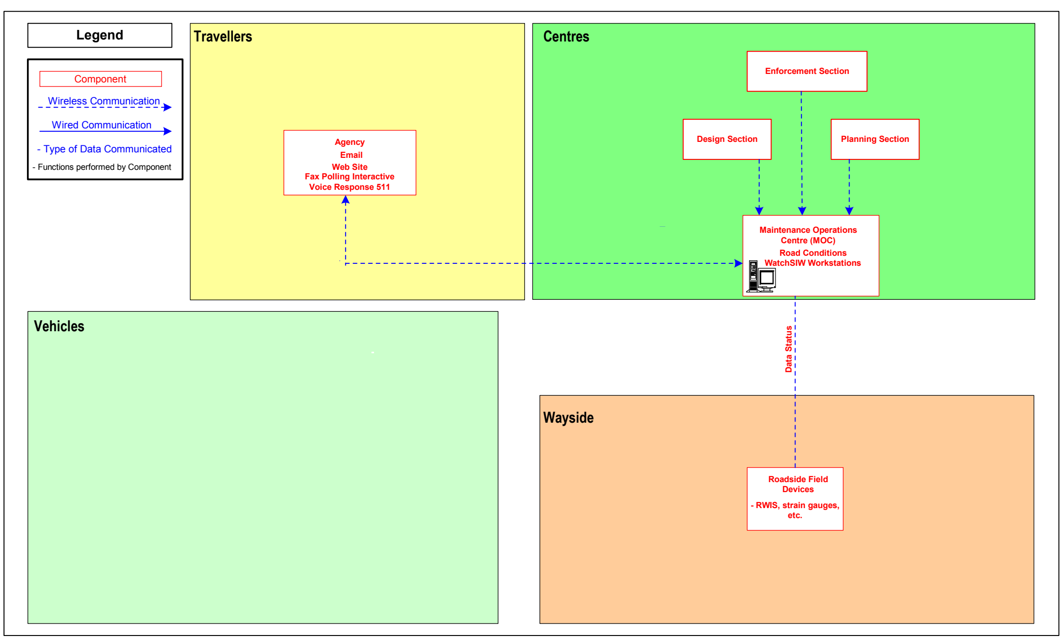

Figure 3: ITS Scheme

Preliminary Costs

Preliminary costs have been prepared for a basic and an advanced system. The costs as well as assumptions are summarized in Tables 3 and 4.

Table 3: Basic System Pricing

	Data Collected	Equipment Type/Name	Unit Cost (CND)	Quantity	Total Equipment Cost (CND)	Installation Cost (CND)	Net Cost (CND)
Basic	Pavement & Air Temperature	RWIS Road Weather Information System	$41,000.00	1	$41,000.00	$4,000.00	$45,000.00
	Strain	Strain Gauge Pavement Strain Transducer for the measurement of strains in Asphalt Concrete (PAST II AC)	$780.00	10	$7,800.00	$1,500.00	$9,300.00
	% Moisture content	Moisture Sensor ECHO Soil Moisture Smart Sensor (S-SMA-M003)	$180.00	3	$540.00	$200.00	$740.00
	Base, Subbase and Subgrade Temperature (Frost Depth)	Multi-point Temperature Probe TDP Temperature Probe (15 sensor points along 72 inch tube)	$2,280.00	1	$2,280.00	$500.00	$2,780.00
	Other Field Requirements	Data Logger, Modem, Cabinet, Power, etc.					$11,000.00
	Central Requirements	Server, Workstation, Database, Miscellaneous	$6,000.00	1	$6,000.00	$0.00	$6,000.00
		Software Development					$167,750.00
				Total Cost:	$57,620.00	$6,200.00	$242,570.00

Table 4: Advanced System Pricing

	Data Collected	Equipment Type/Name	Unit Cost (CND)	Quantity	Total Equipment Cost (CND)	Installation Cost (CND)	Net Cost (CND)
Advanced	Pavement & Air Temperature	RWIS Road Weather Information System	$41,000.00	1	$41,000.00	$4,000.00	$45,000.00
	Strain	Strain Gauge Pavement Strain Transducer for the measurement of strains in Asphalt Concrete (PAST II AC)	$780.00	10	$7,800.00	$1,500.00	$9,300.00
	% Moisture content	Moisture Sensor ECHO Soil Moisture Smart Sensor (S-SMA-M003)	$180.00	3	$540.00	$200.00	$740.00
	Base, Subbase and Subgrade Temperature (Frost Depth)	Multi-point Temperature Probe TDP Temperature Probe (15 sensor points along 72 inch tube)	$2,280.00	1	$2,280.00	$500.00	$2,780.00
	Displacement	Linear Variable Differential Transformer (LVDT) PIz100 (+/-50mm range) arranged to for a multi-depth deflectometer	$577.50	4	$2,310.00	$800.00	$3,110.00
	Other Field Requirements	Data Logger, Modem, Cabinet, Power, etc.					$11,000.00
	Central Requirements	Server, Workstation, Database, Miscellaneous	$6,000.00	1	$6,000.00	$0.00	$6,000.00
		Software Development					$167,750.00
				Total Cost:	$59,930.00	$7,000.00	$245,680.00

Next Steps

Through the development of this document, it became apparent that ITS can play a role in assisting agencies with determining when to implement and lift SLR and WWP. In addition, deployment of ITS equipment to meet this need will also result in data that can assist with other planning and design tasks, thereby increasing the value of this type of system. The system concept discussed herein utilizes existing equipment and proven algorithms, and integrates the data and hardware into a GIS-based central system software package described as RCWatch. The next step will be to develop a pilot project to test the data, algorithms and assumptions, and to ascertain whether there is a value to agencies to deploy this type of system.
In addition, through the research and development that was conducted, it was clear that various academic institutes and government agencies in Canada have established themselves as

leaders in various areas relating to research into and application of SLR and WWP. In order to share this information more easily across Canada, it is suggested that steps be taken to develop a Centre of Excellence that would allow all agencies and institutes to share information relating to SLR and WWP, thus helping to advance research in this area.

Central Tire Inflation (CTI) Systems are becoming more widely used across Canada; furthermore, Commercial Vehicle Operations (CVO) systems are also becoming standard. Future opportunities include the ability to dynamically modify the load restrictions based on in-situ measurements and to broadcast that information in real time to trucking companies. This will allow transportation agencies to protect their assets and trucking companies to maximize their productivity. While the largest benefits occur to both agencies during the period of spring thaw, there will also be benefits associated with winter weight premiums.

SOMMAIRE

Introduction

Les systèmes de transports intelligents (STI) consistent à recourir à la technologie pour solutionner des problèmes de transport. Le présent projet avait d'abord pour objectif d'examiner le rôle potentiel des STI dans l'application et la levée des restrictions de charges printanières (RCP) et des primes de poids hivernales (PPH). Sa portée a par la suite été élargie à l'utilisation possible des STI pour obtenir les données nécessaires à la planification, la conception, l'exploitation et l'entretien des chaussées.

Le réseau routier canadien, routes nationales, provinciales et municipales comprises, a une valeur qui se situe autour de 150 milliards de dollars. La protection de ce patrimoine est capitale, tant pour le mouvement des marchandises que pour la mobilité des gens. Les deux principales causes de la détérioration des routes sont l'environnement et la circulation des véhicules. La conception de chaussées capables de résister à des températures très basses l'hiver et très élevées l'été représente un défi majeur. Et en plus de pouvoir résister à des conditions environnementales extrêmes, les chaussées doivent subir les effets du passage de camions lourdement chargés, qui constituent une importante source de revenus pour notre économie nationale.

Les chaussées sont particulièrement vulnérables à la détérioration lors du dégel printanier. En effet, pendant cette période, l'accumulation d'eau et le dégel différentiel affaiblissent la structure de chaussée. Les dommages peuvent survenir non seulement dans la couche de roulement en asphalte, mais aussi dans les couches de base, de fondation et de forme, selon le degré de saturation et de dégel. C'est ainsi que la chaussée montrera des signes de détérioration prématurée, dus à des dommages structurels permanents. Il s'agit souvent de simples fissures, mais il arrive que les dommages soient plus graves, au point où la route doive être fermée pour réfection immédiate. Il est donc très important que des RCP soient appliquées aux chaussées dont la structure n'est pas conçue pour résister aux effets du dégel printanier, ce qui est le cas de la plupart des routes secondaires.

Les effets du cycle gel/dégel peuvent être coûteux et incommodants tant pour les administrations routières que pour les usagers. Au Canada, beaucoup d'administrations routières ont pris l'habitude d'appliquer des restrictions de charges, afin de limiter les dommages à la structure de chaussée. Les RCP et les PPH diminuent l'endommagement du revêtement routier attribuable à la circulation de camions sur une structure affaiblie. Elles sont un moyen de protéger le réseau routier, à défaut de concevoir et construire toutes les chaussées pour qu'elles puissent porter en tout temps les charges normalement admises.

Une étude du marché a permis de recenser les diverses méthodes utilisées pour déterminer les dates où sont appliquées et où sont levées les restrictions. Les administrations routières canadiennes utilisent, pour ce faire, diverses méthodes quantitatives et qualitatives : dates repères, observations visuelles, température de l'air, température de la sous-surface et essais de déflexion. Il existe plusieurs types de restrictions : limites de charges pour certaines configurations d'essieux, interdiction totale de circuler, réduction des limites de vitesse permises et différentes combinaisons de ces trois types. Les administrations routières du Canada ont fait état de certaines pressions exercées sur elles par les entreprises de camionnage pour que soit réduite la durée des restrictions; elles n'en continuent pas moins de se préoccuper de la gestion de leurs éléments d'actif. Une approche quantitative pourrait représenter une solution intéressante.

Le rapport résume les données nécessaires à la planification, la conception, l'exploitation et l'entretien des chaussées en asphalte. Il illustre également le rôle possible des STI en tant que sources de données pour les RCP et les PPH, et d'autres données utiles reliées à la durée de vie des chaussées.

Besoins de données

Un inventaire a été fait des données nécessaires pour l'établissement des meilleures pratiques canadiennes en matière de planification, de conception, d'exploitation et d'entretien des chaussées en asphalte. Ces données ont ensuite été regroupées sous trois catégories :

- Structure de chaussée
- Circulation
- Environnement

Le tableau 1 donne, pour chacune des catégories (structure de chaussée, trafic, environnement), les types de données nécessaires aux fonctions de planification, de conception, d'exploitation, d'entretien, et d'information des voyageurs.

Il est clair, d'après ces listes, qu'il y a beaucoup de recoupements entre les fonctions de planification et de conception, d'une part, et d'exploitation et d'entretien d'autre part. Il s'ensuit que la collecte de données pour appuyer l'application et la levée des RCP et des PPH (volet exploitation et entretien) bénéficiera également aux fonctions de planification et de conception.

Tableau 1: Données nécessaires pour la planification, la conception, l'exploitation et l'entretien des chaussées

	Structure de chaussée	**Circulation**	**Environnement**
Planification	Déflexion/résistance (données historiques) Résistance de la structure la plus faible (p. ex., un pont) Âge du revêtement Dommages (défauts de surface, fissuration, profondeur d'ornière) Propriétés des matériaux (forme, fondation, base, asphalte) Rugosité	Caractérisation des charges dues au trafic : volume, % de véhicules commerciaux, charge par essieu, nombre d'essieux, écartement d'essieux, masse totale en charge, classe, hauteur, largeur, longueur, vitesse, taux d'occupation des véhicules	Profondeur de gel (données historiques) Températures quotidiennes (min/max/moy) Précipitations (max, nombre de jours)
Conception	Déflexion/résistance Âge du revêtement Propriétés des matériaux (forme, fondation, base, asphalte)	Caractérisation des charges dues au trafic : volume, % de véhicules commerciaux, charge par essieu, nombre d'essieux, écartement d'essieux, masse totale en charge, classe, hauteur, largeur,	Température de la chaussée (à l'heure, moyenne quotidienne, max/min quotidiens, max/min moyens sur 7 jours) Température de l'air (à l'heure, moyenne

	Structure de chaussée	Circulation	Environnement
	Contrainte/déformation Élévation relative de la structure de chaussée (haute ou basse) Teneur en eau de la forme, de la fondation et de la base Tassement de consolidation	longueur, vitesse, taux d'occupation des véhicules	quotidienne, max/min quotidiens, max/min moyens sur 7 jours) Précipitations (à l'heure) Vitesse du vent (à l'heure) % d'ensoleillement (à l'heure ou W/m²) Humidité relative (à l'heure) Profondeur de gel (données annuelles historiques et max) Cycle de gel/dégel Progression du dégel Rayonnement solaire
Exploitation et entretien	Déflexion/résistance Contrainte/déformation Propriétés des matériaux (forme, fondation, base, asphalte) Épaisseur du revêtement Capillarité Élévation relative de la structure de chaussée (haute ou basse) Teneur en eau de la forme, de la fondation et de la base Dommages (défauts de surface, fissuration, profondeur d'ornière)	Caractérisation des charges dues au trafic : volume, % de véhicules commerciaux, charge par essieu, nombre d'essieux, écartement d'essieux, masse totale en charge, classe, hauteur, largeur, longueur, vitesse, taux d'occupation des véhicules	Température de la chaussée (à l'heure, moyenne quotidienne, max/min quotidiens, max/min moyens sur 7 jours) Température de l'air (à l'heure, moyenne quotidienne, max/min quotidiens, max/min moyens sur 7 jours) Précipitations (à l'heure) Profondeur de gel (max/min quotidien) Profondeur de dégel (max/min quotidien) Cycle de gel/dégel Progression du dégel

	Structure de chaussée	Circulation	Environnement
	Rugosité Niveau supérieur de la nappe phréatique Salinité Période de récupération (temps de non-disponibilité) Saturation		Indice de dégel Rayonnement solaire (actuel et prévu) Min/max des températures de l'air prévu chaque jour (5 jours à l'avance)

Les données nécessaires pour diffuser l'information sur les RCP et les PPH aux entreprises de camionnage et autres organismes intéressés ont également été recensées. Les voici :

- routes auxquelles des RCP ou des PPH s'appliquent;
- date d'entrée en vigueur;
- date de levée;
- limite de charge légale révisée;
- adresses de télécopieur/courriel pour le représentant de l'association de camionnage.

Architecture des STI pour le Canada

L'architecture des STI pour le Canada procure un cadre unifié d'intégration et coordonne la mise en œuvre des programmes STI dans les secteurs public et privé. Elle offre aux intervenants une base commune pour réaliser la compatibilité entre les technologies STI, de façon à garantir un déploiement unifié des STI dans une région donnée. C'est pourquoi il est important que l'architecture définie pour l'utilisation des STI aux fins des restrictions de charges variables soit fondée sur l'architecture des STI pour le Canada et qu'elle y demeure conforme.

Le tableau 2 énumère les services aux utilisateurs et les ensembles de marché qui s'appliquent au présent projet. Les définitions sont tirées de l'architecture des STI, afin de mieux illustrer comment les STI pour les RCP et les PPH peuvent s'inscrire dans le contexte global des STI au Canada.

Le tableau 2 illustre les relations entre les services aux utilisateurs et les ensembles de marché.

Tableau 2: Services aux utilisateurs et ensembles de marché applicables

Volet de services aux utilisateurs	Services aux utilisateurs	Sous-services aux utilisateurs	Ensemble de marché
1 Services d'information sur les services aux voyageurs	1.1 Information à l'intention des voyageurs	1.1.1 Information diffusée à l'intention des voyageurs	Système d'information sur la météo routière (SEGC18)
			Fusion des données routières et météorologiques (SEGC21)
			Diffusion de données environnementales (SEGC22)
			Établissement et application d'une limite de vitesse variable (SEGC27)
		1.1.2 Information interactive à l'intention des voyageurs	Système d'information sur la météo routière (SEGC18)
			Fusion des données routières et météorologiques (SEGC21)
			Diffusion de données environnementales (SEGC22)
			Établissement et application d'une limite de vitesse variable (SEGC27)
2 Services de gestion du trafic	2.4 Gestion des conditions environnementales	2.4.1 Détection des conditions environnementales routières	1.1.1.1 Détection des conditions environnementales routières (SEGC20)
		2.4.3 Système d'information sur la météo routière	Système d'information sur la météo routière (SEGC18)
			Détection des conditions environnementales routières (SEGC20)
		2.4.4 Capteurs embarqués	CGT virtuel et détection fondée sur des véhicules (SEGC12)
	2.5 Exploitation et entretien	2.5.1 Gestion de la maintenance de l'infrastructure	Détection des conditions environnementales routières (SEGC20)
	2.6 Avertissement dynamique automatisé et application des règlements	2.6.1 Avertissement routier dynamique	Avertissement routier dynamique (SEGC26)

Volet de services aux utilisateurs	Services aux utilisateurs	Sous-services aux utilisateurs	Ensemble de marché
5 Exploitation de véhicules commerciaux	5.1 Vérification électronique de véhicules commerciaux	5.1.1 Vérification électronique	Établissement et application d'une limite de vitesse variable (SEGC27)
			Vérification électronique (EVC03)
		5.1.3 Pesage routier dynamique (PRD)	Établissement et application d'une limite de vitesse variable (SEGC27)
			Pesage routier dynamique (PRD) (EVC06)
	5.4 Processus administratifs liés aux véhicules commerciaux	5.4.1 Processus administratifs liés aux véhicules commerciaux	Processus administratifs liés aux véhicules commerciaux (EVC04)
8 Services d'entreposage des données	8.1 Gestion des données météorologiques et environnementales	8.1.1 Fusion des données routières et météorologiques	Fusion des données routières et météorologiques (SEGC21)
		8.1.2 Diffusion des données environnementales	Diffusion de données environnementales (SEGC22)
		8.1.3 Mésoprévision et microprévision routières	Microprévision routière (SEGC23)

Concept du système

Un concept de système a été défini en fonction des besoins que génère un système de RCP et de PPH en ce qui a trait à la collecte et à l'analyse des données, et à la diffusion de l'information. Deux méthodes quantitatives ont été élaborées : un système de base, qui utilise des algorithmes présentement utilisés dans tout le Canada, et un système évolué, qui se fonde sur des travaux de recherche effectués au Québec. Le concept comprend les fonctions du système, de même que les ressources matérielles et logicielles nécessaires pour réaliser ces fonctions. Il a été défini de façon à s'inscrire dans l'architecture STI pour le Canada; les coûts préliminaires du système de base et du système évolué ont aussi été établis.

Fonctions du système

Collecte des données

Les données seront colligées en temps réel et elles pourront être regroupées selon un niveau de résolution configurable de cinq minutes à 24 heures. Il sera également possible de déterminer des minimums et des maximums. Toutes les données brutes seront emmagasinées par le système.

Ces données pourront être colligées par différents types d'équipements, selon les préférences de l'administration routière et la disponibilité de la technologie.

Algorithmes

Une analyse des algorithmes actuellement utilisés dans le monde pour déterminer quand appliquer et lever les RCP et PPH a été réalisée. Des algorithmes ont ensuite été proposés pour le système de base et pour le système évolué. Ceux-ci peuvent servir non seulement à établir la date du début et de la fin des restrictions et des primes, mais aussi à donner un préavis de leur entrée en vigueur.

Diffusion de l'information

Les organismes responsables des transports au Canada ont recours à divers outils pour diffuser l'information aux entreprises de transport. L'intégration des données dans un système central fondé sur un système d'information géographique (SIG) aidera ces organismes à diffuser l'information au moyen de diverses technologies, dont les suivantes :

- site Web;
- courriel;
- 511;
- transmission par télécopieur (*fax polling*);
- réponse vocale interactive.

Le système utilisera l'information stockée dans l'ordinateur central pour générer des réponses adaptées aux divers moyens de communication. Ces réponses seront conformes à des modèles prédéfinis et seront approuvées avant d'être diffusées.

Appareillage sur le terrain

Divers appareils peuvent servir à la collecte des données nécessaires pour exécuter les algorithmes. Les administrations ont donc la possibilité d'utiliser leur infrastructure existante ou leurs matériels préférés. Par exemple, si elles disposent déjà d'un système d'information sur la météo routière (SIMR) ou si elles prévoient déployer un tel système, elles pourraient prévoir l'ajout de capteurs. Ou encore, si une administration a déjà des gelmètres installés à certains endroits, elle pourrait vouloir implanter d'autres appareils à ces mêmes endroits.

Le système utilisera aussi des techniques classiques pour garantir la validité des données. Par exemple, comme il existe une corrélation entre la température et la déformation de la chaussée, le système assurera la contre-vérification des mesures de déformation. Il comportera en outre un tableau de corrélation entre la température et la déformation de la chaussée, établi d'après les résultats d'essais en laboratoire.

Tous les appareils seront installés conformément aux recommandations du fabricant.

Deux méthodes sont envisageables pour le traitement des données de terrain : ces données peuvent être envoyées au système central pour traitement ou elles peuvent être traitées localement par des contrôleurs sur le terrain, conçus pour générer des alarmes et pour regrouper les données avant leur transmission au système central. Le choix entre ces deux options est souvent dicté par les besoins de communication et la disponibilité de l'infrastructure pour répondre à ces besoins. Peu importe où est effectué le traitement des données colligées à chaque site, il y aura toujours une fonction centrale de traitement qui stockera, archivera et affichera en un lieu central l'information émanant de tous les sites.

Si l'architecture détaillée indique la nécessité d'un traitement réparti, un contrôleur évolué (AFC, *Advanced Field Controller*) sera alors déployé, y compris les interfaces de communication nécessaires pour regrouper les données de divers capteurs et les traiter localement. Le logiciel précis pour cette application sera développé en même temps que les autres logiciels généraux. L'AFC sera un PC robuste, de type industriel, conçu expressément pour accepter les interfaces matérielles nécessaires, et qui exécutera le logiciel d'application. Mais on préfère généralement un système centralisé, c'est-à-dire l'envoi de toutes les données à un système central pour traitement.

Dans la mesure du possible, le protocole NTCIP (pour *National Transportation Communications for ITS Protocol*) sera utilisé pour les communications avec l'appareillage sur le terrain.

Appareillage central

L'appareillage central comprendra les composantes logicielles et matérielles nécessaires pour colliger, analyser et diffuser l'information RCP et PPH. Le logiciel devra interroger chaque AFC ou contrôleur sur le terrain (et obtenir une information traitée ou brute, selon l'endroit où se fait le traitement) et afficher l'information graphiquement sur une carte SIG. Les alarmes générées à des fins d'avertissement ou de mise en application ou de levée des RCP et des PPH seront représentées graphiquement et soumises à l'examen et l'acceptation d'un utilisateur. Le système central générera également l'information destinée à être diffusée par courriel et par télécopieur et à être envoyée à des systèmes externes faisant appel à d'autres technologies, comme la réponse vocale interactive et le 511. Les données pourront ainsi être diffusées graphiquement, ce qui aidera les utilisateurs à représenter visuellement les endroits où les restrictions s'appliquent.

Les données seront emmagasinées et archivées pour utilisation par les services de planification et de conception des routes.

Le logiciel de suivi des RCP/PPH sera désigné «surveillance de l'état de la chaussée» ou, en abrégé, RCWatch (pour *Roadway Conditions Watch*).

Toutes les exigences de l'application RCWatch sont précisées dans le dossier de spécifications du logiciel (DSL). Le DSL décrit les éléments logiciels de RCWatch qui assurent les fonctions de surveillance et de notification de l'état de la chaussée aux fins d'opérations centralisées. Selon l'implantation matérielle et les capacités de l'appareillage terrain de série, RCWatch comprendra un logiciel qui tournera sur un ou plusieurs ordinateurs centraux et pourra également comporter un logiciel qui tournera sur un réseau réparti de contrôleurs sur le terrain.

La principale fonction du logiciel est de colliger et analyser les données concernant la surface et la sous-surface pour déterminer les périodes pendant lesquelles des RCP et des PPH doivent être en vigueur.

Les principaux processus opérationnels pris en charge par RCWatch sont la collecte et l'analyse des données de surface et de sous-surface pour un réseau routier défini, aux fins de déterminer les périodes pendant lesquelles les programmes de RCP et de PPH doivent être en vigueur.

RCWatch aidera les administrations routières en automatisant la surveillance de l'état de la chaussée et la diffusion de l'information connexe à d'autres ministères et à divers organismes externes. La figure 1 offre un aperçu du logiciel RCWatch.

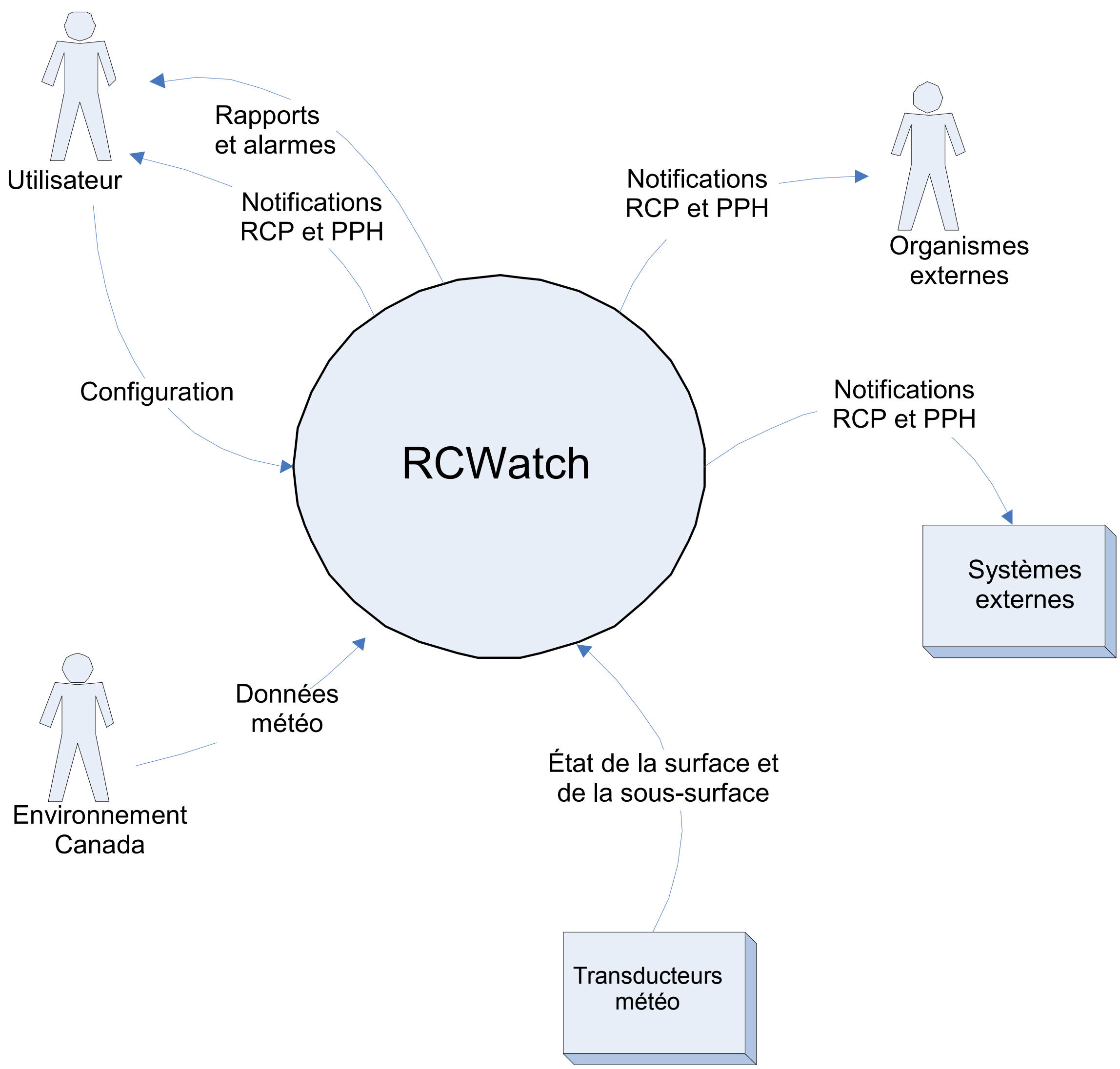

Figure 1: Diagramme contextuel du processus RCWatch

Architecture STI

La figure 2 ci-après illustre le concept du système tel qu'il est défini par l'architecture des STI pour le Canada.

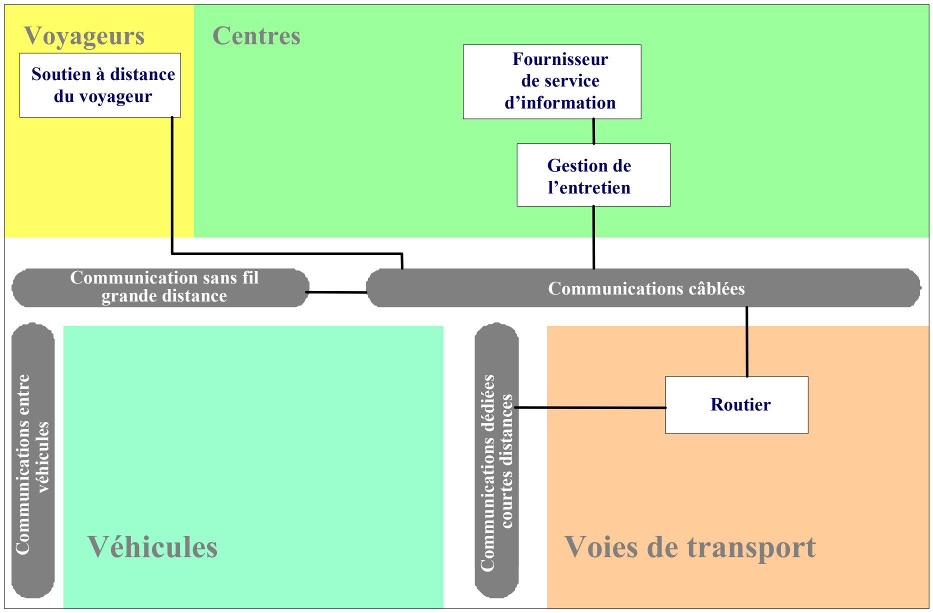

Figure 2: Architecture physique des STI

L'architecture physique a été construite à l'aide du diagramme général. Elle montre l'emplacement physique des éléments STI et les moyens de communication par lesquels ils sont reliés. Pour le concept de système qui nous intéresse, il n'y a pas d'interaction avec les véhicules. Le schéma de la figure 3 donne un peu plus de détails sur les fonctions particulières.

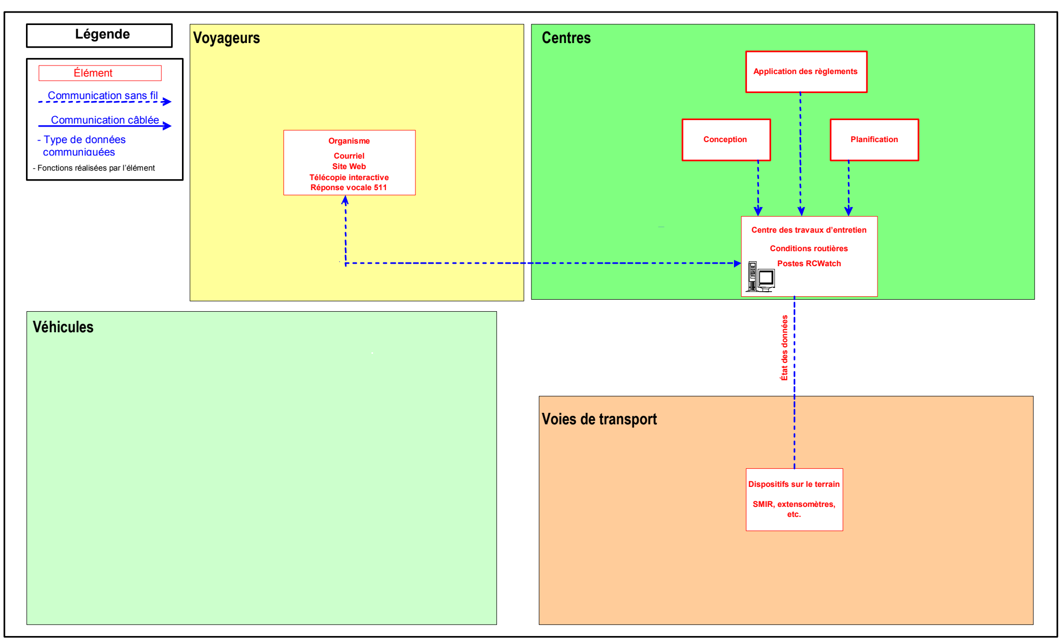

Figure 3: Fonctionnalités STI

Coûts préliminaires

Les coûts préliminaires ont été établis pour un système de base et un système évolué. Ces coûts,
et les éléments de coûts, sont présentés aux tableaux 3 et 4.

Tableau 3: Coûts associés à un système de base

	Données colligées	Type d'équipement/Désignation	Coût unitaire ($CAN)	Quantité	Coût total des équipements ($CAN)	Coût d'installation ($CAN)	Coût net ($CAN)
Système de base	Température de la chaussée et de l'air	SIMR Système d'information sur la météo routière	41 000 $	1	41 000 $	4 000 $	45 000 $
	Déformation	Extensomètre Transducteur de mesure des déformations dans le béton asphaltique (PAST II AC)	780 $	10	7 800 $	1 500 $	9 300 $
	Teneur en eau (%)	Capteur d'humidité Capteur d'humidité intelligent ECHO (S-SMA-M003)	180 $	3	540 $	200 $	740 $
	Température des couches de base, de fondation et de forme (profondeur de gel)	Sonde de température multipoint Sonde de température TDP (15 points de détection sur un tube de 72	2 280 $	1	2 280 $	500 $	2 780 $
	Autres besoins – terrain	Enregistreur de données, modem, armoire, alimentation électrique, etc.					11 000 $
	Besoins – système central	Serveur, poste de travail, base de données, divers	6 000 $	1	6 000 $	0 $	6 000 $
		Développement du logiciel					167 750 $
				Coût total	57 620 $	6 200 $	242 570 $

Tableau 4: Coûts associés à un système évolué

	Données colligées	Type d'équipement/Désignation	Coût unitaire ($CAN)	Quantité	Coût total des équipements ($CAN)	Coût d'installation ($CAN)	Coût net ($CAN)
Système évolué	Température de la chaussée et de l'air	SIMR Système d'information sur la météo routière	41 000 $	1	41 000 $	4 000 $	45 000 $
	Déformation	Extensomètre Transducteur de mesure des déformations dans le béton asphaltique (PAST II AC)	780 $	10	7 800 $	1 500 $	9 300 $
	Teneur en eau (%)	Capteur d'humidité Capteur d'humidité intelligent ECHO (S-SMA-M003)	180 $	3	540 $	200 $	740 $
	Température des couches de base, de fondation et de forme (profondeur de gel)	Sonde de température multipoint Sonde de température TDP (15 points de détection sur un tube de 72	2 280 $	1	2 280 $	500 $	2 780 $
	Déplacement	Transformateur différentiel LVDT (*Linear Variable Differential Transformer*) Plz100 (étendue de mesure ±50 mm) adapté pour un déflectomètre multiniveaux	577,50 $	4	2 310 $	800 $	3 110 $
	Autres besoins – terrain	Enregistreur de données, modem, armoire, alimentation électrique, etc.					11 000 $
	Besoins – système central	Serveur, poste de travail, base de données, divers	6 000 $	1	6 000 $	0 $	6 000 $
		Développement du logiciel					167 750 $
				Coût total	59 930 $	7 000 $	245 680 $

Prochaines étapes

L'élaboration du présent document a mis en lumière l'aide précieuse que peuvent apporter les STI aux administrations routières, au moment de déterminer quand appliquer et quand lever les RCP et les PPH. De plus, l'appareillage STI déployé pour réaliser ces fonctions permettra d'obtenir des données utiles pour d'autres tâches de planification et de conception, ce qui augmente d'autant la valeur de ce type de système. Le concept de système discuté ici utilise le matériel existant et des algorithmes éprouvés, et intègre les données et le matériel dans un progiciel qui pilote un système central fondé sur un SIG, appelé RCWatch. La prochaine étape consistera à mettre au point un projet pilote pour mettre à l'épreuve les données, les algorithmes et les postulats, et pour confirmer qu'il peut être intéressant pour les administrations de déployer ce type de système.

De plus, lors des travaux de recherche et de développement réalisés en marge de ce projet, plusieurs instituts de recherche et organismes gouvernementaux du Canada se sont clairement illustrés comme chefs de file dans le secteur des RCP et des PPH, tant du côté de la recherche que des applications concrètes. Pour favoriser la transmission de ce savoir-faire à l'échelle du Canada, il serait bon de mettre sur pied un Centre d'excellence où tous les organismes et instituts pourraient échanger de l'information sur les RCP et les PPH, ce qui aiderait à faire avancer la recherche dans ce domaine.

Les systèmes centraux de gonflage des pneumatiques sont de plus en plus utilisés au Canada, tout comme les systèmes d'exploitation de véhicules commerciaux. Pour ce qui est des perspectives d'avenir, on peut envisager qu'il sera possible de modifier de façon dynamique les restrictions de charges en fonction de mesures *in situ*, et de diffuser cette information en temps réel aux entreprises de camionnage. Les administrations routières pourront ainsi protéger leurs éléments d'actif, et les entreprises de camionnage, maximiser leur productivité. La plupart des avantages se feront sentir, pour les uns et les autres, pendant la période de dégel printanier, mais on peut aussi prévoir des avantages associés aux primes de poids hivernales.

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GLOSSARY

AASHTO	American Association of State Highway and Transportation Officials
ATIS	Advanced Traveller Information System
ATMS	Advanced Traffic Management System
AVC	Automatic Vehicle Classification
AVI	Automatic Vehicle Identification
BBR	Benkelman Beam Rebound
BBRE	Benkelman Beam Rebound Existing
CGRA	Canadian Good Roads Association
C-SHRP	Canadian Strategic Highway Research Program
CTI	Central Tire Inflation
DMS	Dynamic Message Sign
ESAL	Equivalent Single Axle Load
FAST	Fixed Automated Spray Technology
FHWA	Federal Highway Administration (U.S.)
FWD	Falling Weight Deflectometer
GIS	Geographic Information Systems
GPS	Global Positioning System
HAR	Highway Advisory Radio
IRI	International Roughness Index
ITS	Intelligent Transportation Systems
LTPP	Long Term Pavement Performance
MTGS	Manitoba Transportation & Government Services
MTO	Ministry of Transportation of Ontario
MTQ	Ministère des Transports du Québec
OPAC	Ontario Pavement Analysis of Costs
PCI	Pavement Condition Index
RCI	Riding Comfort Index
RT	Reference Temperature
RTAC	Roads and Transportation Association of Canada
RWIS	Road Weather Information Systems
SHRP	Strategic Highway Research Program (U.S.)
SLR	Spring Load Restrictions
TAC, PSC	Transportation Association of Canada, Pavements Standing Committee
TI	Thaw Index
TMC	Traffic Management Centre
TMS	Traffic Management System
TWin	Thaw Weakening index
VLR	Variable Load Restrictions
WIM	Weigh-In-Motion
WWP	Winter Weight Premiums

1. INTRODUCTION

Intelligent Transportation Systems (ITS) include the application of technology to address transportation issues. Through this research and development project funded by Transport Canada, the use of ITS to assist with variable load restrictions was investigated. Variable load restrictions include spring load restrictions (SLR) and winter weight premiums (WWP). This project outlined the data needs for pavement planning, design, and operations and maintenance, and illustrated how ITS can assist the provision of data for SLR and WWP as well as other pavement life-cycle requirements.

This report summarizes the findings of the various tasks that were completed during the course of this project. Reports prepared for previous tasks are included in Appendices C, D, and E as reference material.

1.1 Objective

The application of technology to transportation issues has been in place in Canada in limited applications since the early 1960s. Over the years, the use of technology in transportation has matured and has been branded as ITS. In addition, ITS has become more common through the years. The development of the Canadian ITS Architecture in early 2000 cemented the role of technology for transportation and provided a common framework and lexicology for Canadians to operate under.

ITS for Traffic Management and Transit were some of the early deployments, with commercial vehicles and border security following suit. The application of ITS to more traditional disciplines, such as pavement operations and maintenance, is still in its infancy. Road weather information systems (RWIS) that track road surface temperatures and salinity are being used to provide “smart” salt applications, and fixed automated spray technology (FAST) is being piloted to automatically deice bridges at freeze conditions.

The objective of this project was to examine whether there is a role for ITS in the implementation and lifting of SLR and WWP. In addition, the scope was expanded to look at how ITS can assist with data provision for pavement planning, design, and operations and maintenance.

Overall, the project involved looking at the opportunity to apply ITS to assist agencies across Canada with SLR and WWP management. The project includes the following tasks:

- Market Scan – review current SLR and WWP policies and practices;
- Parameter Definition – research and determine the pavement and sub-grade parameters that could be monitored;
- Equipment Definition – assess the equipment that is available to quantitatively measure the necessary parameters; and
- Algorithm Definition and System Design – develop the functional definition and system functional requirements to deliver the ITS solution.

This report summarizes all of the tasks. The Market Scan, Functional Definition and Software Requirements Specification are found in Appendices C, D, and E as standalone reports.

1.2 Background

The current asset value of Canada's roads and pavements is in the order of $150 billion, encompassing the national, provincial and municipal road networks. Protecting this investment is of critical importance to the movement of goods and the mobility of people. The two biggest sources of deterioration are the environment and traffic loading. It is a major challenge to design a pavement that will withstand very low temperatures in the winter and high temperatures in the summer. In addition to resisting environmental effects, the pavements must be able to withstand the effects of heavily loaded trucks, which are an important source of revenue to our national economy.

Pavements are especially vulnerable to deterioration throughout the spring thaw. During this time of year, as the thaw progresses, the pavement structure becomes weak due to saturation and differential thaw. Damage can occur not only in the surface asphalt layer but also in the base, sub-base and subgrade layers, depending on the degree of saturation and the degree of thawing. Consequently, the pavements will exhibit signs of premature deterioration due to permanent structural damage. This damage can be limited to cracking or it can be more severe, resulting in a full failure that requires immediate repair. Thus it is critical that SLR be applied to those pavements not structurally designed for spring thaw weakening. This includes much of the secondary highway system.

The effects of frost action and thaw weakening can be both costly and disruptive for transportation agencies and their users. Load restrictions have become a common practice for many transportation agencies in Canada, in an attempt to limit damage to the pavement structure. SLR and WWP reduce pavement distress caused by trucks travelling on the weakened structure. This is used as an alternative to designing and constructing a pavement that is capable of carrying the normal legal loads at any time of the year.

Based on a recent study of agencies [Goodings 2001], methods for determining start and stop dates for restrictions vary from specified calendar dates and visual observations to air temperature measurements, subsurface temperature measurements and deflection testing. The actual types of restrictions include load limits for certain axle configurations, complete restriction, reduced speed limits and various combinations of the three. These differences between agencies were reconfirmed through the market scan (Appendix C).

Paved roads represent the largest in-place asset value of transport infrastructure in most countries. Keeping this asset from depreciating below some specified level while at the same time providing a desired level of service to the road users presents a major challenge to pavement engineers. One of the largest challenges in Canada is to design in order to mitigate damage caused by seasonal effects. Over the past several decades, theoretical and experimental research has been carried out to examine the mechanisms of frost heaving. There is still, however, limited information available on thaw weakening and how that impacts overall pavement performance. Additional issues include pavement safety during the period of spring weakening. In order to properly predict when thaw weakening occurs, it is important that the system is properly managed.

In 1992 the World Bank published a report that stated cost savings ranging from 40 percent up to 92 percent, with an average of 79 percent, could be achieved where seasonal traffic load restrictions were implemented in countries that had annual freeze-thaw cycles. Although these numbers are not available for Canada, it is reasonable to assume that cost savings are achieved when SLR are applied at the right time. The actual cost savings would be dependent on the pavement material properties and thickness of the respective pavement structural layers [C-SHRP 2000].

In April 2000 the Transportation Association of Canada (TAC) Pavements Standing Committee (PSC) met to discuss the issue of current SLR in Canadian provinces. Based on this discussion, it was determined that most agencies do not restrict their primary network; however, restrictions are placed on the secondary and tertiary networks. These restrictions tend to be related to expert judgement and historical records. Typical restrictions are based on the allowable weights and vary from 50 to 90 percent [C-SHRP 2000]. A number of jurisdictions, including Manitoba, the Northwest Territories and Alberta, permit WWP to reflect the additional bearing capacity of the frozen conditions. In addition, it was determined that many Canadian provinces were interested in developing SLR based on mechanistic principles that relate to actual temperatures and moisture within the pavement structure. This flexibility is especially critical, given possible impacts from global warming and continued pressure from the trucking industry to justify SLR restriction periods and to increase truck weights and loads.

In jurisdictions that employ both SLR and WWP, seasonal weight limits can cover up to a seven month period [C-SHRP 2000].

1.3 Approaches to Applying SLR or WWP

There are a number of different ways that transportation agencies determine when to implement SLR or WWP, ranging from fixed date to analytical. The primary goal in implementing SLR and WWP is to strike the right balance between minimizing road damage and maintenance costs, and minimizing economic loss due to restricting weights for trucks. Start and end dates must be properly administered. Inaccurately determining either the SLR or WWP may disrupt the balance and result in higher maintenance costs or reduced economic activity.

The following sections summarize how agencies determine when to implement and when to lift SLR and WWP, but do not address how agencies determine on which roads to implement SLR or WWP. Typically, design criteria and strength are the primary factors in the latter case.

1.3.1 Calendar-Based

A calendar-based imposition system refers to the practice of selecting fixed start and end dates for the SLR or WWP. These fixed start and end dates are typically determined through consideration of historic data and applying an average duration.

1.3.2 Visual Observations/Engineering Judgement

Agency staff typically have a good understanding of their networks and how the roads are performing. Diligent monitoring triggered by temperature changes in conjunction with historical information leads to informed decisions for when to impose and lift the SLR or WWP.

1.3.3 Quantitative

Agencies adopting a quantitative or condition-based approach to SLR and WWP may apply a model or thaw index to measured conditions or predicted temperatures. Agencies may also rely on data relating to frost depth, road strength and temperature to quantitatively determine when to impose and lift the SLR or WWP.

1.3.4 Reduced Tire Pressure

Work has been done throughout Canada and the U.S. on the use of reduced tire pressure to create more road-friendly trucks. Reduced tire pressure increases the footprint of the tire, which reduces the potential horizontal and vertical strain that are applied to the road surface, allowing heavier loads to be carried without increasing the damage to road structures. A Central Tire Inflation (CTI) system allows drivers to monitor and modify tire pressures from their cab [Mahoney 1994]. In addition, the use of a Global Positioning System (GPS) on the truck and a data logger allows the tracking of vehicle location and associated tire pressure. The British Columbia Ministry of Transportation adopted the use of CTI in 2004 as a means of allowing hauling through part of the SLR period. B.C. has a TPCS SLR Program by which trucks operating with tire pressure control systems (TPCS) are exempted from weight restrictions on approved routes, after road strength has recovered to a surface rebound of 1.5 mm. This haul resumption rebound applies to all truck configurations and roads, and is calculated as the average plus two standard deviations (x+2s) from a 10-point Benkelman beam test on the weakest part of the route. The haul resumption rebound is based on results from a mechanistic analysis of critical road strains conducted by FERIC, using typical truck configurations and road structures. B.C.'s restrictions are typically lifted after a surface rebound of 1.25 mm is reached so the program offers significant gains to participants. CTI systems were found to improve ride, traction and mobility [Bradley 1997].

2. USER NEEDS

ITS provides many benefits to the agencies that deploy them, including real-time data collection and warehousing, information dissemination and automated device control. Some of these benefits include enhanced data collection, which can be used to augment traditional data collection methods.

The first step in the development of an ITS is to clearly understand what the user's, or stakeholder's, needs are. These needs vary and may be data needs, operations needs or institutional needs. Without clearly understanding what the needs are, it is nearly impossible for a delivered system to be successful and to satisfy the requirements.

Taking a holistic approach also results in synergies as typically there are multiple uses for data within an organization.

The original scope of this project included the use of ITS for SLR and WWP. Through detailed discussions with Manitoba Transportation and Government Services (MTGS) and the project team it became clear that the data used to determine where and when to implement SLR and WWP is used for a number of other functions within the life cycle of a road, including the planning and design phases. Consequently, the scope of this project was expanded to look at data needs for planning, design, and operations and maintenance.

There are three primary functions that the data collected through an ITS to assist with SLR and WWP could be used for:

- Planning;
- Design; and
- Operations and Maintenance.

Therefore, in addition to assisting with SLR and WWP there are additional benefits and justification for collection of this data.

A market scan, completed as part of the first steps for this project and included as Appendix C, highlighted the differences in how Canadian transportation agencies approach SLR and WWP.

Some agencies do not implement them at all, some use qualitative methods, and others use a combination of qualitative and quantitative methods. One of the common messages received from the transportation agencies was that they are working hard to ensure that the SLR and WWP periods are correct, because infrastructure rehabilitation budgets are tight and there is strong lobbying from the trucking associations to reduce the SLR periods and increase the WWP.

Enhanced data collection was identified as the best means to assist agencies in addressing this issue. Opportunities for enhancements to information dissemination methods were also identified as an area where there could be improvements. These two areas are the primary focus of this report.

Sections 2.1 through 2.3 provide a background on the types of data used by transportation agencies to assist with the three business areas and outline the user needs for those areas. Not all types of data that are used by transportation agencies are included; rather the focus is on data that could potentially be collected through ITS equipment. For example, material properties of subgrade materials, aggregates and asphalt cement are key types of data used for design; however, this type of data is not yet practical to collect through ITS.

2.1 Planning

There is a range of data used for planning purposes. Sections 2.1.1 and 2.1.2 outline the best practices for planning work that can be done and is being performed by transportation agencies across Canada.

For the purposes of this report, the planning function includes:

- Determination of when to rehabilitate roads; and
- Determination of which roads require implementation of SLR and where WWP can be allowed.

2.1.1 Pavement Performance Prediction Models

Pavement performance prediction models can be used to determine when future rehabilitation will be required.

Ideally, the pavement performance prediction model should be divided into two parts: the traffic-associated part and the environment-associated part, as expressed by the following equation [Tighe 2001b]:

$$P = P_0 - P_T - P_E \qquad (1)$$

where: P = Pavement performance index
P_0 = Initial pavement performance index
P_T = Performance losses due to traffic
P_E = Performance losses due to environment

For example, one model that breaks this down in terms of deterioration associated with traffic loss and environmental loss is the Ontario Pavement Analysis of Costs (OPAC) 2000 program. It has been calibrated to Ontario conditions and separates these two factors as follows.

The calculation of the Riding Comfort Index (RCI) loss due to traffic is as following:

$$\Delta RCI_T = 2.4455\Psi + 8.805\Psi^3 \qquad (2)$$

where: Ψ = $3.7239 \times 10^{-6} \times W_S^6 \times N$ (for W_S in mm)
N = number of (80 KN or 18 Kip) equivalent single axle load (ESAL) applications
W_S = Subgrade modulus

The RCI loss due to environment is expressed as:

$$\Delta RCI_E = (P_0 - P_\infty)(1 - e^{\alpha Y}) \qquad (3)$$

where: α = constant
Y = pavement age
P_0 = initial performance
P_∞ = performance at an infinite time

Equation (3) shows that for a particular pavement section, the maximum amount of environment induced performance loss is determined by ($P_0 - P_\infty$), and the rate of loss is at a maximum in the initial years and reduces with time as P_E approaches a hypothetical ultimate value of P_∞ at infinite time. The asymptotic value of P_∞ of a pavement can be made a function of subgrade strength (W_S):

$$P_\infty = \frac{A}{1 + \beta W_s} \qquad (4)$$

where: A and β = constants

By substituting P_∞ into Equation (3), it can be found that P_∞ is larger for stronger pavements (small W_S) and P_E is smaller for stronger pavements, i.e., stronger pavements will be less affected by environmental forces than weaker pavements [Jung 1975]. The Ontario Brampton Road Test was used to determine the constants in the above ΔRCI_E model [Phang 1981]. The final equation for calculating the environment-associated performance loss in the Ontario Pavement Analysis of Costs (OPAC) 2000 model is given as:

$$\Delta RCI_E = P_o\left(1 - \frac{1}{1 + \beta W_S}\right)(1 - e^{\alpha Y}) \qquad (5)$$

where: P_0 = initial RCI
W_S, Y = as previously defined

The annual performance index of a pavement is predicted by substituting P_T and P_E in Equation (1) with ΔRCI_T and ΔRCI_E from Equations (2) and (5), respectively. It should be noted that since the use of RCI in the original OPAC, MTO has gone to a Pavement Condition Index (PCI), on a scale of 0 to 100. PCI includes roughness and pavement distress, and can be correlated with RCI and with the International Roughness Index (IRI).

In summary, the data requirements include:

- Deflection/strength;
- Characterizations of traffic loads
  - volume
  - % commercial
  - axle weight
  - # of axles
  - axle spacing
  - total weight

  - vehicle classification
  - vehicle height
  - vehicle width
  - vehicle length
  - speed
  - occupancy
- Material properties for subgrade, sub-base, base, asphalt;
- Pavement age;
- Pavement distress data (surface defects, cracking, rut depth);
- Roughness; and
- Climatic (daily temperatures (min/max/mean), precipitations (max, day), frost depth).

2.1.2 Spring Load Restrictions

One of the annual planning tasks that is undertaken by transportation agencies is to determine which sections of their network require SLR in order to minimize damage during the thaw period.

These are the steps that are undertaken by some of the provinces.

Step 1 – Identify weak pavement structures

> Typically, the first step of the process involves reviewing the road classification and pavement design that was used. Roads that have been designed for high volume traffic have thick pavements and low volume roads have relatively thin pavements. Typically, SLR are only implemented where the frost depth penetrates down to a frost susceptible subgrade soil. This first step of the screening process identifies the roads that need to be further analysed. At this stage, roads may also be grouped into representative control sections.

Step 2 – Determine restrictions and restriction levels

> The second step involves identifying which of the thin pavement structure roads require restrictions. For agencies where there are multiple levels of restriction, i.e., Level 1 and Level 2, this task also includes classification of the restriction level. This task is complicated by the fact that the cost to analyse each metre of each road is prohibitive. Agencies have developed methods to work around this, for example MTGS completes analysis on approximately a third of their network each year and compares these numbers to previous years.
>
> Analysis includes taking field deflection measurements during the SLR period using Benkelman Beam Rebound (BBR), Falling Weight Deflectometer (FWD) or Dynaflect. These readings need to be calibrated to a reference temperature and either converted to a strength measurement or used as they are. For agencies that are moving from one analysis method to another, a correlation factor between the different types of equipment readings also needs to be completed. This data may also be compared to traffic load data to see where the heaviest loads travel. Sections 2.1.2.1 and 2.1.2.2 provide additional information on the role of the data.
>
> Benkelman beam rebound is a static measurement of road strength while the Falling Weight Deflectometer is an impact load and the Dynaflect is a vibratory load measuring device. The idea of correlating a dynamic deflection with a static deflection is open to criticism because the two methods represent two different patterns of behaviour.

Nevertheless, if the dynamic system is used simply as a faster means of obtaining a number which can be correlated to a number obtained from a static system then the idea is not as faulty. Roads regulators in B.C., Alberta and Saskatchewan have tried unsuccessfully to determine reliable calibrations so that they could move from static to dynamic methods without losing the benefit of historical static measurements. Because of the calibration problem and because each method has strengths and weaknesses a variety of methods are used by Canadian regulators (e.g., B.C., Saskatchewan and Manitoba use BBR while Alberta uses FWD).

The data that is collected is often correlated using a GPS location device and integrated into a GIS map platform. The data is stored in a database and is analysed using statistical analysis to identify weak areas.

Step 3 – Finalize networks

The roads that require restrictions are reviewed from a network perspective. Routes that have multiple levels of restrictions are reviewed and the restrictions modified to provide a contiguous route.

The next steps vary depending on the agency and whether they use a calendar-based, engineering judgement or quantitative approach to ascertaining when to implement the SLR.

The data, as further described in Sections 2.1.2.1 and 2.1.2.2, required to determine where to implement SLR includes:

- Deflection/strength (historic and current);
- Characterizations of traffic loads
  - volume
  - % commercial
  - axle weight
  - # of axles
  - axle spacing
  - total weight
  - vehicle classification
  - vehicle height
  - vehicle width
  - vehicle length
  - speed
  - occupancy
- GPS referenced locations; and
- Database and GIS mapping platform.

2.1.2.1 Deflection/Strength Data

Deflection/strength data needs to be adjusted to account for variations in pavement layer properties relative to temperature, frost and moisture conditions. Temperature is the most significant factor impacting the modulus of asphalt. The stiffness modulus can range from 10 to 15 GPa at 0 to 5°C while at high temperatures, it can be as low as 750 MPa to 1 GPA. Consequently, deflection tests must be normalized to a reference temperature. This reference temperature is usually established as 21°C. The adjustment is carried out for asphalt only and not for unbound materials as stiffness is typically not significantly affected by temperature. However, if the pavement is located in an extreme climate adjustments should be considered [TAC 1997].

Moisture has little effect on asphalt however, it does impact both the unbound base layers and subgrade. The presence of moisture can have a significant impact on the lower pavement layers as it can reduce the modulus and result in lower spring recovery periods. In addition, if a layer is saturated, it will make it difficult to properly interpret the pavement deflection basin. It is noteworthy that the moduli of wet fine grained soils can be as low as 20 to 30 percent of their summer values. Thus, similar to temperature, a spring reduction factor is applied to deflection data to adequately address subgrade type and moisture condition. Some consideration should also be given to a saturated unbound layers if they are known to be weak during spring thaw. However, moisture adjustments are typically just applied based on the subgrade type [TAC 1997].

The discussion herein focuses on the current state of the practice with respect to deflection data measurement and attempts to provide a basis for subsequent needs. Examples of the use of deflection data for spring load restrictions is provided.

The best known procedure which is based on Benkelman Beam deflection is the Canadian Good Roads Association [CGRA 1962] method. The procedure was based on the relationship between deflection, actual pavement rebound and pavement life. During this initial study, approximately 2,500 pavement inventory sections from across Canada were evaluated. The following year an additional 3,000 sections were inventoried. Overall, pavement performance and strength over time were measured. Some sections had spring load restrictions while others did not. Sections with similar design conditions (i.e., traffic, subgrade soils, pavement thickness, etc.) were compared using a statistical analysis. This resulted in the development of load restrictions through monitoring deflection. The study was very thorough and established several important concepts in design [CGRA 1962]. Several agencies still use this today as a basis of setting load restrictions. It should be cautioned that the Benkelman Beam is a static device and does not simulate traffic loading [TAC 1997].

Various agencies still use the Benkelman Beam Rebound (BBR) value as a basis for establishing spring load restrictions. Manitoba Transportation and Government Services (MTGS) has continued to improve and modify its spring load restriction practices since 1997 as detailed in [MTGS 2004]. The system uses a combination of Benkelman Beam Rebound Existing (BBRE) measurements to determine when the pavement is in the weakest state. Pavements more than 15 years in age and Asphalt Surface Treatments warrant spring road restrictions when the BBRE is more than 1.5 mm. Pavements 15 years in age or less warrant spring road restrictions when the BBRE is more than 1.65 mm. Note, only Roads Transport Association of Canada (RTAC) secondary arterials and collectors as well as non RTAC Expressways and primary arterials are restricted while RTAC Expressways and primary arterials are not restricted.

British Columbia's Ministry of Transportation also uses BBR to establish spring load restrictions. The restrictions are based on 50 to 60 pavement sections that were monitored for several year during the spring thaw in the late 1970s. Each test section had ten test points and were tested every week from the start of thaw to the end of the pavement recovery period. The evaluation network was reduced in the early 1990s to approximately 30 sections. In addition to taking BBR measurements, frost tubes and thermometers were installed. The maximum rebound (adjusted to 10°C) was set at 1.6 mm while others are established at 1.25 mm. The B.C. system establishes spring load restrictions based on structural capacity, the conditions from the previous fall and whether or not it was wet or dry, amount of snow cover during winter and temperature during the spring including timing and duration of any warm weather. The main highways are usually restricted to 100 percent of the legal axle load, secondary highways to 70 percent of the load and roadways in poor condition to 50 percent, with details being made available on the British Columbia Ministry of Transportation website [Hein 2002].

In the 1970s the Dynaflect and Road Rater were introduced in an attempt to improve the rate of measurements. These tools also enabled transportation agencies to better examine damage by providing information on the deflection basin. This provided better indications of strength in the various pavement layers during thaw weakening. Various models were developed by Kelvin, Boussinesq, Burmister, etc. [Goodings 2001] to assess the stresses and strains in each respective layer. This resulted in a capacity to better predict damage from thaw weakening.

The City of Ottawa uses the Dynaflect as a basis for establishing their spring load restrictions. The program involves testing eleven sites located across the City of Ottawa. Each site is 550 m in length and has marked test locations within the site. Each site is tested weekly starting in February. The data is corrected for temperature and readings are based on average Sensor One values for each week. A plot, as shown in Figure 2-1 for winter 2004, is constructed. The City of Ottawa has established 0.92 mils as the threshold deflection. This is related to the inflection point where the strength gain begins to plateau after the thaw has ended. This threshold is used for both the removal and implementation. Also, the city publishes a maximum end date (for 2004 it was May 17) so that businesses can plan accordingly. This date varies from year to year, depending on the thaw. For example in 2002, the removal of restrictions occurred April 29th [Goodman 2004].

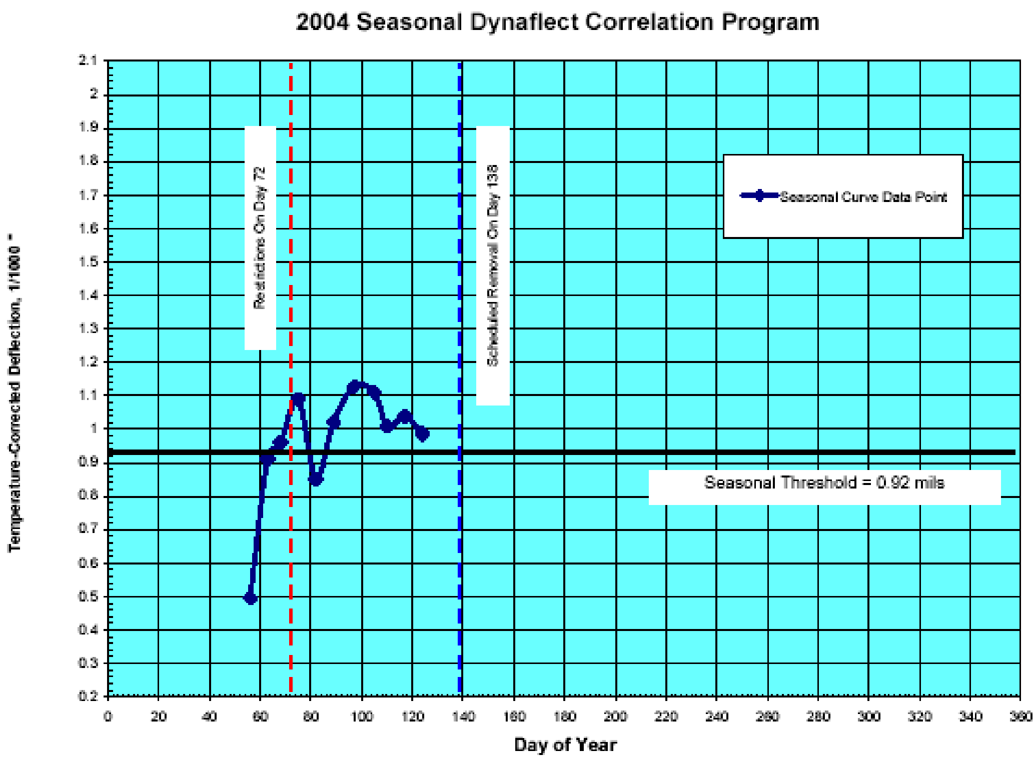

Figure 2-1: Seasonal Dynaflect Correlation for City of Ottawa

Although the Dynaflect can be a useful tool, one primary drawback is that the device operates at low vibrating loadings. It therefore does not provide a sufficient amount of deflection to evaluate materials at lower layers. However, because it does generate a smaller load on the pavement, it may be well suited to municipal roads and surface treated roads because of their thinner structures. In addition, the smaller load may be preferable for testing during spring thaws because of the smaller potential for damage. The Dynaflect user should be careful however because they have also been known to result in liquefaction of soil near saturation and thus results in unrealistically high damage predictions [Goodings 2001].

The falling weight deflectometer (FWD) is an impact device and many jurisdictions have chosen this device because of the speed of testing, accuracy and safety of operators. This device has enabled various transportation agencies to better understand the impacts of thaw weakening and more specifically it is now known that maximum pavement damage can occur shortly after thawing begins [St. Laurent 2002]. Due to the high cost associated with FWD testing, various agencies use FWD to complement air and ground temperature readings.

The ministère des Transports du Québec (MTQ) has used FWD to periodically measure deflections on selected pavement sections within their network. The seasonal damage is then calculated for various time intervals during the year. Factors that MTQ takes into account include [St. Laurent 2002];

- Climate temperature, freezing, thawing (surface water, precipitation, melting snow and ice, state of stress)
- Properties of the pavement layers: thickness, resilient modulus, fatigue strength
- Pavement Deterioration Indicator: strain, structural number, surface curvature index

The FWD is used to measure deflection and subsequently the resilient modulus values are back calculated using elastic layer theory for each respective layer. The resilient modulus values are then used to calculate pavement deterioration indicators and seasonal variations. MTQ also considers the subdivision between thawed layers and frozen layers in the analysis, as shown in Figure 2-2. These depths have been pre-established using frost tubes. It is noteworthy that the presence of firmer frozen layers in the lower portion of the pavement structure needs to be considered in the back calculation analysis, otherwise calculated resilient modulus values will be incorrect [St. Laurent 2002].

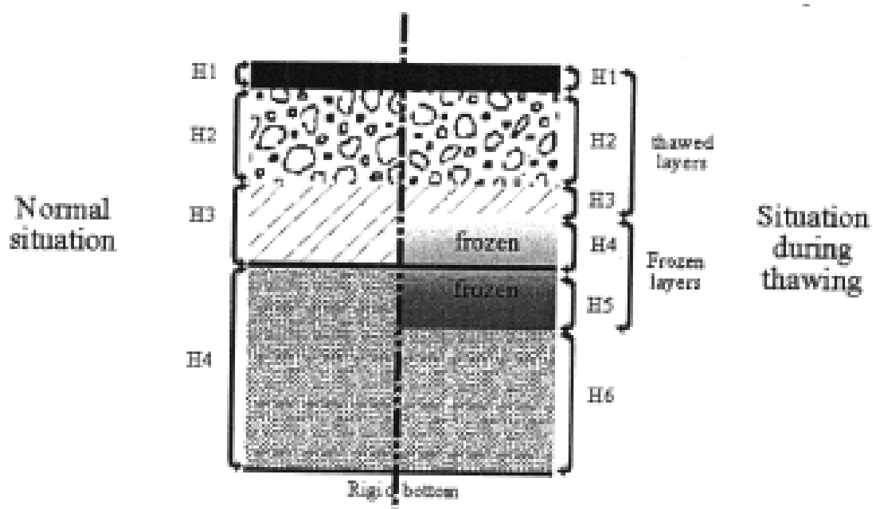

Figure 2-2: Layers for Normal and Freeze/Thaw Period

The resilient modulus is then used to calculate deterioration factors based on the climatic conditions and properties of the pavement layers. Deterioration is calculated in terms of elongation at the pavement base, surface curvature index (related to fatigue cracking) and vertical strain (associated with rutting [St. Laurent 2002]. In addition, MTO considers deterioration related to the serviceability as a pavement quality index, the structural number and the resilient modulus. The MTQ then develops relative deterioration profiles related to specific times of the year when damage can occur. Data from weigh in motion (WIM) scales are also used to supplement the analysis. The seasonal profile including the type of vehicle, ESAL, number of passages, number of axles and weight per axle is taken into consideration [St. Laurent 2002]. MTQ also has determined that significant damage does occur outside the spring thaw restrictions. They have also examined the duration of restrictions, deterioration in spring and summer (which is based on correlations between the Dynaflect deflection and the surface curvature index), and environmental effects on pavement serviceability. Overall, the MTQ does use FWD in combination with theoretical simulations to estimate spring damage and establishes restrictions accordingly [St. Laurent 2002].

Alberta also uses FWD to monitor strength recovery to determine when spring load restrictions can be removed. The FWD evaluations are converted to equivalent Benkelman Beam rebound values using historically developed models [Lew 2000]. Although there is some debate about how these models can be used, deflection data is an important tool for Alberta.

In the future it would be expected that heavy vehicle simulators, rolling wheel simulators and other devices could be used to better understand relationships. These devices and additional developments in laboratory devices will be used to also test new design alternatives [Goodings 2001].

2.1.2.2 Load Data

Another critical aspect in monitoring pavements is to properly estimate the number of loads and respective weight of each load. The effects of traffic loading on the structural integrity and service life although understood in a qualitative sense, are not fully quantified using state-of-the-art mechanistic tools [Clayton 2000].

Pavement service life depends to a large degree on the traffic levels to which it is subjected [TAC 1997]. The pavement damage resulting from each load is dependent on truck axle distribution, tire load and pressure, axle weight and the stiffness and thickness of each pavement layer. The most accurate method of determining the number of Equivalent Single Axle Loads (ESAL) carried by the pavement structure is to measure axle loads using equipment such as weigh-in-motion (WIM) devices. Several generalized relationships have been developed for various provinces in Canada and can be found in [TAC 1997]. It is critical that traffic data be collected. More specifically, designers and managers need to know the gross vehicle weights, axle load spectra and spacing. If the traffic loading is known, then this can be co-ordinated with the pavement structural data to ensure that the roads are not being overloaded during the weakest periods of the year.

2.1.3 Winter Weight Premiums

Unlike Spring Load Restrictions which are implemented because of weaknesses in the road structure, the limiting factor for implementing Winter Weight Premiums are the bearing capacity of the bridge structures. WWPs are allowed only in Western Canada in Manitoba, Saskatchewan, Alberta and the Northwest Territories. These are not allowed in B.C. because of concerns about braking on steep, slippery grades and because of the large number of bridges.

The data required is:

- Deflection/strength of the weakest structure on a route;
- Frost depth; and

- Characterizations of traffic loads
  - volume
  - % commercial
  - axle weight
  - # of axles
  - axle spacing
  - total weight
  - vehicle classification
  - vehicle height
  - vehicle width
  - vehicle length
  - speed
  - occupancy

2.2 Design

Traffic loading, environmental conditions, subgrade soil, construction and maintenance quality are among the various factors, which influence pavement performance. Environmental conditions can have a particularly significant impact on how well pavements will perform. In Canada, pavement designers need to pay special attention to various environmental design considerations such as freeze thaw cycles, spring thaw weakening and frost susceptible soils.

The basic objective of pavement design is to provide structural alternatives that are feasible both technically and economically. This is achieved by specifying pavement layer thickness with proper types of materials based on the traffic and environmental conditions and by life cycle cost analysis. In general, in order to achieve the best possible pavement design, three major groups of activities need to be performed as described in Figure 2-3.

Step 1

> The first step would be to collect information relating to materials, traffic, climate and costs. Other important inputs include the selection of a design period, structural and economic models, identification of objectives and constraints and variance on data inputs.

Step 2

> The second step involves the outputs. This would include the generation of design alternatives with specified life cycle strategies, including the material types and thickness, criteria on structural and economic analysis and various other factors.

Step 3

> In the third set of activities, the structural analysis and economic evaluation of alternatives would be carried out such that the best strategy for implementation would be selected. Overall the design system would include input and output data, separate analysis modules as well as report generating modules [Haas 1994, He 1997].

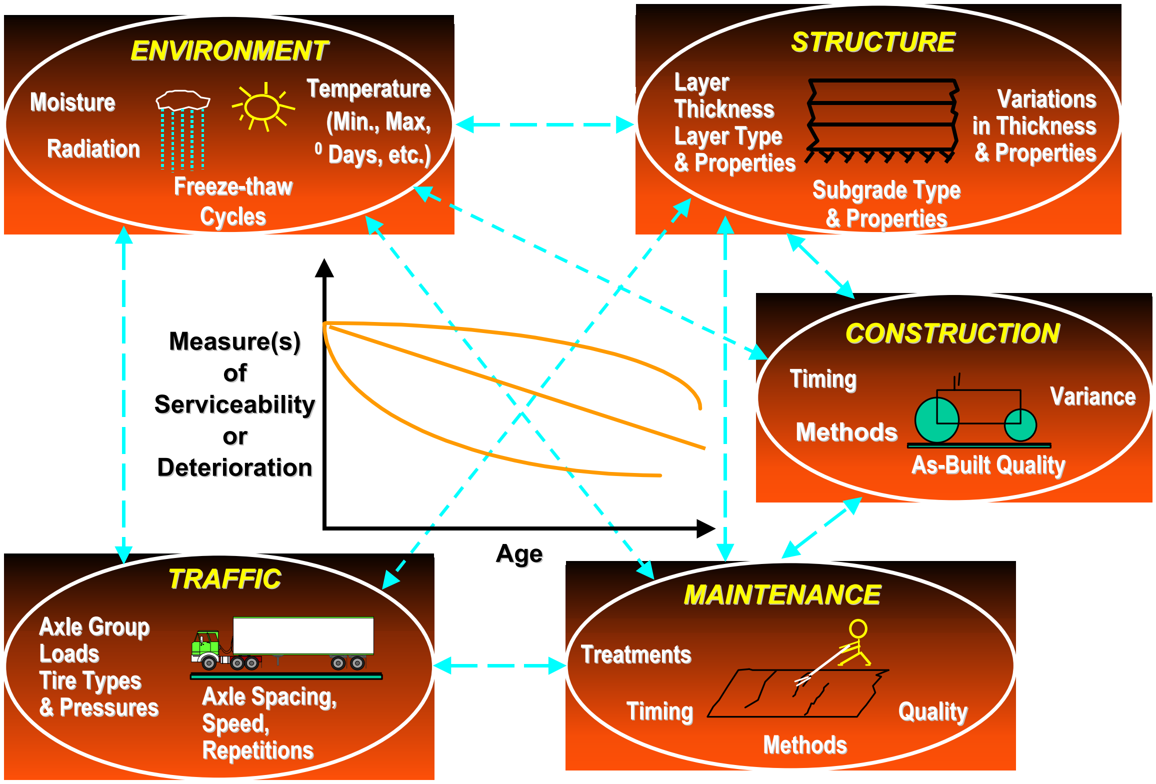

Figure 2-3: Framework of Pavement Design [TAC 1997]

In this study, it is intended to propose methods that reduce damage related to spring thaw, also the environmental design factors that will be required with the introduction of the new AASHTO Mechanistic-Empirical Design Guide will be discussed. The models must account for all pavement factors and the interaction of those factors (either explicitly or implicitly) as outlined in Figure 2-4.

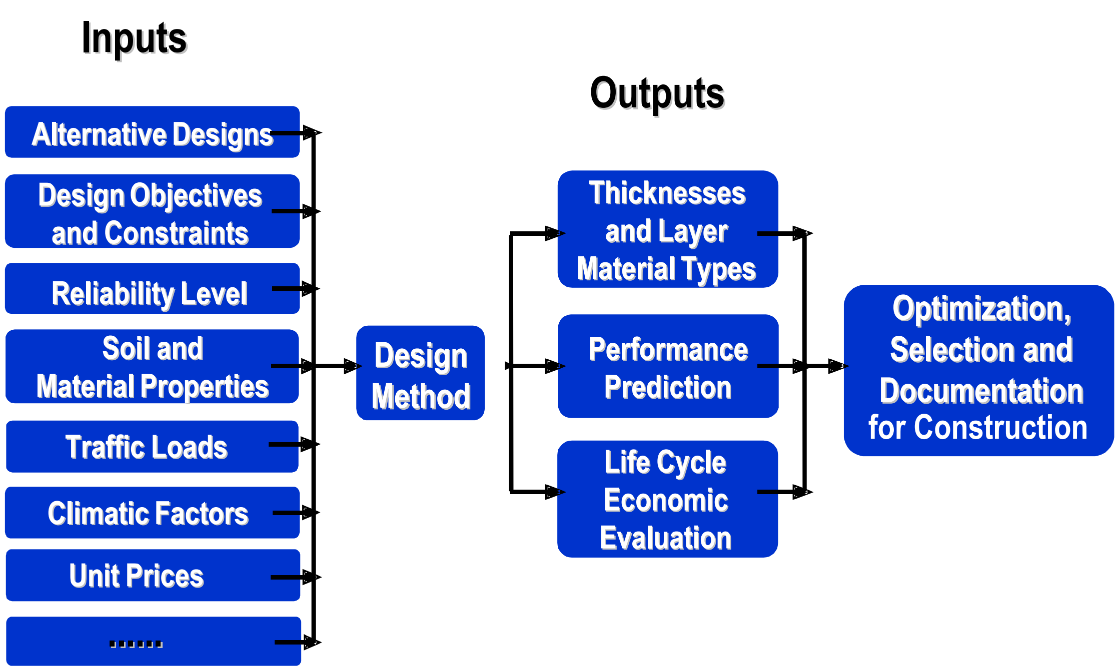

Figure 2-4: Factors Influencing Pavement Performance [Tighe 2001]

2.2.1 Methods

There are a variety of design methods used by different highway agencies. The methodology behind the design can in general be categorized into four groups:

1. Design based on experience with historic performance;

2. Design based on empirical pavement performance models where pavement performance is evaluated with a mathematical relationship developed from field data;

3. Design based on mechanistic analysis whereby design alternatives are evaluated through analyzing mechanistic response of the pavement structure, such as stress, strain and deflections; and

4. Design based on mechanistic-empirical performance model where performance is developed by employing mechanistic models combined with field data [Rauhut 1987].

Experience methods are based on best practise designs for a given region. Traditionally, they categorized pavement subgrades into 3 classifications (weak, medium, strong) and according to traffic levels (low, medium, high). A cross-reference table is developed that correlates pavement subgrade and traffic for the 3 layers, sub base, base, and asphalt thickness. Tables of experience based design thickness in the Canadian provinces are provided in [TAC 1997].

The design methods based on empirical pavement performance models can be reliable for the jurisdictions for which they are developed. A key limitation of the empirical methods is that they are difficult to use in regions where the field conditions are different from those used in developing the methods. Consequently they should be used only in area where conditions are similar to those conditions for which models were developed and caution may still need to be exhibited as field performance of in-service pavements within the inference space of the models have been shown to give different results [He 1997].

Mechanistic methods are based on analysis of the primary response in the pavement structure, such as deflection, stress and strain. Two factors contribute to the limited use of mechanistic models in highway agencies: (a) mechanistic methods require inputs from extensive laboratory testing and/or relatively precise field measurements, which is not always practical for highway agencies; (b) researchers in this field have realized that pavement performance will likely be influenced by a number of factors which will not be precisely modeled by mechanistic methods [AASHTO 1993].

The mechanistic-empirical approach is getting increased attention in various highway agencies and research bodies. The procedure calibrates the mechanistic (primary response) performance prediction model with observed performance indices, i.e. empirical correlation [Jung 1975]. Main benefits of such a procedure include: improved reliability, ability to predict specific types of distresses, ability to extrapolate from limited field and laboratory results [AASHTO 1993]. This type of model was recommended for the recent SHRP/LTPP studies in the United States and Canada [AASHTO 1993].

The new Mechanistic-Empirical Design Guide (known earlier as AASHTO 2002) has a revised set of standards for pavement design which include a variety of data. Required hourly information is air temperature, precipitation, wind speed, percentage sunshine (used to define cloud cover) and relative humidity. Data is also necessary in these four broad categories; general information, weather-related information, ground water related information, drainage and surface properties and pavement structure and materials [NCHRP 1-37A 2004].

Most pavement designs attempt to design the pavement structure to mitigate both environmental and load associated (traffic) damage. For the purpose of this report it will focus on environmental considerations. Several design features attempt to mitigate environmental damage. These include: removal of fine grained soils prior to paving, addition of sub-base and base layers to add protection for frost and the addition of drainage systems. Ultimately, pavement designers attempt to mitigate distresses by designing pavements that resist damage associated with both the environment and traffic.

The collection of field data could assist with any of the models used by transportation agencies. The data required for each model would be different:

Data requirements for experience models:

- Subgrade properties;
- Pavement thickness; and
- Characterizations of traffic loads
  - volume
  - % commercial
  - axle weight
  - # of axles
  - axle spacing
  - total weight
  - vehicle classification
  - vehicle height
  - vehicle width
  - vehicle length
  - speed
  - occupancy

Data requirements for Empirical models:

- Pavement age;
- Deflection/strength; and
- Characterizations of traffic loads
  - volume
  - % commercial
  - axle weight
  - # of axles
  - axle spacing
  - total weight
  - vehicle classification
  - vehicle height
  - vehicle width
  - vehicle length
  - speed
  - occupancy

Data requirements for Mechanistic models:

- Deflection/strength;
- Precipitation (hourly);
- Material properties for subgrade, sub-base, base, asphalt;
- Wind speed (hourly);
- Stress/strain;
- Percentage sunshine (used to define cloud cover) hourly or W/m²;
- Characterizations of traffic loads
  - volume
  - % commercial
  - axle weight
  - # of axles
  - axle spacing
  - total weight
  - vehicle classification
  - vehicle height
  - vehicle width
  - vehicle length
  - speed
  - occupancy
- Relative humidity (hourly);
- Pavement temperature (20 mins or hourly);
- Air temperature (20 mins or hourly); and
- Solar radiation.

Data requirements for Mechanistic-empirical models (AASHTO Guide):

- Stress/strain;
- Pavement temperature (hourly);
- Material properties for subgrade, sub-base, base, asphalt
- Air temperature (hourly);
- Precipitation (hourly);
- Wind speed (hourly);
- Percentage sunshine (used to define cloud cover) (hourly or more frequently);
- Relative humidity (hourly); and
- Solar radiation.

Data is also necessary in these four broad categories; general information, weather-related information, ground water related information, drainage and surface properties and pavement structure and materials [NCHRP 1-37A 2004 available at http://www.fhwa.dot.gov/pavement/dgitdata.htm].

2.2.2 Binder Selection

Temperature data plays a key role in pavement design and has an impact on the planning and operations and maintenance.

Temperature variations are incorporated in asphalt pavement design and construction through selection of asphalt cements (and asphalt emulsions for surface treated roads) for both low (winter) and high (summer) service conditions. The intent is to minimize thermally associated cracking under cold temperatures while at the same time, minimizing traffic associated rutting under summer temperatures. For example, in southern Ontario, an asphalt cement would likely be chosen to be a PG 58-28. This means the characteristics are such that it meets a minimum pavement temperature requirement of -28°C with 98 percent reliability. As well, it meets an average 7-day maximum temperature of 58°C, again with 98 percent reliability [Haas 2004].

If average temperatures increase, the minimum temperature requirement should be no problem. However, longer and warmer summers may well lead to increased rutting, higher maintenance costs and shortened service life. In other words, to accommodate the climate change, a PG 64-28 should perhaps be the required asphalt (the increment in grades is 6°C), which may have to be polymer or otherwise modified and thus more expensive. But of course, this can only be accomplished by either resurfacing with the new grade of asphalt (i.e., when the existing pavement has reached the end of its service life, which could be earlier than originally planned if excessive rutting has occurred), or reconstruction.

Another potential problem due to warmer temperatures is flushing or “bleeding” of asphalt to the pavement surface. This can occur for both hot mix asphalt surfaces and bituminous surface treatments (the latter being used extensively, for example, in the Yukon). Proper design and construction should be able to avoid this problem. However, some older pavements and/or those with excess asphalt content (i.e., an asphalt mix has to be carefully designed and compacted to have air voids in a range that minimizes rutting but at the same time maximizes durability) could be vulnerable. Even for these situations, the problem only occurs under several continuous days of record or near record temperatures [Haas 2004].

Another aspect that should be considered is the overall frost depth in the design. For example, additional base and sub-base can be included in the pavement structure to account for the frost depth. As noted in [TAC 1997] additional base and sub-base layer thickness with experience base designs is associated with deeper frost depth penetration. For example, in southern Ontario, a typical design for a given traffic volume and subgrade type would be 150 mm asphalt over 150 mm granular base and 450 mm of granular sub-base. However, if the design were placed in Northern Ontario, it would be 150 mm asphalt over 150 mm granular base and 600 mm of granular sub-base. The additional sub-base accounts for the increased depth of frost penetration.

Data requirements include:

- Characterizations of traffic loads
  - volume
  - % commercial
  - axle weight
  - # of axles
  - axle spacing
  - total weight
  - vehicle classification
  - vehicle height
  - vehicle width
  - vehicle length
  - speed
  - occupancy
- Historic temperature of asphalt surface (average daily, peak/minimum daily, average 7 day maximum);
- Traffic loading (static, slow moving or free flow); and
- Historic frost depth.

2.2.3 Design Considerations for Colder Climates

The design of pavement sections in cold regions involve additional aspects that may need to be included in the conventional design approach, these include [Mokwa 2004]:

- Evaluation of the depth of seasonal freezing;
- Consideration of changes that may occur in the active layer as a result of changes in the thermal and hydraulic regime;
- Potential damage as a result of frost heave deformation;
- Differential settlement caused by changes in soil strength and compressibility as a result of freeze/thaw cycles;
- Deformation and consolidation settlement as a result of thaw;
- Creep in ice-rich soils and permafrost;
- Thermal interaction between the structure and the ground; and
- Thermal aspects of backfill material.

Mechanical properties of subgrade soils are greatly affected by seasonal changes in temperature and soil moisture. This compounds the difficulties in determining an accurate value of soil modulus for projects constructed in cold regions. In addition to pavement distress caused by the freezing and heave phenomena, excessive damage may occur in cold regions during the spring as a result of thaw settlement, reduced bearing capacity, and increased compressibility [Mokwa 2004].

Data requirements include:

- Maximum depth of winter freezing;
- Consolidation settlement;
- Moisture content in subgrade, base and sub-base;
- Freeze/thaw cycles;
- Relative elevation of pavement structure;
- Material properties for subgrade, sub-base, base, asphalt; and
- Thaw progressions.

2.3 Operations and Maintenance

Operations and maintenance of road networks varies by transportation agency and encompasses a broad spectrum of responsibilities from snow removal to grass cutting, minor repairs such as potholes and cracks, replacement or repair of static signs and numerous others.

For the purposes of this report, the Operations and Maintenance function includes:

- Determination of when to impose and lift SLR; and
- Determination of when to permit and lift WWP.

The various factors that impact pavement performance and how that pertains to temperatures in the spring include, thawing that commences from above and below the frozen layer. During the thaw period, segregated water may not effectively drain out of the soil because the surrounding frozen ground is relatively impermeable [Mokwa 2004]. Consequently, the subgrade becomes temporarily saturated with water, which reduces the bearing capacity (strength) of the soil for supporting vehicular traffic or other loads. This process is commonly referred to as spring thaw or thaw weakening. During spring thaw, paved roads on top of frost-susceptible soils may experience a loss of 50 percent or more of the normal bearing capacity, while gravel-surfaced roads on frost susceptible soil may experience bearing capacity losses in excess of 70 percent. Damage to highways in the northern regions of the United States and Canada is economically significant, with cold weather related maintenance costs alone estimated to exceed 2 billion dollars annually, not including the costs of loss productivity, lost mobility, and delays [FHWA 2001, C-SHRP 2000].

One of the complicating factors with determining when to implement and lift SLR and WWP is the interrelationship between the allowable weights and the enforcement. Trucking agencies need to have sufficient advance notice in order to be able to plan their trips and their loads in order to meet the restrictions. Once a vehicle is loaded, its weight cannot be dynamically modified while enroute. Central Tire Inflation (CTI) provides another way to address dynamic loading, by adjusting the tire pressure to reduce the impact of the load on the road.

Although it varies by province, agencies typically require a minimum of 5 days of lead time to notify trucking agencies, consequently there needs to be some predictive or advance warning of when the SLR will be warranted.

2.3.1 Background

In order to better understand the issues surrounding SLR, Sections 2.3.1.1 and 2.3.1.2 outline:

- The mechanics of frost heave;
- The process of road deterioration; and
- The potential for climate change to further affect SLR and WWP policies.

2.3.1.1 Frost Heave/Thaw Weakening

Since the 1930s, numerous researchers have demonstrated that heave resulting from the formation of ice lenses is considerably greater than heave associated solely with expansion of freezing pore water in the soil voids. It is now generally recognized that frost heave is caused primarily by a phenomenon called ice segregation, which describes the basic mechanism that occurs as in-situ pore water is drawn from unfrozen soil to the freezing front where ice lenses are formed. Frost heave is associated with the volumetric expansion caused by migration of water into active ice lenses and the associated expansion that occurs when the water freezes [Mokwa 2004].

When frost susceptible soil freezes, individual ice lenses form as the freezing front advances downward. These ice lenses are generally lenticular in shape and are oriented roughly parallel to the isothermal freezing surface [Farouki 1981]. The rate of heave depends on the rate of heat extraction, the rate of water flow to the growing ice lens, and the compressibility of the unfrozen soil. This coupled process between heat flow and moisture flow is further complicated because the thermal and hydraulic properties of water, ice, and soil minerals are dependent functions of temperature, degree of saturation, and effective stress [Mokwa 2004].

A number of frost heave theories have been proposed to address the coupled thermal and hydrologic phenomena of ice lensing and frost heave. In general, the theories can be categorized under the following three headings:

1. Capillary Rise Theory

   When first introduced in the late 1950s by [Martin 1959], the capillary rise model represented a significant breakthrough in explaining the physics of frost heave. Although the model needed to be later modified, it did provide a basis for subsequent work. According to this theory, the capillary suction pressure that develops at the ice/water interface causes water to move towards a growing ice lens resulting in heave and heave pressures [Mokwa 2004].

However, subsequent experimental work [Miller 1972, Loch 1975, Penner 1980] indicates that in many cases the capillary model greatly underestimates the calculated values of heaving pressure.

2. Secondary Heave Theory

One of the primary limitations of the capillary model is that ice lens growth in partially frozen soil occurs some distance behind the freezing front [Miller 1972]. According to the secondary heave theory, water migration occurs through an intermediate partially frozen zone called the frozen fringe. A shortcoming of this theory is that modeling and predicting the rate and quantity of water migration is difficult because pore ice pressure (pi) and pore water tension (pu) vary within the frozen fringe during ice lens growth, and soil effective stress changes (increases) in the zone surrounding a forming ice lens. Additional estimates must be made when using the model to account for the variation of hydraulic conductivity within the frozen fringe, and the variation of thermal conductivity with temperature and water content [Mokwa 2004].

3. Segregation Potential Theory

The segregation potential theory is based on the concept that a continuous penetration of the frost front occurs in soil during unsteady heat flow, and that properties within the frozen fringe vary in response to temperature changes. A predictive frost heave model is somewhat limited if the model requires precise point measurements of hydraulic conductivity, temperature, and suction within the frozen fringe. Based on that premise, the segregation potential theory was developed in which a general formulation quantitatively describes the simultaneous heat and mass transfer phenomena in frozen soil using the overall characteristic properties of the frozen fringe as input, which are deduced from controlled laboratory freezing tests [Mokwa 2004].

The segregation potential theory provides an attractive approach for modelling the response of frozen soil using the following basic steps [Mokwa 2004]:

1. The segregation potential is determined by performing laboratory frost heave tests.

2. The segregation potential is calculated and used to compute the incremental frost heave across the frozen front

3. The total frost heave and ice content are computed by summing the incremental values of frost heave obtained at each time step. The rate and quantity of moisture migration

A recent study by Dore and Imbs [Dore 2004] suggests that the three most important factors affecting the behaviour of pavements during spring thaw include:

1. The amount of frost heave that occurs per unit thickness in the considered layer.
2. The rate at which the layer is thawing.
3. The rate at which the layer consolidates.

The work by Dore further suggests that a thaw weakening index should be developed to assist in predicting weakening in the pavement structure. It is proposed as:

$$TWin = (h/D) \times (X/S) \quad (6)$$

Where:
- TWin = Thaw weakening index
- h = Total heave resulting from frost action in subgrade soil (min)
- D = Thickness of subgrade soil affected by frost action (min)
- X = Thawing rate (mm/day)
- S = Settlement rate (mm/day)

This dimensionless index incorporates several factors that have been identified as being important with respect to the weakening behaviour of a given material. The rate of thawing is identified as a function of the climatic conditions during spring, and the resulting thermal response of the material. In addition, the consolidations and volume change is incorporated into the prediction [Dore 2004].

The TWin then needs to involve a field validation which includes collection of the more specific site data [Dore 2004]:

- Thickness of the frozen soil layer (frost depth);
- Total frost heave (assuming no significant frost heave occurs in the pavement granular layers);
- Thaw progression as a function of time during the spring;
- Relative elevation of the pavement structure as a function of time during spring thaw and the associated recovery period; and
- A measurement of the evolution of the pavement bearing capacity with time.

Data requirements include:

- Material properties for subgrade, sub-base, base, asphalt;
- Capillary action;
- Frost depth;
- Freeze/thaw cycles;
- Water level table;
- Thaw progression;
- Moisture content;
- Relative elevation of the pavement structure;
- Pavement temperature (maximum, average);
- Air temperature (max, min, average); and
- Deflection/strength.

2.3.1.2 Road Deterioration

Road deterioration is influenced by a set of factors and their interactions as schematically illustrated in Figure 2-4. The actual deterioration, as shown in the mid part of the diagram, can be concave down, straight line or concave up. Consequently, it must be recognized that environment or climate factor effects occur in combination with all the other factors of Figure 2-4.

Recognizing this complexity, it is still possible to estimate climate factor effects on road deterioration and cost, as indicated in the Cold Climate Paper [Haas 2004], which classifies roads as paved, gravel and snow and ice. While the latter are important in several areas of

Canada, they are comparatively minor in terms of mileage, investment and traffic. Gravel roads comprise nearly two-thirds of the total Canadian mileage, but they are usually low volume and represent a much smaller investment than the paved road network. Nevertheless, gravel roads, in the Western part of Northern Canada, are a vital part of the road transportation system.

The major factors of Tables 2–2 and 2–3 [Haas 2004] affecting road deterioration and in turn costs, is freeze-thaw cycles, as well as temperature change. All the other factors can be important to specific areas or locations but should be comparatively small in the total cost picture. While few, if any, road deterioration models incorporate freeze-thaw cycles as an independent variable (i.e., freeze-thaw cycles are indirectly incorporated through regional calibration, such as the separate OPAC 2000 models for northern and southern Ontario [He 1997]) it is well recognized that a high number of freeze-thaw cycles can accelerate road deterioration. This is particularly the case where a frost susceptible subgrade and a high amount of precipitation exist.

In fact, a recent analysis of a comprehensive, Canada-wide study on long-term pavement performance has clearly demonstrated that the highest rate of deterioration occurs in wet, low-freeze zones with fine grained subgrades [Tighe 2001a] as subsequently illustrated. The term, low-freeze, applies to areas with a high number of freeze-thaw cycles. If climate change increases the area(s) of high number of freeze-thaw cycles, as estimated, for example in several of the zones in Table 2-1, then the net effect would certainly be accelerated road deterioration, higher maintenance costs and higher life-cycle costs.

Table 2-1: Estimated Climatic Factor Changes or Effects Accompanying Temperature Increases [Haas 2004]

Zone	Climatic Factor and Likely Change or Effect					
	Freeze-Thaw Cycles	Flooding and Washouts	Slope Failures	Thermal Degradation	Precipitation (Snow & Rain)	Icing
1. Coastal B.C. and Lower Main.	Minimal	Increase	Increase	N/A	?	Minimal
2. Interior B.C.	Increase	Increase	Increase	N/A	Increase	?
3. W. Arctic & N. Portion of Prairie Provinces	Increase	?	Increase	Increase	?	Increase
3. W. Arctic (Continuous Permafrost Zone)	Minimal	?	Increase	Increase	?	Increase
5. S. Portion of Prairie Provinces	Increase	?	?	N/A	Decrease (?)	Decrease
6. Northern Ont.	Increase	?	Increase	Increase	Decrease (?)	Increase
7. Southern Ont.	Increase	?	Minimal	N/A	Decrease(?)	Decrease
8. Northern Que.	Increase	Increase	Increase	N/A	Decrease(?)	Increase
9. S. & Eastern Que.	Increase	Increase	Increase	N/A	Decrease(?)	Decrease

Zone	Climatic Factor and Likely Change or Effect					
	Freeze-Thaw Cycles	Flooding and Washouts	Slope Failures	Thermal Degradation	Precipitation (Snow & Rain)	Icing
10. Atlantic Provinces	Minimal	Increase	Increase	N/A	Increase	Decrease

Table 2-2: Factor Effects on Road Deterioration and Costs: (A) Paved Roads [Haas 2004]

Factor	Remarks	Maintenance Costs	Life-Cycle Costs
Increased freeze-thaw cycles	Increased rate of deterioration and shortened service life, particularly in areas of fine-grained (frost susceptible) soils	Higher	Higher
Increased flooding and washout	More frequent replacement	Higher	Higher
Increased slope failures	More frequent repairs	Higher	Higher
Thermal degradation	a) Existing discontinuous permafrost zone will be reduced b) Existing continuous permafrost zone will be reduced (part will become discontinuous)	Little change Higher Higher	Little change Higher
A) Precipitation increase	More skidding accidents and accelerated moisture damage to pavement	Lower	Higher
B) Precipitation decrease	Less of above	Little change	Lower
A) Icing increase	More accidents	Little change	Little change
B) Icing decrease	Fewer accidents		Little change

Table 2-3: Factor Effects on Road Deterioration and Costs: (B) Gravel Roads [Haas 2004]

Factor	Remarks	Maintenance Costs	Life-Cycle Costs
Increased freeze-thaw cycles	Increased rate of deterioration and shortened service life, particularly in areas of fine-grained (frost susceptible) soils	Little change	Little change
Increased flooding and washouts	More frequent replacement	Higher	Higher
Increased slope failures	More frequent repairs	Higher	Higher
Thermal degradation	a) Existing discontinuous permafrost zones reduced	Little change	Little change
	b) Existing continuous permafrost zones reduced, but part becomes discontinuous	Higher	Higher
A) Precipitation increase	More frequent gravel replacement	Higher	Higher
B) Precipitation decrease	Less frequent gravel replacement	Lower	Lower
C) Icing increase	More accidents	Little change	Little change
D) Icing decrease	Fewer accidents	Little change	Little change

The reason that increased freeze-thaw cycles result in accelerated deterioration for the foregoing situations is due to frost heaving in the freezing cycle (where the subgrade is saturated) combined with subsequent thaw weakening of the structure. In colder (high freeze) areas, the freezing front progresses rapidly into the subgrade, and stays there until spring thaw weakening (i.e., only one or very few freeze-thaw cycles). This means that the structure stays strong throughout the winter. The problem with a warmer condition and a larger number of freeze-thaw cycles is usually exacerbated by a freezing front that only penetrates to a limited depth in the subgrade, thereby incurring the uptake of water due to capillary rise, and adding to the frost heave and subsequent thaw weakening [Haas 2004].

Fatigue damage in asphalt pavements weakened by spring thaw can significantly reduce pavement life and serviceability. During the spring thaw, large quantities of water become trapped in pavement layers. Several factors that can contribute to this include: material expansion from drawn up groundwater (via capillary forces) and pavement thaw from surface down to subgrade occurs and saturated conditions do not allow for drainage of the layers [Tighe 2000]. Normally an asphalt pavement structure will behave in such a manner that the load is transferred through the structure as shown in Figure 2-5. However when the pavement structure is partially thawed and saturated, the vertical stress on the saturated layer is transformed into strain. This is related to the fact it is saturated at this point. In this state, the pavement structure will be subject to load related deformations. The worst case occurs when the thaw enters into the subgrade as the pavement structure experiences a very severe loss of strength. When heavy loads are repeatedly applied to the pavement in the weakened condition, extensive fatigue damage can occur [Gough 1985]. Thus, measures that can adequately predict weakened state can provide cost savings and reduce damage to pavement life. In short if heavy truck loading is minimized or eliminated during this period, it will mitigate fatigue damage associated with thaw weakening.

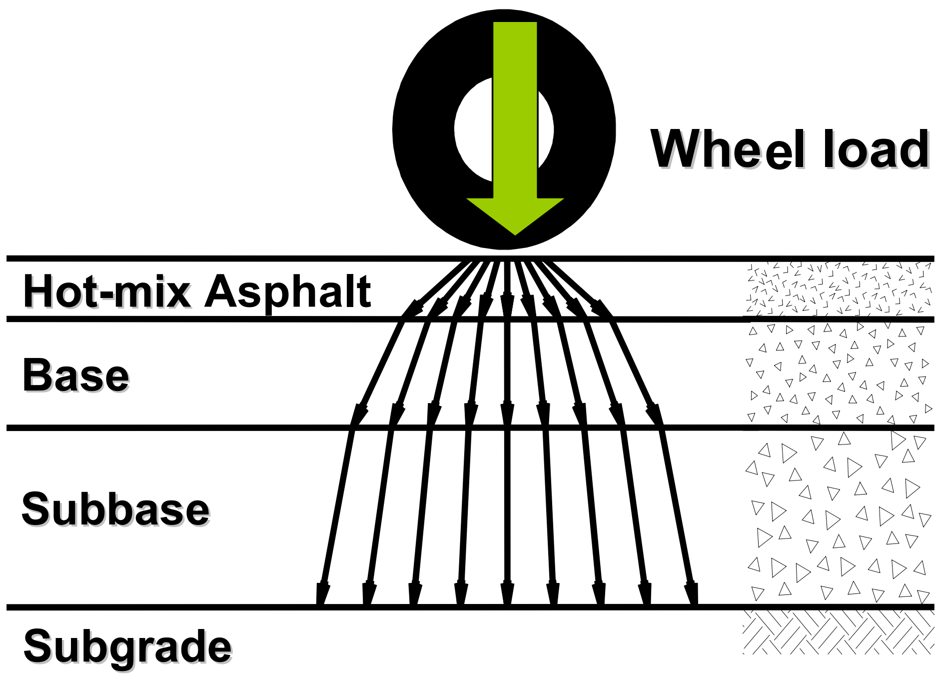

Figure 2-5: Flexible Structure

Data requirements include:

- Roughness;
- Absorption and albido (solar reflection);
- Pavement condition index;
- Pavement distress; and
- Deflection/strength.

2.3.2 SLR Implementation

Spring Load Restrictions are implemented using a number of different methods. Many transportation agencies base their imposition of load restrictions in visual observations of conditions such as water pumping, near cracks and shoulders. One disadvantage to this is that often once surface damage occurs, significant damage has already occurred in the lower layers. Others use fixed start dates that are derived through analysis of historic thaw periods, but that are not able to deal with annual fluctuations.

This section outlines quantitative methods including:

- Deflection/strength of the road structure;
- Depth of frost; and
- Thaw Index.

Deflection/strength data is used by some agencies to determine when to implement the SLR. In addition to the data being used for planning purposes, to determine which roads to implement the SLR on, for agencies that do not used a calendar based approach deflection data can help to pin point the best start date or to modify a planned fixed start date.

Deflection measurement equipment, as described in Section 2.1.2.1 is used as the weather starts to warm up in the spring to determine when the road is starting to weaken and to loose strength.

Although deflection measurements are time and labour intensive they provide a good method to quantitatively assess the road strength.

Deflection data correlates to road strength, so an alternative method of determining road strength would also provide a method to deliver the SLR implementation date quantitatively.

The depth of frost and its dissipation is a function, in part, on the magnitude and duration of the temperature differential of the pavement structure and the ambient air temperature. The thawing index is a function of the number of “degree-days” above a reference temperature that would result in the onset of pavement structure thawing. A number of jurisdictions have developed models to determine a thawing index as a function of a reference temperature, which varies by the time of year. The reference temperature takes into account the solar radiation variations in the spring months. SLRs are imposed when weather forecasts predict that the cumulative Thaw Index exceeds a defined threshold, based on the following modified Minnesota model:

$$Ti_{date} = Ti_{previous\ date} + \text{Reference Temperature} + \text{Daily Mean Temperature}_{date}$$

where:

TI = Thawing Index

Reference Temperature = 1.7°C beginning March 1 and increasing 0.06°C per day (Manitoba) or 1.5°C beginning February 1 and increasing 0.56°C per week (Ottawa)

Daily mean temperature = (maximum + minimum Daily Air Temperatures)/2

The reference temperature increases throughout March in order to account for the increase in radiation. Once the cumulative thaw index reaches 13-15°C (dependent on Agency), then the SLR is implemented. The MTGS uses a reference temperature (RT) on March 1st of every year and the daily incremental temperature is assumed to be 0.06°C. The RT is added to a daily Thaw Index (TI) on a daily basis. Once the TI exceeds 15°C and the forecast according to Environment Canada indicates continued increases in the TI then the spring road restrictions are applied. Note, provincial monitoring is divided into two areas based on climatic conditions. Essentially if the TI indicated that the fixed date is premature, then the TI takes precedence [MTGS 2004].

The Thaw Index method is effectively used by a number of jurisdictions including Manitoba and Minnesota. Ottawa has also begun using the Thaw Index for Spring 2005.

Thaw depth readings are used by some agencies to set the SLR implementation date. Once the thaw depth reaches a specified depth, the road is considered to be weak and the SLR is implemented.

Data requirements:

- Pavement thickness;
- Deflection/strength (tensile stain);
- Stress/strain;
- Pavement surface temperature (peak/min daily, average daily);
- Air temperature (peak/min daily, average daily);
- Characterizations of traffic loads
  - volume
  - % commercial
  - axle weight
  - # of axles
  - axle spacing
  - total weight
  - vehicle classification
  - vehicle height
  - vehicle width
  - vehicle length
  - speed
  - occupancy
- Moisture content of base, sub-base, and subgrade materials;
- Solar radiation (current and predictive);
- Saturation;
- Forecasted temperatures (minimum of 5 day); and
- Frost depth.

2.3.3 SLR Lifting

Spring Load Restriction lifting is currently done primarily through qualitative or fixed date methods. Some agencies rely on deflection data to determine when the road strength is recovering or rebounding to confirm that the fixed date. Other agencies use thaw depth to lift the SLR.

Data requirements:

- Moisture content of base, sub-base, subgrade;
- Frost depth; and
- Recovery period (lag time).

2.3.4 WWP Implementation

Winter Weight Premiums are not used as consistently as SLR across Canada. There are two methods currently used to determine when to implement WWP including frost depth and number of days of temperatures at less than 0°C.

Data requirements:

- Frost depth;
- Air temperature (peak/min daily, average daily); and
- Pavement temperature (peak/min daily, average daily).

2.3.5 WWP Lifting

The lifting of WWP is most typically done by fixed date across Canada. Alberta uses frost depth to determine when to lift WWP.

Data requirements:

- Material properties for subgrade, sub-base, base, asphalt;
- Frost depth;
- Salinity; and
- Strength/deflection.

2.4 Information Dissemination

Once a transportation agency has determined which roads will have SLR or WWP and when they will be in place, they need to disseminate the information to the agencies that will be affected by them. Typically this is the various trucking agencies and enforcement agencies.

Each agency uses a number of methods in order to distribute the information. Regulatory requirements such as static signs are supplemented by other methods including:

- Web site;
- Newspapers;
- E-mail;
- 511;
- Fax polling service; and
- Interactive Voice Response.

Information has typically been distributed in text format, with tables or lists summarizing which roads have restrictions and what the level of restriction is. Agencies have been moving to providing the information graphically as this is more easily understood.

In order to provide the SLR/WWP imposition and lifting information, the following information must been known:

- Roads that have SLR or WWP (either highway name or GIS based);
- Date of imposition;
- Date of lifting;
- Revised legal load limit; and
- Fax/e-mail addresses for trucking association representative.

3. DATA REQUIREMENTS

The data requirements for each of the functions were consolidated. Sections 3.1 to 3.4 provide an overall list of the data types required for the planning, design, operations and maintenance, and traveller information function. A summary table for the planning, design, and operations and maintenance has also been included (see Table 3-1) that groups the requirements into Road Structure, Traffic or Environmental requirements.

It is clear from the lists that there is a lot of duplication between the planning, design, and operations and maintenance functions. Therefore, collection of data to support the imposition and lifting of SLR and WWP will have benefits for the planning and design functions as well.

3.1 PLANNING

The following types of data are required for the Planning function:

- Deflection/strength of the road structure (historic);
- Strength of the weakest structure (bridge);
- Frost depth (historic);
- Characterizations of traffic loads
  - volume
  - % commercial
  - axle weight
  - # of axles
  - axle spacing
  - total weight
  - vehicle classification
  - vehicle height
  - vehicle width
  - vehicle length
  - speed
  - occupancy
- Material properties for subgrade, sub-base, base, asphalt;
- Pavement age;
- Pavement distress data (surface defects, cracking, rut depth);
- Roughness;
- Climatic (daily temperatures (min/max/mean), precipitations (max, day);
- GPS referenced locations; and
- Database and GIS mapping platform.

3.2 DESIGN

The following types of data are required for the Design function:

- Deflection/strength of the road structure;
- Pavement age;
- Characterizations of traffic loads
  - volume

- % commercial
- axle weight
- # of axles
- axle spacing
- total weight
- vehicle classification
- vehicle height
- vehicle width
- vehicle length
- speed
- occupancy

- Stress/strain;
- Pavement temperature, current and historic (hourly, daily average, max/min daily, average 7 day max/min);
- Air temperature (hourly, daily average, max/min daily, average 7 day max/min);
- Precipitation (hourly);
- Wind speed (hourly);
- % Sunshine (used to define cloud cover) hourly or W/m^2;
- Relative humidity (hourly);
- Frost depth (historic, yearly and max);
- Freeze/thaw cycle;
- Thaw progression;
- Consolidation settlement;
- Nature of traffic loading (static, slow moving or free flow);
- Relative elevation of pavement structure (up or down);
- Moisture content in subgrade, sub-base and base;
- Solar radiation; and
- Material properties for subgrade, sub-base, base, asphalt.

3.3 OPERATIONS AND MAINTENANCE

The following types of data are required for the Operations and Maintenance function:

- Deflection/strength of the road structure;
- Stress/strain;
- Material properties for subgrade, sub-base, base, asphalt;
- Pavement thickness;
- Capillary action;
- Characterizations of traffic loads
  - volume
  - % commercial
  - axle weight
  - # of axles
  - axle spacing
  - total weight
  - vehicle classification
  - vehicle height
  - vehicle width
  - vehicle length
  - speed

  - occupancy
- Pavement distress including type, severity and density;
- Roughness of surface;
- Pavement temperature (hourly, daily average, max/min daily, average 7 day max/min);
- Air temperature (hourly, daily average, max/min daily, average 7 day max/min);
- Precipitation (hourly);
- Frost depth, current;
- Freeze/thaw cycle;
- Thaw progression;
- Thaw index;
- Water level table;
- Relative elevation of pavement structure;
- Moisture content in subgrade, sub-base and base materials;
- Forecasted temperature (5 day);
- Thaw depth, current;
- Salinity;
- Solar radiation (current and predictive);
- Recovery period (lag time); and
- Saturation.

3.4 INFORMATION DISSEMINATION

Data requirements for Information Dissemination include:

- Roads that have SLR or WWP;
- Date of imposition;
- Date of lifting;
- Revised legal load limit; and
- Fax/e-mail addresses for trucking association representative.

3.5 SUMMARY

Table 3-1 summarizes the data requirements for the planning, design, and operations and maintenance functions. The data has been sorted into three categories that relate to the type of information and include road structure, traffic and environmental data types.

Table 3-1: Data Requirements for Planning, Design, and Operations and Maintenance Functions

	Road Structure	Traffic	Environmental
Planning	Deflection/strength (historic) Strength of weakest structure (i.e., bridge) Pavement age Distress data (surface defects, cracking, rut depth) Material properties for subgrade, sub-base, base, asphalt Roughness	Characterizations of traffic loads: volume, % commercial, axle weight, # of axles, axle spacing, total weight, vehicle classification, vehicle height, vehicle width, vehicle length, speed, occupancy	Frost depth (historic) Daily temperatures (min/max/mean) Precipitation (max, day)
Design	Deflection/strength Pavement age Material properties for subgrade, sub-base, base, asphalt Stress/strain Relative elevation of pavement structure (up or down) Moisture content in subgrade, sub-base and base Consolidation settlement	Characterizations of traffic loads: volume, % commercial, axle weight, # of axles, axle spacing, total weight, vehicle classification, vehicle height, vehicle width, vehicle length, speed, occupancy	Pavement temperature (hourly, daily average, max/min daily, average 7 day max/min) Air temperature (hourly, daily average, max/min daily, average 7 day max/min) Precipitation (hourly) Wind speed (hourly) % Sunshine (hourly or W/m^2) Relative humidity (hourly) Frost depth (yearly historic and max) Freeze/thaw cycle Thaw progression Solar radiation

	Road Structure	Traffic	Environmental
Operations & Maintenance	Deflection/strength Stress/strain Material properties for subgrade, sub-base, base, asphalt Pavement thickness Capillary action Relative elevation of pavement structure (up or down) Moisture content in subgrade, sub-base and base Distress data (surface defects, cracking, rut depth) Roughness Water level table Salinity Recovery period (lag time) Saturation	Characterizations of traffic loads: volume, % commercial, axle weight, # of axles, axle spacing, total weight, vehicle classification, vehicle height, vehicle width, vehicle length, speed, occupancy	Pavement temperature (hourly, daily average, max/min daily, average 7 day max/min) Air temperature (hourly, daily average, max/min daily, average 7 day max/min) Precipitation (hourly) Frost depth (daily max/min) Thaw depth (daily max/min) Freeze/thaw cycle Thaw progression Thaw index Solar radiation (current and predictive) Forecast min/max daily air temperatures (5 days in advance)

A consolidated list of all of the requirements includes:

Road Structure

- Deflection/strength (historic and current);
- Strength of weakest structure (i.e., bridge);
- Pavement age;
- Distress data (surface defects, cracking, rut depth);
- Material properties for subgrade, sub-base, base, asphalt;
- Roughness;
- Stress/strain;
- Relative elevation of pavement structure (up or down);
- Moisture content in subgrade, sub-base and base;
- Consolidation settlement;
- Pavement thickness;

- Capillary action;
- Water level table;
- Salinity;
- Recovery period (lag time); and
- Saturation.

Traffic

- Characterizations of traffic loads
  - volume
  - % commercial
  - axle weight
  - # of axles
  - axle spacing
  - total weight
  - vehicle classification
  - vehicle height
  - vehicle width
  - vehicle length
  - speed
  - occupancy

Environmental

- Pavement temperature (hourly, daily average, max/min daily, average 7 day max/min);
- Air temperature (hourly, daily average, max/min daily, average 7 day max/min);
- Precipitation (hourly, max, day);
- Wind speed (hourly);
- % Sunshine (hourly or W/m^2);
- Relative humidity;
- Frost depth (historic max, daily max/min);
- Freeze/thaw cycle;
- Thaw progression;
- Thaw depth (daily max/min);
- Solar radiation (current and predictive); and
- Forecast min/max daily air temperatures (5 days in advance).

Other

- Roads that have SLR or WWP;
- Date of imposition;
- Date of lifting;
- Revised legal load limit; and
- Fax/e-mail addresses for trucking association representative.

4. CANADIAN ITS ARCHITECTURE

The ITS Architecture for Canada provides a unified framework for integration to guide the coordinated deployment of ITS programs within the public and private sectors. It offers a starting point from which stakeholders can work together to achieve compatibility among ITS elements to ensure unified ITS deployment for a given region. It is for this reason that it is important that the architecture defined for the use of ITS for Variable Load Restrictions, be based on, and remain compliant with, the ITS Architecture for Canada.

The ITS Architecture for Canada is based on a group of User Services that define the functionality of ITS components and the information flows among ITS elements to achieve total system goals. The User Services are hierarchically organized into User Service Bundles, User Services, User Sub-Services, and User Service Requirements. Section 4.1 uses the relevant User Services to define the high level functional requirements for this project.

The ITS Architecture for Canada includes separate Logical and Physical Architectures. The Logical Architecture defines processes and data flows between processes required to support the User Services defined for the ITS Architecture for Canada. The Physical Architecture provides a physical representation (though not a detailed design) of the important interfaces, in the form of Architecture Flows. It also identifies major system components, in the form of Subsystems and Terminators. The Physical Architecture provides a high-level structure around the processes and data flows defined in the Logical Architecture.

The Canadian ITS Architecture is a useful ITS tool to assist agencies with the delivery of interoperable systems. It is developed based on User Needs and maps out Market Packages that can be used to deliver those User Needs.

The User Services and Market Packages that are applicable for this project are included in Sections 4.1 and 4.2. The definitions include the full architecture definition, which helps to illustrate how ITS for SLR and WWP can fit into a larger ITS context.

4.1 User Services

A review of the user requirements against the Canadian ITS Architecture identifies the following User Service Bundles, User Services and User Sub-services:

1 Traveller Information Services

1.1 Traveller Information

1.1.1 Broadcast Traveller Information

Provides the user with a basic set of ATIS services; its objective is early notification. It involves the collection of traffic conditions, road conditions, advisories, general public transportation, toll and parking information, incident information, air quality and weather information, and the near real time dissemination of this information over a wide area through existing infrastructures and low cost user equipment (e.g., FM sub carrier, cellular data broadcast). Different from the user sub-service 2.1.5 – Traffic Information Dissemination – which provides the more basic HAR and DMS information capabilities, this sub-service provides the more sophisticated digital broadcast service. Successful deployment of this user sub-service relies on availability of real-time traveller information from roadway instrumentation, probe vehicles or other sources.

1.1.2 Interactive Traveller Information

Provides tailored information in response to a traveller request. Both real-time interactive request/response systems and information systems are supported, which "push" a tailored stream of information to the traveller based on a submitted profile. The traveller can obtain current information regarding traffic conditions, road conditions, transit services, ride share/ride match, parking management, and pricing information. A range of two-way wide-area wireless and wireline communications systems may be used to support the required digital communications between traveller and the information service provider. A variety of interactive devices may be used by the traveller to access information prior to a trip or en-route to include phone, kiosk, Personal Digital Assistant, personal computer, and a variety of in-vehicle devices. Successful deployment of this user sub-service relies on availability of real-time transportation data from roadway instrumentation, probe vehicles, parking managers, transit providers, or other means.

2 Traffic Management Services

2.4 Environmental Conditions Management

2.4.1 Roadway Environmental Sensing

This Canadian user sub-service monitors road and weather conditions using data collected from environmental sensors deployed on and about the roadway. In addition to fixed sensor stations at the roadside, sensor systems located on the Maintenance Vehicle Subsystem can provide information on road and weather conditions. The collected environmental data is analysed by the Traffic Management Subsystem to detect and forecast environmental hazards such as icy road conditions, dense fog, and approaching severe weather fronts. This information can be used to support ATMS and ATIS functions including more effectively deploy road maintenance resources, issue general traveller advisories, and support location specific warnings to drivers using the user sub-service 2.1.5 – Traffic Information Dissemination – or the user sub-service 8.1.2 – Environmental Information Dissemination.

2.4.3 Road Weather Information System

Monitors current and forecast road and weather conditions using a combination of weather service information and data collected from environmental sensors deployed on and about the roadway. The collected road weather information is monitored and analysed to detect and forecast environmental hazards such as icy road conditions, dense fog, and approaching severe weather fronts. This information can be used to more effectively deploy road maintenance resources, issue general traveller advisories, improve emergency management and response, and support location specific warnings to drivers using the user sub-service 2.1.5 – Traffic Information Dissemination.

2.4.4 Vehicle-Based Sensing

Provides for special requirements of rural road systems. Instead of a central TMC, the traffic management is distributed over a very wide area (e.g., a whole province or collection of provinces). Each locality has the capability of accessing available information for assessment of road conditions. The sub-service uses vehicles as smart probes that are capable of measuring road conditions and providing this information to the roadway for relay to the Traffic Management Subsystem and potentially direct relay to following vehicles (i.e., the automated road signing equipment is capable of autonomous operation). In-vehicle signing is used to inform drivers of detected road conditions.

2.5 Operations and Maintenance

2.5.1 Infrastructure Maintenance Management

This Canadian user sub-service supports automated management of fleets of maintenance, construction, or special service vehicles. These types of vehicles include snowplows and sand/salt trucks. This Canadian user sub-service includes the infrastructure-based systems that monitor vehicle location, vehicle status, and the output of sensors (such as environmental or road surface sensors) which are mounted on the vehicles. Also included are the systems within the maintenance vehicles that create this information and send it to the control centre or control system. The infrastructure systems perform vehicle dispatch, routing, and asset management.

2.6 Automated Dynamic Warning and Enforcement

2.6.1 Dynamic Roadway Warning

This Canadian user sub-service supports the dynamic presentation of warning information to drivers. Warnings may be generated in response to roadway weather conditions, road surface conditions, traffic conditions, obstacles or animals in the roadway, and any other transient events that can be sensed. Warnings may also be generated that recognise the limitations of a given vehicle for the geometry of the roadway, (e.g. rollover risk for tall vehicles). This user sub-service differs from “Traffic Information Dissemination” in that it is possible for all processing to occur remotely at the roadside, making this capability autonomous for remote application. It also expands the capabilities of user sub-service 2.1.5 – Traffic Information Dissemination by focusing on non-traffic roadway issues.

5 Commercial Vehicle Operations

5.1 Commercial Vehicle Electronic Clearance

5.1.1 Electronic Clearance

Provides for automated clearance at roadside check facilities. The roadside check facility communicates with the Commercial Vehicle Administration subsystem over wireline to retrieve infrastructure snapshots of critical carrier, vehicle, and driver data to be used to sort passing vehicles. This user sub-service allows a compliant driver/vehicle/carrier to pass roadside facilities at highway speeds using transponders and dedicated short-range communications to the roadside. The roadside check facility may be equipped with AVI, weighing sensors, transponder read/write devices, computer workstation processing hardware, software, and databases.

5.1.3 Weigh-In-Motion (WIM)

Provides for high-speed weigh-in-motion with or without AVI attachment. Primarily this user sub-service provides the roadside with additional equipment, either fixed or removable. If the equipment is fixed, then it is thought to be an addition to the electronic clearance and would work in conjunction with the AVI and AVC equipment in place.

5.4 Commercial Vehicle Administrative Processes

5.4.1 Commercial Vehicle Administrative Processes

Provides for electronic application, processing, fee collection, issuance, and distribution of CVO credential and tax filing. Through this process, carriers, drivers, and vehicles may be enrolled in the electronic clearance program provided by a separate user sub-service which allows commercial vehicles to be screened at mainline speeds at commercial vehicle check points. Through this enrolment process, current profile databases are maintained in the Commercial Vehicle Administration Subsystem and snapshots of this database are made available to the commercial vehicle check facilities at the roadside to support the electronic clearance process.

8 Information Warehousing Services

8.1 Weather and Environmental Data Management

8.1.1 Roadway and Weather Data Fusion

This Canadian user sub-service supports the fusion of roadway environmental data with general weather forecasts and observations. Roadside sensor systems, or sensor systems mounted on maintenance vehicles collect roadway environmental data while the national weather service (Meteorological Service of Canada) provides the basic weather data and modelling functions.

8.1.2 Environmental Information Dissemination
This Canadian user sub-service supports the dissemination of roadway and weather data to centres which can utilize it as part of their operations, or to the Information Service Providers who can provide the information to travellers.

8.1.3 Roadway Meso and Micro Prediction
This Canadian user sub-service supports advanced systems which use the data from the Roadway and Weather Data Fusion user sub-service, along with advanced algorithms, to create micro-predictions of roadway conditions which can support improved maintenance planning and dispatch.

4.2 Market Packages

The following Market Packages map to the User Services defined in Section 4.1.

Virtual TMC and Vehicle-Based Sensing (ATMS12)
This market package provides for special requirements of rural road systems. Instead of a central TMC, the traffic management is distributed over a very wide area (e.g. a whole province or collection of provinces). Each locality has the capability of accessing available information for assessment of road conditions. The package uses vehicles as smart probes that are capable of measuring road conditions and providing this information to the roadway for relay to the Traffic Management Subsystem and potentially direct relay to following vehicles (i.e., the automated road signing equipment is capable of autonomous operation). In-vehicle signing is used to inform drivers of detected road conditions.

Road Weather Information System (ATMS18)
This market package monitors current and forecast road and weather conditions using a combination of weather service information and data collected from environmental sensors deployed on and about the roadway. The collected road weather information is monitored and analysed to detect and forecast environmental hazards such as icy road conditions, dense fog, and approaching severe weather fronts. This information can be used to more effectively deploy road maintenance resources, issue general traveller advisories, and support location specific warnings to drivers using the Traffic Information Dissemination Market Package.

Roadway Environmental Sensing (ATMS20)
This Canadian Market Package monitors current road and weather conditions using data collected from environmental sensors deployed on and about the roadway. In addition to fixed

sensor stations at the roadside, sensing of the roadway environment can also occur from sensor systems located on the Maintenance Vehicle Subsystem. The collected environmental data is analysed by the Traffic Management Subsystem to detect and forecast environmental hazards such as icy road conditions, dense fog, and approaching severe weather fronts. This information can be used to more effectively deploy road maintenance resources, issue general traveller advisories, and support location specific warnings to drivers using the Traffic Information Dissemination Market Package or the Environmental Information Dissemination Market Package.

Roadway and Weather Data Fusion (ATMS21)
This Canadian Market Package supports the fusion of roadway environmental data with general weather forecasts and observations. The roadway environmental data comes from roadside sensor systems, or sensor systems mounted on maintenance vehicles. The weather data comes from the Weather Service (Environment Canada).

Environmental Information Dissemination (ATMS22)
This Canadian Market Package supports the dissemination of roadway and weather data to centers which can utilise it as part of their operations, or to the Information Service Providers who can provide the information to travellers.

Roadway Micro-Prediction (ATMS23)
This Canadian Market Package supports advanced systems which use the data from the Roadway and Weather Data Fusion Market Package, along with advanced algorithms, to create micro-predictions of roadway conditions which can support improved maintenance planning and

Dynamic Roadway Warning (ATMS26)
This Canadian Market Package supports the dynamic presentation of warning information to drivers. Warnings may be generated in response to roadway weather conditions, road surface conditions, traffic conditions, obstacles or animals in the roadway, and any other transient events that can be sensed. Warnings may also be generated that recognise the limitations of a given vehicle for the geometry of the roadway, e.g. rollover risk for tall vehicles. This Canadian Market Package differs from Traffic Information Dissemination in that it is possible for all processing to occur remotely at the roadside, making this capability autonomous for remote application. It also expands the capabilities of Traffic Information Dissemination by focusing on non-traffic roadway issues.

Variable Speed Limit and Enforcement (ATMS27)
This Canadian Market Package supports the ability to dynamically vary speed limits in response to roadway conditions. This could include lowering speed limits due to weather or traffic conditions, to reduce the risk of accidents. This Canadian Market Package also relates to the Smart Work Zones Market Package when it is used to aid in traffic calming around roadwork areas. A key capability of this Canadian Market Package is the ability to provide automated enforcement of the variable speed limit, by detecting and conveying violation information to law enforcement. This Canadian Market Package can be used to build on the capability of Dynamic Roadway Warning, to create an enforceable lowering of the speed limit in response to transient, localised roadway conditions.

Electronic Clearance (CVO03)
This market package provides for automated clearance at roadside check facilities. The roadside check facility communicates with the Commercial Vehicle Administration subsystem over wireline to retrieve infrastructure snapshots of critical carrier, vehicle, and driver data to be used to sort passing vehicles. This package allows a compliant driver/vehicle/carrier to pass roadside facilities at highway speeds using transponders and dedicated short-range communications to the roadside. The roadside check facility may be equipped with AVI, weighing sensors,

transponder read/write devices, computer workstation processing hardware, software, and databases.

Commercial Vehicle Administrative Processes (CVO04)
This market package provides for electronic application, processing, fee collection, issuance, and distribution of CVO credential and tax filing. Through this process, carriers, drivers, and vehicles may be enrolled in the electronic clearance program provided by a separate market package which allows commercial vehicles to be screened at mainline speeds at commercial vehicle check points. Through this enrolment process, current profile databases are maintained in the Commercial Vehicle Administration Subsystem and snapshots of this database are made available to the commercial vehicle check facilities at the roadside to support the electronic clearance process.

Weigh-In-Motion (WIM) (CVO06)
This market package provides for high speed weigh-in-motion with or without AVI attachment. Primarily this market package provides the roadside with additional equipment, either fixed or removable. If the equipment is fixed, then it is thought to be an addition to the electronic clearance and would work in conjunction with the AVI and AVC equipment in place.

4.3 Summary

Table 4-1 summarizes the interrelationship between the User Services and the Market Packages.

Table 4-1: Applicable User Service and Market Packages

User Service Bundle	User Service	User Sub-Service	Market Package
1 Traveller Information Services	1.1 Traveller Information	1.1.1 Broadcast Traveller Information	Road Weather Information System (ATMS18)
			Roadway and Weather Data Fusion (ATMS21)
			Environmental Information Dissemination (ATMS22)
			Variable Speed Limit and Enforcement (ATMS27)
		1.1.2 Interactive Traveller Information	Road Weather Information System (ATMS18)
			Roadway and Weather Data Fusion (ATMS21)
			Environmental Information Dissemination (ATMS22)
			Variable Speed Limit and Enforcement (ATMS27)
2 Traffic Management Services	2.4 Environmental Conditions Management	2.4.1 Roadway Environmental Sensing	Roadway Environmental Sensing (ATMS20)
		2.4.3 Road Weather Information System	Road Weather Information System (ATMS18)
			Roadway Environmental Sensing (ATMS20)
		2.4.4 Vehicle-Based Sensing	Virtual TMC and Vehicle-Based Sensing (ATMS12)
	2.5 Operations and Maintenance	2.5.1 Infrastructure Maintenance Management	Roadway Environmental Sensing (ATMS20)
	2.6 Automated Dynamic Warning and Enforcement	2.6.1 Dynamic Roadway Warning	Dynamic Roadway Warning (ATMS26)
5 Commercial Vehicle Operations	5.1 Commercial Vehicle Electronic Clearance	5.1.1 Electronic Clearance	Variable Speed Limit and Enforcement (ATMS27)
			Electronic Clearance (CVO03)
		5.1.3 Weigh-In-Motion (WIM)	Variable Speed Limit and Enforcement (ATMS27)
			Weigh-In-Motion (WIM) (CVO06)
	5.4 Commercial Vehicle Administrative Processes	5.4.1 Commercial Vehicle Administrative Processes	Commercial Vehicle Administrative Processes (CVO04)
8 Information Warehousing Services	8.1 Weather and Environmental Data Management	8.1.1 Roadway and Weather Data Fusion	Roadway and Weather Data Fusion (ATMS21)
		8.1.2 Environmental Information Dissemination	Environmental Information Dissemination (ATMS22)
		8.1.3 Roadway Meso and Micro Prediction	Roadway Micro-Prediction (ATMS23)

5. EQUIPMENT

There are many equipment manufacturers that provide all types of equipment to meet the data needs for planning, design, and operations and maintenance.

Appendix A provides a summary table of many different manufacturers, their products, applications and some preliminary costing (where available).

The equipment required for the specific system concept defined to address SLR and WWP is outlined in Section 6.2. This equipment forms a subset of the equipment defined in Appendix A.

6. SYSTEM CONCEPT

The system concept includes the definition of the system functionality, the hardware required to deliver the functionality and the software required to meet the functionality. The system concept was also outlined within the context of the Canadian ITS Architecture. A preliminary cost was prepared for a basic and an advanced system.

6.1 System Functionality

The three primary stages in the determination and implementation/termination of SLR and WWP are:

1. Collection of relevant weather and roadway data;
2. Analysis of data to make decision; and
3. Dissemination of information.

Each of these three stages are described in further detail in Sections 6.1.1 to 6.1.3. In addition, the three stages have been broken down into requirements for a basic system and requirements for an advanced system.

6.1.1 Data Collection

6.1.1.1 Data Collection – Basic

Section 3.5 identified data requirements for the planning, design, and operations and maintenance of asphalt pavement in Canada. A review of the data necessary to allow quantitative analysis efforts for determining when to implement and lift SLR and WWP, resulted in identification of a subset of this data Based on the algorithms that were selected in Sections 6.2.1 to 6.2.4, the list of data that will be collected through in-situ equipment or derived from collected data includes:

- Road Structure
  - Deflection/strength;
  - Stress/strain;

  - Moisture content in subgrade, sub-base and base;
  - Pavement, base, sub-base thickness; and
  - Recovery period (lag time).
- Environmental
  - Pavement temperature;
  - Air temperature;
  - Frost depth;
  - Freeze/thaw cycle;
  - Thaw depth;
  - Thaw indices;
  - Solar radiation; and
  - Forecast min/max daily air temperatures (5 days in advance).
- Other
  - Roads that have SLR or WWP;
  - Date of imposition;
  - Date of lifting;
  - Revised legal load limit; and
  - Fax/e-mail addresses for trucking association representative.

The data will be collected in real time and aggregated into configurable resolutions ranging from 5 minutes to 24 hours. The identification of minimums and maximums will also be possible. All raw data will be stored by the system.

This data may be collected by a number of different types of equipment, depending on the preferences of the agency and availability of technology. Further information may be found in Section 6.3.1.

6.1.1.2 Data Collection – Advanced

The data collection requirements for the Advanced System include the requirements for the Basic System plus the following requirements:

- Road Structure
  - Displacement or relative elevation of pavement structure (up or down); and
  - Consolidation settlement.

6.1.2 Algorithms

An analysis of existing algorithms that are currently used internationally to determine when to implement and lift SLR and WWP was completed. See Appendix D for details of this analysis. The algorithms that have been suggested for use for this system concept for SLR and WWP implementation and lifting are included in Sections 6.1.2.1 to 6.2.2.6.

6.1.2.1 SLR Implementation

The most commonly used equations are the Thaw Index and the measured depth of thaw. The other equations, such as the MBE, have not been used for operational purposes within Canada. Minnesota completed testing of the MBE [Berg 1997] and the report published in March 1997 compares computer frost depths using MBE to measured frost depths. Further work done by Minnesota in 2000 [Ovik 2000] to define the Thaw Index and Freezing Index did not include use of this equation. Calculation of a thaw weakening index is considered to be at the leading edge of the quantitative analysis of spring road conditions. The equation that has been proposed is in its infancy and may be subject to further modifications with further research. Therefore, the use of this equation has been included in the Advanced System description.

6.1.2.2 SLR Implementation – Basic

A combination of algorithms is proposed to address the need adequately and to allow for alarm verification. There will initially be two algorithms used for generating SLR implementation alarms. Algorithm 1 will detect an alarm state. Algorithm 2 will be used to assist with providing 5 day advance notice.

1. SLR implementation will be determined based on the following logic statement:

   If Strain ≥ a and thaw depth ≥ b and moisture content ≥ c then SLR

   -OR-

   If Strain ≥ a and 5 day thaw index ≥ b and moisture content ≥ c then SLR

   where:

   Strain – measured at the bottom of asphalt (maximum for day)

   Thaw Depth – measured

   Moisture content – measured

   5 Day thaw index – is a computed thawing Index for specific date (where this date is in the future, forecasted air temperatures are used and converted to pavement temperatures using the reference temperature)

   a and c are configurable values calibrated in a lab

   b is configurable per area but generally within 20-30 cm

   NOTE: That Moisture content is also represented by a % moisture content that exists in the subgrade.

2. Advance warning of SLR implementation will be determined by the following logic statements:

   If Strain < a and thaw depth ≥ b and Moisture content ≥ c then SLR advance warning

   -OR-

   If Strain ≥ a and thaw depth < b and Moisture content ≥ c then SLR advance warning

   -OR-

If Strain ≥ a and 5 Day thaw index < b_1 and Moisture content ≥ c then SLR advance warning

-OR-

If Strain < a and 5 Day thaw index ≥ b_1 and Moisture content ≥ c then SLR advance warning

where:

Strain – measured at the bottom of asphalt (maximum for day);

5 Day thaw index – is a computed thawing Index for specific date (where this date is in the future, forecasted air temperatures are used and converted to pavement temperatures using the reference temperature)

Moisture content – measured

a and c are configurable values calibrated in a lab or developed through field observation

b is configurable per area but generally within 20-30 cm

b_1 is configurable per area but generally 13-15°C

5 Day Thaw Index details:

$TI_{date}=TI_{previous\ date}$ + Reference Temperature + Daily Mean $Temperature_{date}$

where:

$TI_{previous\ date}$ = summation of mean measured pavement temperatures from a specified start date.

Reference Temperature = p°C beginning q and increasing r (where p = 1.7 for Manitoba and p=1.5 for Ottawa), q = March 1 for Manitoba and q = February 1 for Ottawa, r = 0.06°C/day for Manitoba and r = 0.56°C/week for Ottawa

Daily mean temperature = (maximum + minimum Daily Air Temperatures)/2

This equation is run using measured pavement temperatures from the previous day, along with forecasted air temperatures for the next 5 days. These forecasted air temperatures will be entered into the system by the user. The user will obtain this information from Environment Canada. The reference temperature converts the air temperature to pavement temperature. Alternatively, the TAC conversion could be used.

An alternative for this equation, that would take Solar Radiation measurements into account, would be:

$TI_{date}=TI_{previous\ date}$ + Solar Radiation Factor * Daily Mean $Temperature_{date}$

where:

TI_{date} = Thawing Index for specific date (where this date is in the future, forecasted air temperatures are used and converted to pavement temperatures by multiplying by a Solar Radiation Factor)

$TI_{previous\ date}$ = summation of mean measured pavement temperatures from a specified start date

Solar Radiation Factor = calculated based on historic radiation (either last 5 days or based on previous years information) and factor developed through comparative analysis

Daily mean temperature = (maximum + minimum Daily Air Temperatures)/2

6.1.2.3 SLR Implementation – Advanced

If an Advanced System is deployed, the following equation would be run in parallel to the equations defined in Section 2.2.1.1 to determine when to implement SLR.

SLR implementation is determined necessary if the thaw weakening index computed as TWin = (h/D) x (X/S) exceeds a user defined threshold.

where:

TWin = Thaw weakening index

h = Total heave resulting from frost action in subgrade soil (mm)

D = Thickness of subgrade soil affected by frost action (mm)

X = Thawing rate (mm/day)

S = Settlement rate (mm/day)

6.1.2.4 SLR LIFTING – Basic and Advanced

1. A determination to lift and implement SLR will be based on the following logic statement:

   If Strain ≤ d and thaw depth ≥ e and Moisture content ≤ f then SLR lifting

   where:

   Strain – measured at the bottom of asphalt

   Thaw Depth – measured

   Moisture content – measured

   d,f are configurable values calibrated in a lab

   e is configurable per area but generally within 100-125 cm

NOTE: there are several agencies doing Dynaflect, FWD or Benkelman Beam testing throughout the spring and other periods of the year. There may be value in allowing these measured values to be added to the system, along with the date and time so as to allow a comparison between strain measured at the sensor and the Dynaflect, FWD or Benkelman Beam measurements.

2. Advance warning of SLR lifting will be determined by the following logic statements:

   If Strain ≤ d and 5 Day thaw index ≥ e and Moisture content ≤ f then SLR lifting advance warning

   where:

   Strain – measured at the bottom of asphalt

   5 Day thaw index – see Section 2.2.1.1

   Moisture content – measured

   d,f are configurable values calibrated in a lab

   e is configurable per area but generally within 100-125 cm

6.1.2.5 WWP IMPLEMENTATION – Basic and Advanced

A combination of algorithms is proposed to address the need adequately and to allow for alarm verification. There will initially be two algorithms used for generating WWP implementation alarms. Algorithm 1 will detect an alarm state. Algorithm 2 will be used to assist with providing 5 day advance notice.

1. WWP implementation will be determined based on the following logic statement:

   If Strain ≤j and frost depth ≥ k then WWP

   -OR-

   If Strain ≤j and 5 day freeze index ≥ k_1 then WWP

   where:

   Strain – measured at the bottom of asphalt (maximum for day)

   Frost Depth – measured

   5 Day freeze index – is a computed freezing Index for specific date (where this date is in the future, forecasted air temperatures are used and converted to pavement temperatures using the reference temperature)

   j, k and k_1 are configurable values calibrated in a lab

2. Advance warning of WWP implementation will be determined by the following logic statements:

If Strain ≤j and frost depth < k then WWP

-OR-

If Strain ≤j and 5 day freeze index < k_1 then WWP

-OR-

If Strain >j and frost depth ≥ k then WWP

-OR-

If Strain >j and 5 day freeze index ≥ k_1 then WWP

where:

Strain – measured at the bottom of asphalt (maximum for day)

Frost Depth – measured

j, k and k_1 are configurable values calibrated in a lab

5 Day freeze index – is a computed freezing Index for specific date (where this date is in the future, forecasted air temperatures are used and converted to pavement temperatures using the reference temperature)

$FI = \sum(0^{\circ}C - T_{mean})$

where:

FI = Freezing Index

T_{mean} = mean daily temperature, °C = ½ (T1 + T2)

T_1 = maximum daily air temperature

T_2 = minimum daily air temperature

This equation is run using measured pavement temperatures from the previous day, along with forecasted air temperatures for the next 5 days. These forecasted air temperatures will be entered into the system by the user. The user will obtain this information from Environment Canada. The reference temperature converts the air temperature to pavement temperature. Alternatively, the TAC conversion could be used.

6.1.2.6 WWP LIFTING – Basic and Advanced

1. WWP lifting will be determined based on the following logic statement:

   If Strain ≥l and frost depth ≤ m then WWP

   -OR-

   If Strain ≥l and 5 day freeze index ≤ m_1 then WWP

   where:

   Strain – measured at the bottom of asphalt (maximum for day)

   Frost Depth – measured

   5 Day freeze index – is a computed freezing Index for specific date (where this date is in the future, forecasted air temperatures are used and converted to pavement temperatures using the reference temperature)

   l, m and m_1 are configurable values calibrated in a lab

2. Advance warning of WWP lifting will be determined by the following logic statements:

   If Strain ≥l and frost depth > m then warning

   -OR-

   If Strain ≥l and 5 day freeze index > m_1 then WWP

   -OR-

   If Strain <l and frost depth ≤ m then WWP

   -OR-

   If Strain <l and 5 day freeze index ≤ m_1 then WWP

   where:

   Strain – measured at the bottom of asphalt (maximum for day)

   Frost Depth – measured

   5 Day freeze index – is a computed freezing Index for specific date (where this date is in the future, forecasted air temperatures are used and converted to pavement temperatures using the reference temperature)

   l, m and m_1 are configurable values calibrated in a lab

   $FI = \sum(0^{o}C - T_{mean})$

where:

FI = Freezing Index

T_{mean} = mean daily temperature, °C = ½ (T1 + T2)

T_1 = maximum daily air temperature

T_2 = minimum daily air temperature

This equation is run using measured pavement temperatures from the previous day, along with forecasted air temperatures for the next 5 days. These forecasted air temperatures will be entered into the system by the user. The user will obtain this information from Environment Canada. The reference temperature converts the air temperature to pavement temperature. Alternatively, the TAC conversion could be used.

6.1.3 Information Dissemination

Transportation agencies across Canada use a diverse set of tools to disseminate information to commercial agencies. Integration of the data into a GIS-based central system will assist with electronic dissemination through the various technologies employed by these agencies, including:

- Web site;
- E-mail;
- 511;
- Fax polling service; and
- Interactive Voice Response.

The system will generate responses for the various dissemination devices using the information stored in the central computer. These responses will be developed using predefined templates and will be approved by the users prior to dissemination.

6.2 HARDWARE REQUIREMENTS

The high-level system functional requirements were described in Section 6.1. The physical equipment required to deliver this functionality is described in this section. These have been broken down by their physical location into field components and central components.

There are two alternatives for how the field data can be processed. Field data can be sent to the central system for processing or field data can be processed locally through field controllers, which generate alarms and aggregate data for transmission to the central system. The choice of field or central processing is often driven by communication requirements and infrastructure availability. Regardless of where the data processing for each site is performed, there will always be a central processing function to store, archive and visually display information from all of the sites in a central location.

6.2.1 Field Components

The data that is required to run the algorithms can be delivered by a variety of equipment. Therefore, wherever possible, agencies can make use of their existing infrastructure or their hardware preferences. For example, if there are existing Remote Weather Information Systems (RWIS) or planned RWIS deployments, these sites could be augmented with additional sensors to meet all of the requirements. Alternatively, if an agency has frost probes in place, it may wish to add additional equipment at that location.

Table 6-1 summarizes what type of hardware can be used to provide the information and whether the data is gathered directly from the installed equipment or derived through calculation from other data.

Table 6-1: Equipment Versus Data Summary

	Environmental/Road												Traffic												Deflection/Strength						
	Earth pressure cells	Dynamic soil pressure cell	Frost probes	Thermocouples / thermistor probes	Pavement sensors (passive)	Time domain detectors/ time domain reflectometry probe (TDR)	Frequency domain reflectometry/ radio frequency sensors (FDR)	Soil moisture sensor	Moisture block (watermark) sensors	Net radiation sensor	Solar radiation sensor	Road weather information system (RWIS)	Inductive loop detectors (ILD)	Non-invasive microloops	Piezoelectric sensors	Load-cells	Active infrared detection systems	Microwave sensors	Overhead profiler	Ground-based profiler	Video image detection systems (VID)	Axle treadle	Weigh-in-motion systems (WIM)	Remote control weigh station (RCWS)	Linear variable differential transducers	Linear variable differential transformers (LVDT)	Strain gauges	Strain gauge: biaxial embedment	Accelerometer	Pressure transducer	Comments
Road Structure																															
Deflection/strength																															Deflection will be manually entered into the system based on FWD or BB readings that are completed by the agency. Deflection may be able to be derived from measured strains.
Stress/strain	√	√																									√	√	√	√	
Relative elevation of pavement structure (up or down)																									√	√					
Moisture content in subgrade, sub-base and base						√	√	√	√																						
Consolidation settlement																															Calculated from displacement.
Pavement, base, sub-base thickness																															This information will be available from the design process.
Recovery period (lag time)																															Difference between start and end of SLR.
Saturation						√	√	√	√																						
Environmental																															
Pavement temperature					√							√																			
Air temperature												√																			
Frost depth			√	√		√	√		√																						
Freeze/thaw cycle																															Calculated based on frost/thaw depth over time.
Thaw progression																															Calculated based on thaw depth over time.
Thaw depth			√	√		√	√		√																						
Solar radiation										√	√	√																			
Forecast min/max daily air temperatures (5 days in advance)																															Provided by Environment Canada. In the future it may be possible to have a system-to-system interface.
Other																															
Roads that have SLR or WWP																															Determined in advance by the agency based on its assessment of road design and road condition.
Date of imposition																															Calculated by the system using predefined algorithms.
Date of lifting																															Calculated by the system using predefined algorithms.
Revised legal load limit																															Determined in advance by the agency based on its assessment of road design and road condition.
Fax/e-mail address for trucking association representative																															Collected by the agency and configured in the system.

The system will also include other checks and balances, using more traditional approaches, to ensure that data is valid. For example, as there is a correlation between pavement temperature and strain, the system will also include a check and backup for the strain measurements. A table will be configured in the system, based on laboratory results, that correlates pavement temperature to strain.

All equipment will be installed in accordance with the equipment manufacturer's recommendations.

If the final design architecture identifies a need for distributed processing, then some sort of Advanced Field Controller (AFC) would be deployed that comprises the necessary communication interfaces to consolidate the various sensor devices and perform local processing of data. Software specific to this application would be developed in conjunction with the central software requirements. The AFC will be a rugged, industrial PC custom designed to support the necessary hardware interfaces and that will run the software application. It is generally preferred that a centralized system be used, where all of the data will be sent to the central system for processing.

National Transportation Communications for ITS Protocol (NTCIP) standards will be used wherever possible for communication to field devices.

6.3 Central Components

The central system components will comprise the necessary software and hardware elements to collect, analyze and disseminate the SLR and WWP information. The software will be developed to poll each of the AFCs or field device controllers for information (either processed or raw, depending on where the processing is completed) and to display the information graphically on a GIS-based map. The alarms that are generated for warning or for SLR implementation and lifting and WWP implementation and lifting will be graphically displayed here for review and acceptance by a user. The central system will also generate the information for dissemination through e-mail and facsimile and to external systems that may deploy other technologies such as interactive voice and 511. This will allow data to be graphically disseminated, which will be helpful for users to illustrate where there are restrictions in place.

Data will be stored and archived for use by the planning and design departments.

The software requirements of an SLR/WWP automated monitoring system will be referred to as the "Roadway Conditions Watch" application or RCWatch for short.

The full set of RCWatch requirements are outlined in the Software Requirements Specification (SRS) in Appendix E. The SRS describes the software components of RCWatch that provide the roadway condition monitoring and notification functions for a centralized operations centre. Depending on physical implementation and the capabilities of off-the-shelf field equipment, RCWatch will comprise software that runs on one or more centrally located computers and may additionally include software running on a distributed network of field controllers.

The principal function of the software is to collect and analyze surface and sub-surface data to identify periods for which to implement SLR and WWP.

The primary business process supported by RCWatch is the collection and analysis of surface and sub-surface data for a defined roadway network for the purpose of determining the appropriate periods during which the SLR and WWP programs are to be implemented.

RCWatch will aid operating agencies by automating the process of roadway condition monitoring and the dissemination of these conditions to various other departments and external agencies as required.

6.3.1 External Entities

Figure 6-1 contains the context diagram of the application software, which defines the scope and logical boundaries of RCWatch. The diagram depicts RCWatch as a single element connected (either logically or physically) to external entities that can comprise hardware, software and human operators.

6.3.1.1 User

The User is any system operator designated by the RCWatch owner to monitor and control the RCWatch application. There may be one or more Users of RCWatch at any given time. The term 'User' is used throughout this document when referring to any person that interacts with the system, including daily system operators, supervisors and engineers.

6.3.1.2 Weather Transducers

The Weather Transducer block represents the various field devices that directly collect the surface and sub-surface data required by RCWatch. The network of field devices and their associated communications infrastructure are considered to be outside the scope of the RCWatch effort. However, the RCWatch scope will include any software that needs to be developed for distributed field data collection, based upon the overall hardware and communications architecture design.

6.3.1.3 Environment Canada

Environment Canada will provide necessary weather data to the RCWatch application for use in the determination of SLR and WWP implementation periods. As a minimum, RCWatch will include capabilities for manual entry of this data but will optionally allow for an automated exchange of data.

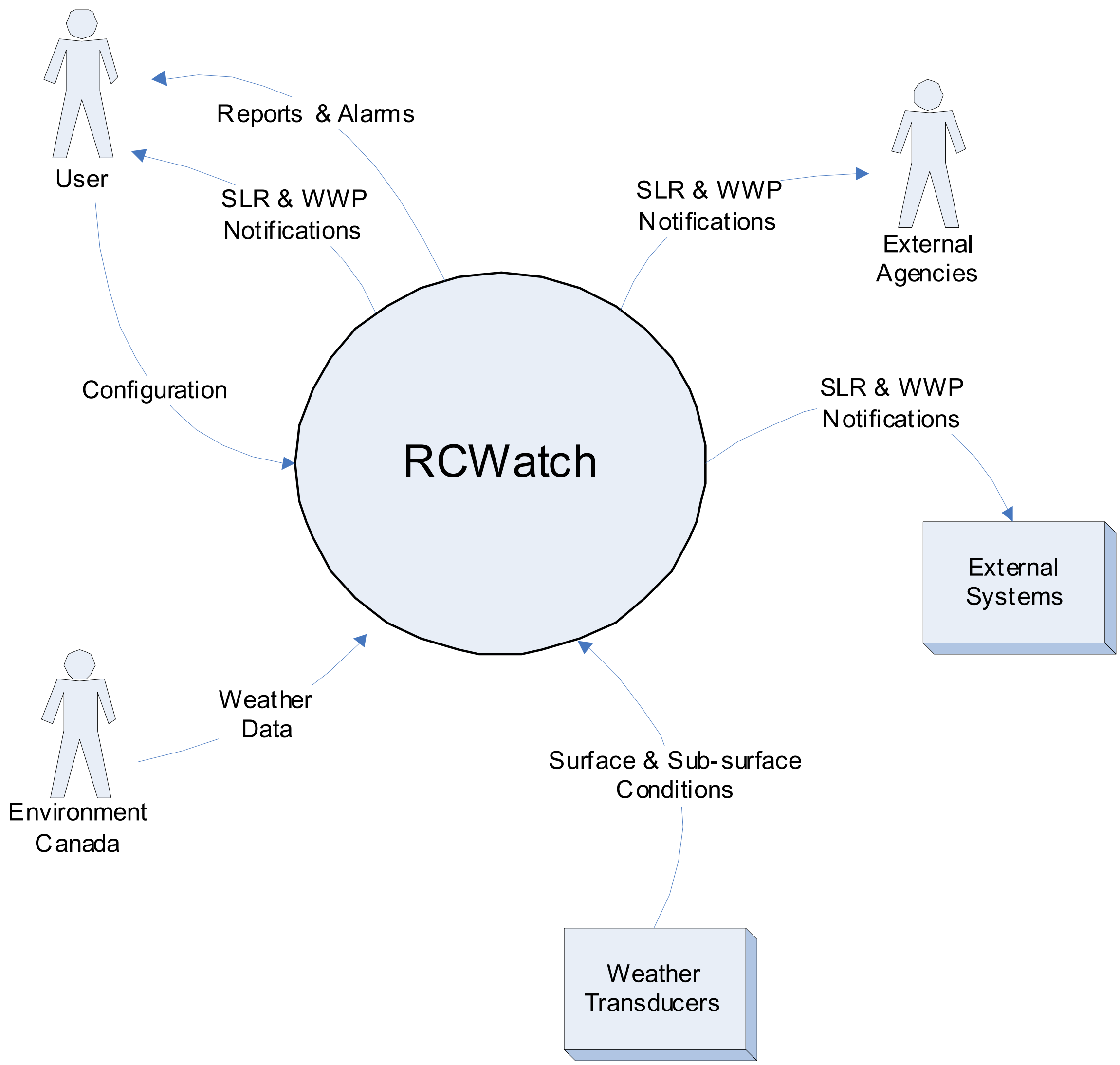

Figure 6-1: RCWatch Context Diagram

6.3.1.4 External Agencies

The RCWatch application will generate data in a suitable format for dissemination to relevant external departments and agencies. RCWatch will include options for the dissemination technologies such as e-mail and facsimile.

6.3.1.5 External Systems

The RCWatch application will provide necessary hooks for future integration and data exchange with external systems such as an Interactive Voice, 511 or Advanced Traffic Management Systems.

6.3.2 Product Functions

The primary functions provided by the RCWatch software are graphically depicted in Figure 6-2. A bubble represents each function, and the external 'actors' or entities with which the software must interact are represented by stick figures. The lines that join the actors to the functions simply indicate that some level of interaction exists between the actor and the particular RCWatch capability.

The lines that are drawn from one function to another indicate the existence of some level of functional reliance. A function that <<extends>> another function can be viewed as a function that adds value to the primary goal(s) of the other functions. A function that <<includes>> another function can be viewed as a function that requires the work of that other function for the realization of its primary goal(s).

The primary RCWatch functions are described below. As previously stated, this requirements document does not impose any particular physical design. An RCWatch function is simply a collection of related requirements and does not necessarily represent a software process or executable.

DATA COLLECTION

The Data Collection function of RCWatch will collect all relevant data from the configured field sensor devices. The function will ensure that the data is retrieved at regular intervals appropriate for the various sensors and for the other functions of the application. The Data Collection function will run on computer(s) in the Central Operations Centre (COC). Data Collection will also accept relevant weather data (either manually or through an automated interface) from Environment Canada.

TRANSDUCER COMM

The Transducer Comm function comprises all the necessary software drivers to directly interact with the field devices. The drivers will implement the communication protocols specific to each sensor subsystem. Depending on the physical architecture of the deployed system, the Transducer Comm function may run solely on computer(s) in the COC or may be spread across computer(s) at the COC and distributed controllers strategically locate in the field.

DATA ARCHIVE

All raw data collected by the system will be saved to a relational database by the Data Archive function.

DATA ANALYSIS

The Data Analysis function of RCWatch will utilize the raw field data collected by the Data Collection function to determine the appropriate periods for which the SLR and WWP programs are to be implemented. The function will incorporate a number of industry approved algorithms to aid in the decision making process. These algorithms are defined in more detail in Section 6.1.2.

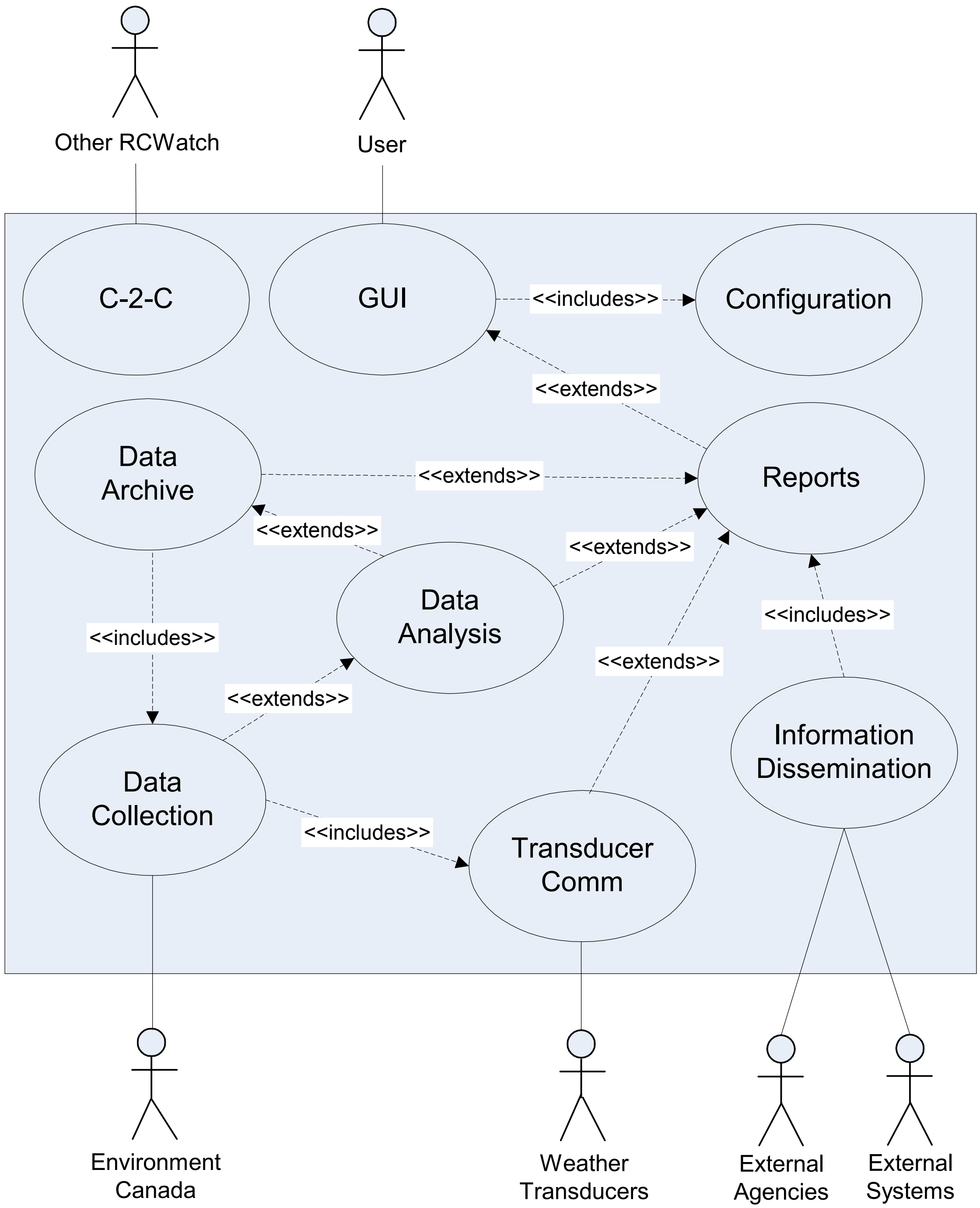

Figure 6-2: RCWatch Functional Decomposition

REPORTS

The Reports function of the application will be responsible for generating canned system reports for viewing and/or printing (e.g., equipment status reports, SLR & WWP historical reports, and various data reports).

GUI

The GUI will be a GIS based graphical interface that will allow the users to interact with the RCWatch application to monitor roadway conditions, generate reports, and initiate SLR and WWP programs. The GUI function will allow for multiple and simultaneous users of RCWatch and will be designed to accommodate access to the application whether the user is local or remote to the system (using appropriate network communication standards).

INFORMATION DISSEMINATION

RCWatch will include an Information Dissemination function that provides capabilities to send information to external agencies and systems through a number of dissemination technologies. The function will accommodate the concept of "service subscribers" such that individuals or agencies may be configured by dissemination service type and information content.

CONFIGURATION

The Configuration function provides the necessary tools to view and modify the various parameters that control the overall operation and configured field devices of RCWatch.

6.3.3 User Characteristics

The typical users of RCWatch can be classified by the following categories:

O&M	The Operations and Maintenance (O&M) user will be the primary user of the RCWatch system. The O&M user will monitor all aspects of system operation and will ultimately be responsible for the implementation of the SLR and WWP programs. The O&M user may also access current and historical information for the purpose of general analysis and reporting.
Planning	The Planning user will typically access historic information and review the performance of roadways over the past year(s). The Planning user would determine which roads are to get which particular restriction(s).
Design	The Design user will typically access historic information for input into their pavement design models. There is a quantitative model NCHRP 1-37A 2004 (for example) that uses measured data to determine pavement design criteria.
Enforcement	The Enforcement user plays a key role in ensuring trucks are complying with the SLR and WWP programs. This user would typically have read-only access to the RCWatch application.
Public	The Public user comprises various trucking agencies, associations and companies that need to modify their loads and/or their shipping routes in accordance with the SLR and WWP programs. These users will typically receive the required information through a number of sources including the internet, e-mail, IVR, and facsimile.
Engineer	The Engineer user interacts with RCWatch to configure the application parameters, enable and disable subsystem operation, and to troubleshoot hardware, software and communication problems directly related to the RCWatch application. The Engineer will completely understand the system architecture and functionality, but may only have a broad understanding of the agency operations and management processes.

6.4 ITS ARCHITECTURE

The system concept can be described by the following Physical Architecture (Figure 6-3) as defined by the Canadian ITS Architecture.

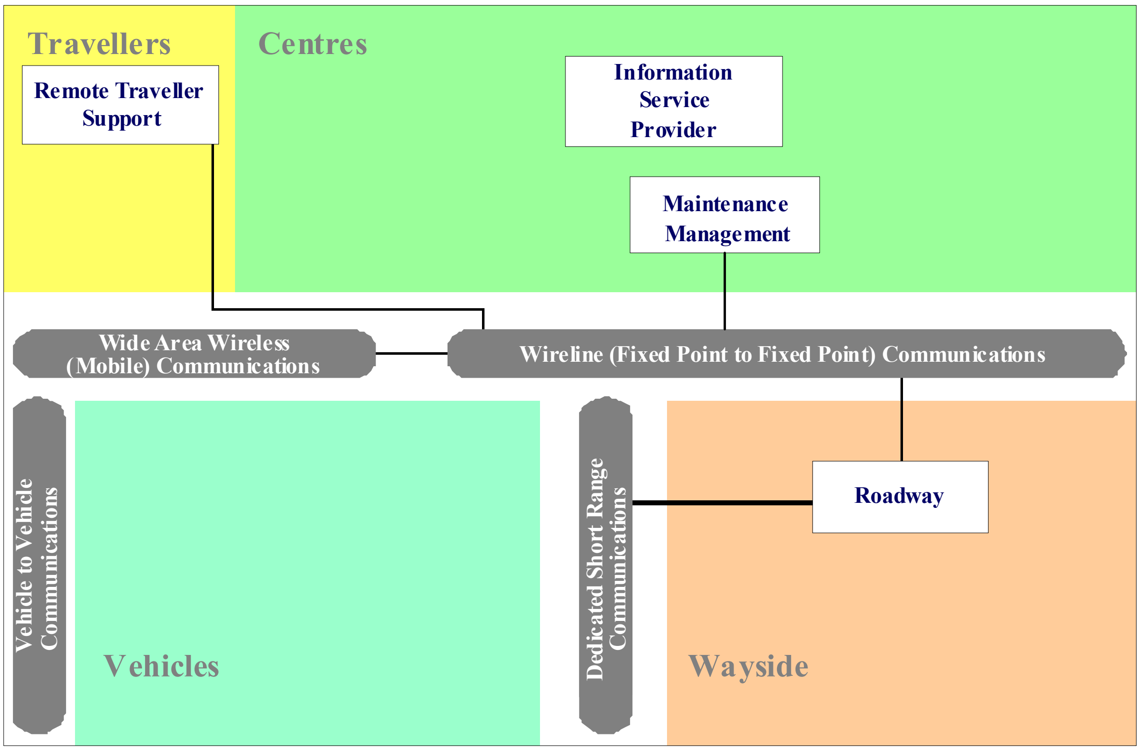

Figure 6-3: ITS Physical Architecture

The Physical Architecture has been constructed using the "sausage diagram" and shows the physical location of the ITS components and the communications medium used to connect them. For this system concept, there is no interaction with the vehicles. The schematic included in Figure 6-4 includes a few more details about the particular functions.

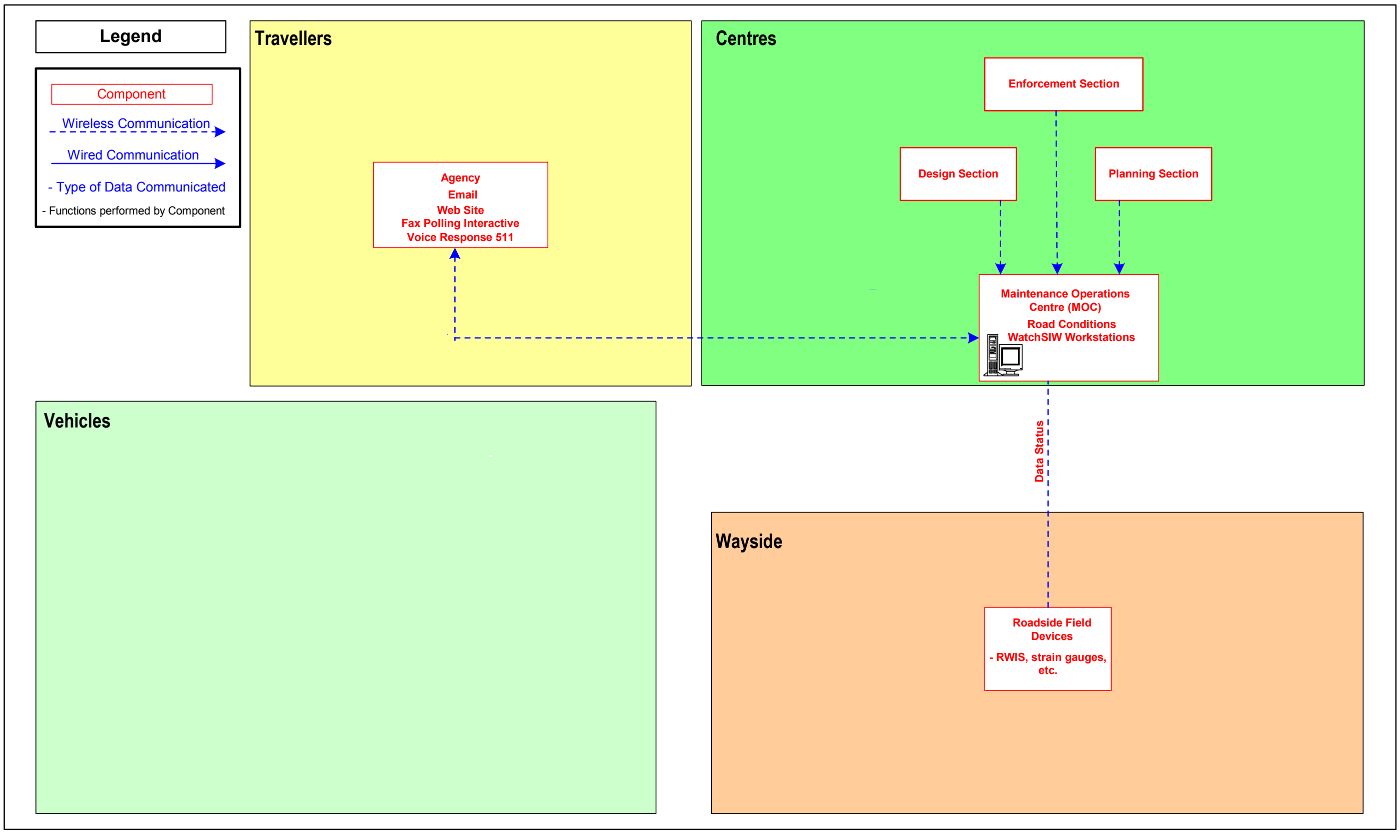

Figure 6-4: ITS Scheme

6.4.1 Constraints, Assumptions and Dependencies

RCWatch is expected to operate 24 hours per day, 7 days per week. The RCWatch application may be shut down for short periods (in the order of hours) during off-peak operational hours to facilitate maintenance and software upgrades.

RCWatch will support multiple simultaneous users of the application.

6.5 Preliminary Costs

Preliminary costs have been prepared for a basic and an advanced system. The costs as well as assumptions are summarized in Tables 6–2 and 6–3. All costs are estimates and have been derived using capital costs along with estimates for installation mark ups.

Table 6-2: Basic System Pricing

	Data Collected	Equipment Type/Name	Unit Cost (CND)	Quantity	Total Equipment Cost (CND)	Installation Cost (CND)	Net Cost (CND)
Basic	Pavement & Air Temperature	RWIS Road Weather Information System	$41,000.00	1	$41,000.00	$4,000.00	$45,000.00
	Strain	Strain Gauge Pavement Strain Transducer for the measurement of strains in Asphalt Concrete (PAST II AC)	$780.00	10	$7,800.00	$1,500.00	$9,300.00
	% Moisture content	Moisture Sensor ECHO Soil Moisture Smart Sensor (S-SMA-M003)	$180.00	3	$540.00	$200.00	$740.00
	Base, Subbase and Subgrade Temperature (Frost Depth)	Multi-point Temperature Probe TDP Temperature Probe (15 sensor points along 72 inch tube)	$2,280.00	1	$2,280.00	$500.00	$2,780.00
	Other Field Requirements	Data Logger, Modem, Cabinet, Power, etc.					$11,000.00
	Central Requirements	Server, Workstation, Database, Miscellaneous	$6,000.00	1	$6,000.00	$0.00	$6,000.00
		Software Development					$167,750.00
				Total Cost:	$57,620.00	$6,200.00	$242,570.00

Table 6-3: Advanced System Pricing

	Data Collected	Equipment Type/Name	Unit Cost (CND)	Quantity	Total Equipment Cost (CND)	Installation Cost (CND)	Net Cost (CND)
Advanced	Pavement & Air Temperature	RWIS Road Weather Information System	$41,000.00	1	$41,000.00	$4,000.00	$45,000.00
	Strain	Strain Gauge Pavement Strain Transducer for the measurement of strains in Asphalt Concrete (PAST II AC)	$780.00	10	$7,800.00	$1,500.00	$9,300.00
	% Moisture content	Moisture Sensor ECHO Soil Moisture Smart Sensor (S-SMA-M003)	$180.00	3	$540.00	$200.00	$740.00
	Base, Subbase and Subgrade Temperature (Frost Depth)	Multi-point Temperature Probe TDP Temperature Probe (15 sensor points along 72 inch tube)	$2,280.00	1	$2,280.00	$500.00	$2,780.00
	Displacement	Linear Variable Differential Transformer (LVDT) PIz100 (+/-50mm range) arranged to for a multi-depth deflectometer	$577.50	4	$2,310.00	$800.00	$3,110.00
	Other Field Requirements	Data Logger, Modem, Cabinet, Power, etc.					$11,000.00
	Central Requirements	Server, Workstation, Database, Miscellaneous	$6,000.00	1	$6,000.00	$0.00	$6,000.00
		Software Development					$167,750.00
				Total Cost:	$59,930.00	$7,000.00	$245,680.00

7. NEXT STEPS

7.1 Pilot Deployment

Through the development of this document, it became apparent that ITS can play a role in assisting agencies with determining when to implement and lift SLR and WWP. In addition, deployment of ITS equipment to meet this need will also result in data that can assist with other planning and design tasks, thereby increasing the value of this type of system.

The system concept that has been discussed in this report utilizes existing equipment and proven algorithms, and integrates the data and hardware into a GIS-based central system software package described as RCWatch.

The next step will be to develop a pilot project to test the data, algorithms and assumptions, and to ascertain whether there is a value to agencies to deploy this type of system.

7.2 Centre of Excellence

Various academic institutes and government agencies in Canada have established themselves as leaders in various areas relating to research into and application of SLR and WWP. In order to share this information more easily across Canada, it is suggested that steps be taken to develop a Centre of Excellence. A Centre of Excellence would allow all agencies and institutes to share information relating to SLR and WWP, and would help to advance research in this area.

7.3 Future Opportunities

Central Tire Inflation (CTI) Systems are becoming more widely used across Canada. In addition, Commercial Vehicle Operations (CVO) systems are also becoming standard. Future opportunities include the ability for transportation agencies to dynamically modify the load restrictions based on in-situ measurements and to broadcast that information in real time to trucking companies. This will allow both players to be able to meet their divergent objectives – transportation agencies will be able to protect their assets and trucking companies will be able to maximize their productivity. While the largest benefits occur to both agencies during the period of spring thaw, there will also be benefits associated with winter weight premiums.

REFERENCES

[AASHTO 1993] American Association of State Highway and Transportation Officials, "AASHTO Guide for Design of Pavement Structures", Washington, D.C., 1993

[Berg 1997] Richard Berg, "Calculating Maximum Frost Depths at Mn/ROAD Test Cells", Report No MN/RC-97/21, Minnesota Department of Transportation, March 1997

[Bradley 1997] Allan Bradley, "The Effect of Reduced Tire Inflation Pressures on Road Damage: A Literature Review", FERIC Special Report SR-123, May 1997

[CGRA 1962] Canadian Good Roads Association, "Pavement Evaluation Studies in Canada", International Conference on the Structural Design of Asphalt Pavements Proceedings, University of Michigan, Ann Arbour, Michigan, August 1962, p. 137-218

[Clayton 2000] Alan Clayton, Jeannette Montufar, Ahmen Shalaby, Kean Lew, and Kai Han, "Study for the Harmonization of Spring Weight Premiums for Roads and the Prairie Provinces Opportunities for a Partially Rationalized Approach to Spring Weight Restrictions & Winter Weight Premiums Phase 1 Task 1, 2, 3, 4", 2000

[C-SHRP 2000] Canadian Strategic Highway Research Program, "Seasonal load restrictions in Canada and around the world", Technical Brief No. 21, Ottawa, Ontario, September 2000, p. 1-8

[Dore 2004] Guy Dore and Cedric Imbs, "Development of a new mechanistic index to predict pavement performance during spring thaw", Cold Regions Engineering, 2004, p. 348-359

[Farouki 1981] O.T. Farouki, "Thermal properties of soils", CRREL Monograph 81-1, Hanover, New Hampshire, 1981

[FHWA 2001]. "FHWA Road weather management: Better information and tools improve operations, save lives", U.S. Department of Transportation, Publication No. FHWA-OP-01-012, 2001

[Goodings 2001] Deborah J. Goodings, David Van Deusen, Maureen Kestler, and Billy O'Connor, "Frost Action Transportation in the New Millennium", Transportation Research Board Committee A2L04: Committee on Frost Action, Transportation Research Board, Washington D.C., 2001

[Goodman 2004] Steve Goodman, "Spring Load Restrictions", Personal Communication with S. Tighe, May 2004

[Gough 1985] J.W. Gough and Ralph Haas, "Development of a Rational System for Seasonal Road Restrictions" Transportation Forum Volume 1-4, Roads and Transportation Association of Canada, March 1985, p. 57-65

[Haas 1994] Ralph Haas, W. Ronald Hudson, and John Zaniewski, "Modern Pavement Management", Kreiger Publishing Company, Melbourne, Florida, 1994

[Haas 2004] Ralph Haas, Lynne Cowe Falls, Donaldson MacLeod, and Susan Tighe, "Climate Impacts and Adaptions on Roads in Northern Canada", Cold Regions Engineering and Construction Conference and Expo, Edmonton, Alberta, May 2004

[He 1997] Zhiwei He, Gerhard Kennepohl, Yinyin Cai, and Ralph Haas, "Development of Performance Models for Ontario's New Mechanistic-Empirical Pavement Design Method", Proceedings, 8th International Conference on Asphalt Pavements, Vol. I, Seattle, Washington, 1997, p. 43-60

[Hein 2002] David K. Hein and Rhett M. Cole, "Establishment of Monitoring of Pavement Load Restrictions in the Province of British Columbia", Annual Conference and Exhibition of the Transportation Association of Canada, Winnipeg, Manitoba, 2002

[Jung 1975] F. Jung, R. Kher and W.A. Phang, "A Performance Prediction Subsystem", Ministry of Transportation and Communication of Ontario Research Report RR200, 1975

[Lew 2000] Kean Lew, "Study for the Harmonization of Spring Weight Restrictions and Winter Weight Premiums For Roads in the Prairie Region: Availability and Potential Use of Advanced Technologies in the Harmonization and Enforcement Process Phase 1 Task 3", University of Manitoba and EBA Engineering, 2000

[Loch 1975] J.P. Loch and R.D. Miller, "Tests of the concept of secondary soil freezing", Soil Science Society of America, Proceedings, Vol 39, No 6, 1975, p. 400-406

[Martin 1959] R.T. Martin, "Rhythmic ice banding in soil", Highway Research Board Bulletin 218, 1959, p. 11-23

[Miller 1972] R.D. Miller, "Freezing and heaving of saturated and unsaturated soils." Highway Research Record, No 393, 1972, p. 1-11

[Mokwa 2004] Robert Mokwa, "Transportation Engineering in Cold Regions: State of the Practice Review", Cold Regions Engineering and Construction Conference and Expo, Edmonton, Alberta, May 2004

[MTGS 2004] Manitoba Transportation and Government Services, Materials Engineering Branch, Pavement Section, Standards MRB7-20, MRB7-14, MRB7-15, MRB7-07, 2004

[NCHRP 1-37A 2004] National Cooperative Highway Research Program, "Mechanistic-Empirical Pavement Design Guide", NCHRP 1-37A Project, 2004 (www.fhwa.dot.gov/pavement/dgitdata.htm)

[Ovik 2000] Jill M. Ovik, John A. Siekmeier, and David A. Van Deusen, "Improved Spring Load Restriction Guidelines Using Mechanistic Analysis", MN/RC-2000-18, July 2000

[Penner 1980] E. Penner and L.E. Goodrich, "Location of segregated ice in frost susceptible soil", 2nd International Symposium on Ground Freezing, Trondheim, Norway, June 24-26, 1980, p. 626-639

[Phang 1981] W.A. Phang and G.M. Scott, "Pavement Condition and Performance Observations, Brampton Test Road", Asphalt Paving Technology, Vol 50, 1981, p. 345-378

[Rauhut 1987] J.B. Rauhut and D.S. Gendell, "Proposed Development of Pavement Performance Prediction Models from SHRP/LTPP Data", Proceedings of the Second North American Conference on Managing Pavements, Vol 2, Toronto, Ontario, 1987, p. 2.21-2.37

[TAC 1997] Transportation Association of Canada, "Pavement Design and Management Guide", Ottawa, Ontario, 1997

[Tighe 2000] Susan Tighe, "Ontario Spring Load Restriction", Presentation to the Transportation Association of Canada Pavements Standing Committee, Ottawa, Ontario, Spring 2000

[Tighe 2001a] Susan Tighe, Zhiwei He, and Ralph Haas, "Environmental Deterioration Model For Flexible Pavement Design: An Ontario Example", Transportation Research Record No. 1755, National Academy Press, Washington, D.C., 2001, p. 81-89

[Tighe 2001b] Susan Tighe, Ralph Haas, and Ningyuan Li, "Overlay Performance in the Canadian Strategic Highway Research Program's LTPP Study", Transportation Research Record No. 1778, National Academy Press, Washington, D.C., 2001, p. 191-200

BIBLIOGRAPHY

Harvey Allen and David Bullock, “Evaluation of Deflection Data as Criteria for the Posting and Removal of Spring Load Limits”, Transportation Research Record 1106, 1987, p. 140-145

Colin Blair, “Investigation into Improved Road-Friendliness Offered by Optimized Tire Pressures on Thawing Thin Pavement Roads”, FERIC, June 2001

Colin Blair, “Using road-friendly technologies to extend the haul season on thawing roads”, FERIC Advantage report, Vol 2, No 48, August 2001

J.T. Christian, “In Situ Measurement of Pavement Behaviour Under Load”, Transportation Forum Volume 1-4, Roads and Transportation Association of Canada, March 1985, p. 44-51

Canadian Strategic Highway Research Program, "Pavement Research Technical Guidelines", Transportation Association of Canada, Ottawa, Ontario, 1989

Jerome F. Daleiden, “Pavement Monitoring, Evaluation, and Data Storage”, A2B06: Committee on Pavement Monitoring, Evaluation and Data Storage

David A. Van Deusen and Jill M. Ovik, “Spring Load Restrictions Improving Minnesota’s Policy”, TR News 211, November-December 2000

The Green Lane™, Environment Canada's World Wide Web site, http://www.mb.ec.gc.ca/

William Gallus, “Improved Frost Forecasting through Coupled Artificial Neural Network Time-series Prediction Techniques and a Frost Deposition Model”, FHWA-HRT-04-109, October 2004, p. 19-26

Gordon L. Hanek, Mark A. Truebe, and Maureen A. Kestler, “Evaluating Moisture Sensors and Monitoring Seasonal Moisture Variation in Low Volume Roads”, Paper No. 01-0248

Gordon L. Hanek, Mark A. Truebe, and Maureen A. Kestler, “Using Time Domain Reflectometry (TDR) and Radio Frequency (RF) devices to monitor seasonal moisture variation in forest road subgrade and base materials”, FHWA Forest Service Technology and Development Program, July 2001

Gordon L. Hanek and Mark A. Truebe, “Guidelines on the Use of Thermistor and Time Domain Reflectometry Instrumentation for Spring Thaw Road Management on Low-Volume Asphalt Roads”, FHWA Forest Service Technology and Development Program, December 2001

N. Irwin and W.F. Johnson, “The Implications of Long-Term Climatic Changes on Transportation in Canada”, report prepared for Transport Canada by the IBI Group, Toronto, Ontario, 1988

Jukka Isotalo, “Seasonal Truck Load Restrictions: Mitigating Effects of Seasonal Road Strength Variations”, Sixth International Conference on Low-Volume Roads, Minneapolis, Minnesota, June 1995

Maureen A. Kestler, Richard L. Berg, Sac-Im Nam, and Charles E. Smith, "Reduced Tire Pressure: Review of an Alternate Road Usage Technique for Springtime Damage on Low Volume Roads", Cold Regions Engineering: Cold Regions Impacts on Transportation and Infrastructure, 2002, p. 382-393

Maureen A. Kestler, Gordon Hanek, Mark Truebe, and Peter Bolander, "Removing Spring Thaw Load Restrictions from Low-Volume Roads, Development of a Reliable Cost-Effective Method", Transportation Research Record, No 1652 Volume 2, Washington, D.C., 1999

Maureen A. Kestler, Thomas Knight, and Audrey S. Krat, "Thaw Weakening and Load Restriction Practices on Low Volume Roads", ERDC/CRREL TR-00-6, June 2000

Maureen A. Kestler, "Techniques for Extending the Life of Low Volume Roads in Seasonal Frost Areas", Transportation Research Board, Washington, D.C., 2003

Joe Mahoney, Brian Sweet, Ronald Copstead, and Robert Keller, "The Potential Use of Central Tire Inflation During Highway Load Restriction Periods", SAE Technical Paper Series 942245, November 1994, p. 53-60

Minnesota Department of Transportation, "Improved Spring Load Restriction Guidelines Using Mechanistic Analysis", MnDOT Federal Report 2000-18, July 2000

R.A. Moreno, "Industry, Energy and Transportation: Impacts and Adaption, Contribution of Working Group II to the Second Assessment Report of the Intergovernmental Panel on Climate Change", 1996, p. 364-398

Fritz Prophète and Denis Saint-Laurent, "Using WIM and FWD Data to Evaluate the Impact of Load Restrictions on Pavements", Pre-Proceedings of the Third International Conference on Weigh-In-Motion (ICWIM3), Orlando, Florida, May 2002

Lutfi Raad, George Minassian, and Stephan Saboundjian, "Mechanistic Evaluation of the Effect of Tire Inflation Pressure on Pavement Damage under Spring-thaw Weaking", TRB Board Meeting, Washington D.C., January 1998

Geir Refsdal, "The lifting of axle load restrictions during spring thaw – a Norwegian Experiment", 5th International Conference on the Bearing Capacity of Roads and Airfields, Norwegian Public Roads and Administration, 1998, p. 103-108

Geir Refsdal, Paul Senstad, and Arne Soerlie, "The Lifting of All Seasonal Load Restrictions in Norway in 1995 – Background and Effects", TRB Annual Meeting, 2004

Ruth L. Roberson and John Siekmeier, "Determining Frost Depth in Pavement Systems Using a Multi-Segment Time Domain Reflectomerty Probe", TRB Session: Effects of Moisture and Temperature on Pavement Systems, 2000

Denis Saint-Laurent and Fritz Prophète, "Mechanistic Evaluation of the Impact on Flexible Pavement of Spring Load Restrictions", Annual Conference & Exhibition of the Transportation Association of Canada, Winnipeg, Manitoba, 2002

C.R. Webb and L.M. Kelly, "Monitoring frost levels in thawing roadbeds to maximize the hog hauling season", FERIC Advantage Report, Vol 1, No 37, November 2000

Appendix A

Equipment Manufacturers/Products

	Sensor name	Description of methodology	Output	Possible Application	Manufacturer/ Models/ Price	Specs/ Installation
1. <u>Environmental/Road</u>						
1	Earth pressure cells	Constructed from 2 stainless steel plates welded together around their periphery and separated by a narrow gap filled with hydraulic fluid. External pressures squeeze the 2 plates together creating an equal pressure in the internal fluid. A tube connects the fluid filled cavity to a pressure transducer that converts the fluid pressure into an electrical signal transmitted by cable to the readout location. Measure traffic-induced stresses on roadway sub grades, airport runways or under railroad tracks.	An electrical signal (e.g. the 3500 series can have an output of 2mV/V, 0-5VDC or 4-20mA) directly proportional to pressure. Generally can measure from 0 to 7Mpa, in temperatures from –20 to +80^{o}C.	- Stress/Strain	**<u>Geokon</u>**: Earth Pressure Cells. Standard model price **US$515**, cable **62 cents/foot**. **<u>Geonor</u>**: (Same merchandise as Geokon) Total Earth pressure cell: Model P-100 (Range 0-300kPa) and Model P-105 (Range 0-700kPa). **<u>MnDOT (Minnesota Dept of Transportation)</u>**: Dynamic soil pressure cell – 2 types used by MnDOT – **US$791** and **US$223**	**<u>Geokon</u>**: Specs online. Stainless steel casings. **<u>Slope Indicator</u>**: Specs online. **<u>Geonor</u>**: Specs online. Stainless steel casings. **<u>MnDOT (Minnesota Dept of Transportation)</u>**: specs online. **<u>Gage Technique</u>**: catalogue online.

	Sensor name	Description of methodology	Output	Possible Application	Manufacturer/ Models/ Price	Specs/ Installation
		The P-100 and P-105 EPC's measure total pressure (soil effective stress plus pore-water pressure) acting on structure surfaces, i.e. soil-structure interface pressure. Measures pressure up to 700kPa.				
2	Dynamic soil pressure cell	Vertical pressure sensors used. Measures the vertical stress distribution in the base and subgrade layers.	A voltage that is linearly proportional to the pressure applied.	- Stress/Strain		
3	Frost probes	A temperature probe inserted into the ground. Measures temperatures at multiple fixed depths.	Outputs temperature. (Probe length 2m, temperature range –40°C to +60°C. 20 sensors, spaced at 10cm.)	- Frost depth - Thaw depth	**ANS Inc**: Model TP210 ("robust, low cost" according to website). **CAN$4300**	
4	Thermocouples / Thermistor probes	Devices whose resistance changes with temperature. Measures ground temperature at multiple depths. Can be used to determine freezing and thaw points.	Outputs a voltage proportional to the subsurface temperature.	- Frost depth - Thaw depth	**Surface Systems, Inc**: Subsurface temperature probe (Model S16UG-D): measures temp up to 17inches below ground. Determines frost depth. **CAN$1088 each** Thermistor Probe, Model TP101 "SHRP" (consists of 15 thermistors, spaced	**Surface Systems, Inc**: Specs online. **Temperature Systems International**: More info on request. **Thermo Sensors Corporation**: Specs online.

	Sensor name	Description of methodology	Output	Possible Application	Manufacturer/ Models/ Price	Specs/ Installation
					over 6 feet). (Salesman couldn't find this model when called – gave quote for Passive Pavement Sensor instead) **<u>Temperature Systems International</u>**: limited range of Thermocouples **<u>Thermo Sensors Corporation</u>**: large range of Thermocouples (hard to get pricing unless specific needs are known).	
5	Pavement sensors (passive)	Road surface conditions.	Outputs: - Surface temperature - Dry/Wet pavement - Chem Wet (film of water and ice mixture at or below 0°C with enough chemical to keep the moisture from freezing - Snow/Ice Warning - Snow/Ice Watch	- Pavement temp.	**<u>Surface Systems, Inc</u>**: Model FP2000 – Passive pavement sensor (150 foot long). 1 sensor - **CAN$3996** 3-5 sensors - **CAN$3596 each** 6-10 sensors - **CAN$3197 each**	**<u>Surface Systems, Inc</u>**: Specs online.
6	Time domain detectors/Time domain reflectometry probe (TDR)	Probe installed vertically in the pavement to measure a profile of the soil's dielectric properties. (Dielectric	Provides a series of electric (i.e. voltage or current) wave forms that indicate the profile of dielectric constants	- Thaw depth - Frost depth - Moisture content in subgrade, sub-base and base	**<u>Dynamax Inc.</u>**: Models TR-100 and TR-200. These 2 models are accurate, but expensive and	**<u>Dynamax Inc.</u>**: Specs online. Fiberglass waterproof case available.

	Sensor name	Description of methodology	Output	Possible Application	Manufacturer/ Models/ Price	Specs/ Installation
		constant for water >> that of dry or frozen soil.) Electromagnetic wave sent through the probe, and propagation velocity is measured.	throughout the soil. This directly indicates the water content of the soil, and therefore thawing.		complicated to use – One system (16 sensors) costs around **US$16,000** NOTE: Dynamax noted that TDR is more than is needed in this case (its is mostly for research applications). Dynamax suggested that THLog soil moisture data logger, which provides a direct moisture readout and costs a lot less. Alternatively, the THLogger (with 1, 2 or 4 channels – i.e., sensors) directly outputs the soil moisture. A 4-channel system costs **US$2500** **Sowacs.com**: Extensive listing of manufacturers of TDR probes. **Campbell Scientific**: Sells the TDR100 Reflectometer, and ranges of related peripherals like dataloggers, multiplexers and power	**Sowacs.com**: Specs online for some. **Campbell Scientific**: Extensive specs online. Plastic casing available. **Spectrum**: Specs online.

	Sensor name	Description of methodology	Output	Possible Application	Manufacturer/ Models/ Price	Specs/ Installation
					supplies. **Prenart Equipment ApS**: A full soil moisture kit consisting of Campbell Scientific's TDR100, plus peripherals. **Spectrum**: Model TDR300 **(US$1195)** Model TDR200 **(US$945)** Model TDR100 **(US$795)**	
7	Frequency domain reflectometry/ Radio frequency sensors (FDR)	Same set-up as TDR above, but the probe emits a radio frequency pulse instead.	Provides the profile of dielectric constants, which indicates frost depth.	- Frost depth - Moisture content in subgrade, sub-base & base - Thaw depth	**AquaPro Sensors**: AquaPro moisture sensor (Radio frequency sensor) – intended for gardening applications.	**AquaPro Sensors**: Specs online.
8	Soil moisture sensor	Uses TDR technology to measure soil moisture. Additional temperature sensors can also be added.	If placed vertically: moisture gauge averages the moisture level through a column of soil equal to its length. If placed horizontally: gauge measures moisture at the depth it is placed. Measurement range of 0-100% water saturation. Output range 4-20mA.	- Moisture content in subgrade, sub-base & base	**Spectrum**: WatchDog Irrigation Stations, using Watermark Soil Moisture Sensors. **(US$316 or US$462)** Soil Moisture Testers **(~US$80)** **Global Water Instrumentation Inc.**: Model AT210 **(US$245)**	**Spectrum**: Further specs upon request. **Global Water Instrumentation Inc.**: Specs online. **Intermountain Environmental Inc.**: Limited specs online.

	Sensor name	Description of methodology	Output	Possible Application	Manufacturer/ Models/ Price	Specs/ Installation
9	Moisture block (watermark) sensors	Electrical resistance increases with dryness and therefore can be used to measure soil water tension or suction in thawed conditions, or the depth of frozen conditions.		- Frost depth - Moisture content in subgrade, sub-base & base - Capillary action - Thaw depth	**Intermountain Environmental Inc.**: Range of soil moisture sensors using electrical and resistance methods to measure soil water potential.	
10	Net radiation sensor	Based on a thermopile sensor, whose voltage output is proportional to the net radiation.	Solar energy measurements (output a voltage proportional to the net radiation. Can be directly connected to a voltmeter or data logger.)	- Solar radiation	**Environmental Measurements Ltd.**: Model NRS2	**Environmental Measurements Ltd.**: Specs online.
11	Solar radiation sensor		Solar energy measurements.	- Solar radiation	**Environmental Measurements Ltd.**: Model SKS1110 (for wavelengths 350-1100nm).	**Environmental Measurements Ltd.**: Specs online.
12	Road weather information system (RWIS)		- Roadway surface conditions (incl. water layer thickness, surface freezing point) - Ground temp - Ground frost - Wind speed, direction & gusts - Visibility - Solar radiation - Flux metering - Snow depth - Sub-surface temperature - Precipitation levels and type	- Air temp - Pavement temp - Solar radiation - Precipitation - Wind speed - Relative humidity	**Vaisala**: Extremely comprehensive range of products, featuring lines of sensors for the following categories: Humidity; dewpoint; barometric pressure; wind sensors; present weather; automatic weather stations; road weather; lightning systems; windprofiler. Vaisala ROSA Road Weather Station **US$19,926** (includes 2	**AerotechTelub**: More info on request. **Traffic Technology 2000**: More info on request. **Vaisala**: Detailed descriptions for each product online, but specs available on request. **SSI**: Specs online for pavement sensor range.

	Sensor name	Description of methodology	Output	Possible Application	Manufacturer/ Models/ Price	Specs/ Installation
			- Metrological parameters (incl. Humidity, dewpoint)		road surface centers) without installation. This price is for ANS Inc. Provides real time data on: - road/runway surface conditions - visibility - precipitation type - meterological parameters **SSI**: Extensive range of RWIS products, including a selection of pavement sensors. AerotechTelubL RWIS system **Traffic Technology 2000**: ARWIS system	
2. Traffic						
1	Inductive loop detectors (ILD)	Inductive loops mounted within pavement. Vehicles passing over loops produce a magnetic profile. Loops used in single and multi-lane environments, but vehicles changing lanes	Single loops: - Count vehicles - Headways Dual loops('traps'): - Count vehicles - Headways - Speed - Vehicles length - Vehicle classification	- Volume - Occupancy - Speed - Vehicle length - Vehicle classification (by length)	Typical cost: Classification and Counting station – **CAN$12,000** Counting station – **CAN$4,000** - Intertraffic, Counters & Accessories Ltd., Loop Profiler	

	Sensor name	Description of methodology	Output	Possible Application	Manufacturer/ Models/ Price	Specs/ Installation
		in the vicinity of loops introduce some counting error.	(based of axle) - Dual wheel detection possible		- PEEK Traffic, Idris (ADR6000) - PEEK Traffic, (ADR3000 Plus) (also can be used for Piezo-electric detectors) - International Road Dynamcis, Permanent Inductive Loops - Golden River Traffic, 8-loop and 2-loop Traffic Classifiers (accurate) - TEC Traffic Systems, Marksman 660 Classifier - Counting only – numerous vendors	
2	Non-invasive microloops	Non-intrusive. Convert changes in the vertical component of the earth's magnetic field to changes in inductance. Vehicles passing over loop increase the magnetic field. Sensors placed in bored conduits <24in below pavement surface.	- Detect vehicles - Vehicle count - Dual loops can also provide speed and length	- Volume - Occupancy - Speed - Vehicle Length - Vehicle classification (by length)	- 3M, Canoga VDS: Non-Invasive Microloop Model 702.	Online
3	Piezoelectric sensors	Sensors embedded in pavement. Convert	- Count axles - Axle spacing	- # of axles - Axle spacing	- International Road Dynamics Inc.,	Online

	Sensor name	Description of methodology	Output	Possible Application	Manufacturer/ Models/ Price	Specs/ Installation
		mechanical strain into electrical charge when an axle crosses the sensor.	- Dynamic axle weights - Some models provide vehicle classification	- Axle weights - Vehicle classification (by axles)	RoadTrax BL and Vibracoax. - Electronique Controle Mesure, Piezo Sensors - Golden River Traffic, 16-loop and 8-loop Piezo Traffic Classifiers (provide accurate vehicle classification)	
4	Load-cells	Each cell, made of steel or concrete, holds an embedded strain gauge. Cells are embedded in the pavement.	- Axle weight - Total truck weight	- Axle weight - Total weight	- Avery Weight-Tronix, Traxle, SteelBridge XT and BridgeMont (*all for trucks with similar axle configuration*). - Central Weighing Limited, SupaWeigh Axle Weighbridge (static or dynamic weighing; optional "Securitag" automatic vehicle recognition & GPS), Cheklode Freeweigh Cable Free (portable, dynamic weighing) - Electronique Controle Mesure, Resistive sensors	Online

	Sensor name	Description of methodology	Output	Possible Application	Manufacturer/ Models/ Price	Specs/ Installation
5	Active infrared detection systems	Non-intrusive. Focus a narrow beam of energy and either measure the reflected energy (from a passing vehicle) or the energy disruption by an infrared-sensitive cell. IR beam can be transmitted from overhead or from roadside.	- Height - Width - Length - Vehicle classification (in some cases) - Speed	- Vehicle height - Vehicle width - Vehicle length - Speed - Vehicle classification	- ASIM Technologies, TT290 Series PIR/US/MW detectors. (Provides vehicle classification)	Online
6	Microwave sensors	Non-intrusive. Works on the same principle as an active infrared detector, using microwaves.	- Length - Vehicle count - Speed - Occupancy	- Volume - Occupancy - Speed	- Electronique Controle Mesure, LOREN multi-lane microwave detector - RTMS by EIS	
7	Overhead profiler	Mounted above roadway. Eye safe laser scans roadway, and measure beams reflected from passing vehicles. Generates a vehicle profile, which is compared to a database of standard templates to determine vehicle class. 3-D profiles of the vehicle can be generated using 2 laser beams, as with OSI Laser Scanners (see right). Multiple scanner	- Vehicle class (based on vehicle profile) - Efficient at distinguishing between a vehicle-trailer combination and two separate vehicles - Using an integrated second scanner beam, can also detect vehicle speed and direction - Length - Width	- Vehicle classification (by profile) - Speed - Vehicle length - Vehicle width	Typical cost: **CAN$12,000** - OSI Laser Scanners, AUTOSENSE II (Overhead OR ground based). Information collected: Axle count, classification, enforcement camera triggering, integration with Idris available. - Transport Data Systems, Overhead AVC –	Online

	Sensor name	Description of methodology	Output	Possible Application	Manufacturer/ Models/ Price	Specs/ Installation
		devices used to cover multi-lane and shoulder environments. POTENTIAL PROBLEMS: Trouble in poor weather conditions (wet road surface, fog, snow), but it is claimed recent improvements have addressed this.			multiple classification systems offered. - SICK, TCS 200 - EFKON, TOM 2000, Ecotoll - TEC Traffic Systems, TOM Laser Vehicle Detection	
8	Ground-based profiler	Use horizontal light curtain to generate side profile of passing vehicles. Transmitter located on side of roadway emits series of horizontal beams of light to receiver on opposite side of road. Most suitable for single lane applications. POTENTIAL PROBLEMS: Misalignment of receiver-transmitter; sun interfering with receiver.	- Vehicle class (based on vehicle profile) - Efficient at distinguishing between a vehicle-trailer combination and two separate vehicles - Single scanner does NOT detect vehicle direction or speed - Axle count - Height - Length	- Vehicle classification (by profile) - Axle count - Vehicle height - Vehicle length	Typical cost: **CAN$6,000** - STI Scanners, Side profiling vehicle scanners, VS6500 - Transport Data Systems, AVC Systems - Banner Engineering Corp, MINI-ARRAY AVC System. Dimension & AutoCad drawings available.	Online
9	Video image detection systems (VID)	Non-intrusive. Consists of one or more cameras, a system to process the video image, and a module to interpret processed image.	- Count vehicles - Vehicle length - Classify vehicles (based on length) - Height - Speed - Headway	- Volume - Occupancy - Speed - Classification (by length) - Height - Vehicle length	- PEEK Traffic, VideoTrak Plus	Online

	Sensor name	Description of methodology	Output	Possible Application	Manufacturer/ Models/ Price	Specs/ Installation
			- Delay - Queue length - Lane occupancy - Density			
10	Axle treadle	Several fibre-optic or piezo-electric sensors housed in a frame and set in the roadway. The sensors emit a signal that is distorted as vehicles drive over them. Distortion of the signal can be analyzed. Most suitable for single lane applications. Sensor strips are subject to wear from the sustained physical contact with vehicle wheels, but not difficult to replace individual sensor strips. Treadle frame is designed to lift snowplough blades over sensor strips, but it is desirable not to plough over treadles.	- Axle count - Axle spacing - Dual tires, and single wheel (motorcycle) - Vehicle classification based on axle count, axle spacing dual tires, and single wheel parameters - Direction - Speed - Dual wheel detection possible	- Speed - Classification (by axle count, axle spacing) - Axle count - Axle spacing	Typical cost: **CAN$6,000** - International Road Dynamics, DYNAX treadles, DYNAX Axle Sensor, DYNAX Single/Dual Tire Sensor, Kistler Quartz Sensor - Telvent, AVC (Automatic Vehicle Classification)	Online
11	Weigh-in-motion systems (WIM)	Weight vehicles with no interruption to their travel. Permanent WIM sites consist of loop & axle sensors embedded in pavement. 3 established	- Count vehicles. - Vehicle direction and speed. - Classify vehicles. - Vehicle's DYNAMIC (not static) axle weights.	- Volume - Speed - Dynamic weight - Classification (by weight)	Typical cost: **CAN$20,000** (Bending plate system: for 3.5m lane width) - International Road Dynamics Inc., TCC540 and TRS	Online

	Sensor name	Description of methodology	Output	Possible Application	Manufacturer/ Models/ Price	Specs/ Installation
		types of WIM technology: 1. Piezoelectric cable (least accurate, least life, least cost) 2. Bending plates with strain gauges 3. Single hydraulic load cells (most accurate, longest life, highest cost) New WIM technologies: 4. Quartz-piezoelectric sensors 5. Fiber-optic sensors 6. Box culvert VIM sensors Accuracy depends on: 1. Technology used 2. Vehicle speed 3. Truck volume 4. Pavement temperature 5. Pavement condition 6. Calibration policies Presence of snow build-up may affect device accuracy. **NOTE**: dynamic axle weights NOT the same as static vehicle weights; cannot be used in terms of legal load limits	- Dual wheel detection possible.		WIM systems, and DAW 300PC Dynamic Axle Weighing System. - Mettler Toledo WIM System - Sterela, SASV (2 piezoelectric sensors & 1 electromagnetic loop per lane; plus video camera for license plate capture Image is sent to a site where a selected truck can be weighed more precisely). - Technolution, custom-made solutions. See example of a WIM installation. - Transport Data Systems, AVC Systems - FATA DTS, WIM Systems. - CAPTELS LS-WIM Systems - TEC Traffic Systems, Kistler WIM - Electronique	

	Sensor name	Description of methodology	Output	Possible Application	Manufacturer/ Models/ Price	Specs/ Installation
					Controle Mesure, HESTIA WIM - Golden River Traffic, M671/2 WIM	
12	Remote control weigh station (RCWS)	Combination of technologies to allow one operator, situated at a central location, to control multiple weight stations on a random and intermittent, or an as-required basis. Each RCWS operates as if it has an operator on-site. Provide excellent opportunities for extending service coverage in weight and dimensions compliance checks and limited mechanical fitness checks on commercial vehicles.	Basic model: - Weight & dimension - Classification - Compliance verification (weight & dimension) - Safety checks of signals (brake lights, turn signals, taillights and headlights) - Detection of non-functional brakes - Data collection Advanced model: - All features of the Basic model - Automatic credential check - CVIEW capability for self-serve safety check reporting - CVISN tie-in capability for inter-provincial & international data exchange	- Vehicle weights - Vehicle lengths - Vehicle widths - Vehicle classification	- International Road Dynamics, Inc. - ~ **US$200,000** for basic model	Document received from Jeremy Breker (IRD)

	Sensor name	Description of methodology	Output	Possible Application	Manufacturer/ Models/ Price	Specs/ Installation
3.	**Deflection/Strength**					
1	Linear variable differential transducers	Measured vertical displacement can be measured to assess displacements in surface, base and subgrade materials due to load. Data can be used to verify analytical models and determine failure criteria.	Linear displacement, ranging from 1-2000mm	- Relative elevation of pavement structure (up or down)	**Peltron Ltd:** Comprehensive range. **MnDOT (Minnesota Dept of Transportation): US$352**	**Peltron:** Specs available on request. Most models have stainless steel housing (not nec. Waterproof). **MnDOT (Minnesota Dept of Transportation):** Specs online
2	Linear variable differential transformers (LVDT)	Translate the linear movement of a ferromagnetic armature into an AC voltage. Vertical displacement of pavement.	An AC voltage that is linearly proportional to the armature position (i.e. displacement). Ranges of linear motion include 0.005 inches to 0.15 inches; 0.04 inches to 0.3 inches; 1.0 inch to 3.0 inch; 0.1 inch to 1.0 inch, etc.	- Relative elevation of pavement structure (up or down).	**Columbia Research Labs**: 5 ranges of LVDT's, designed for rugged-environment military and industrial application.	**Columbia**: Product specs online.
3	Strain gauges (crack propagation gauge, metal backing gauge for concrete surface etc.)	Strain across flexible road surfaces, changes in load.	Strain (mm/mm). Max measurable strain generally 2-3%. Operating temp. generally –20 to +80°C.	- Stress/strain	**Gage Technique:** 4 types: Spot-weldable and Surface-Mount (for strain in steel); Rebar and Embedment (for strain in concrete). None appear to be for heavy-duty all-weather. Embedment strain gauges **US$125**, cable **65 cents/ft**.	**Hoskin**: Product specs online. Can buy additional coating materials (like rubber) **Gage Technique**: Product specs online. **Geonor**: Product specs online.

	Sensor name	Description of methodology	Output	Possible Application	Manufacturer/ Models/ Price	Specs/ Installation
					Hoskin Scientific: Comprehensive range of gauges (incl. crack propagation, bolt, metal backing, temperature integrated, waterproof, digital strain, etc.). **Geonor**: Vibrating wire strain gauge (Model P-280W) costs **US$100**	
4	Strain gauge: biaxial embedment strain gauge	4 electrical resistance strain gauges embedded in asphalt. 2 gauges in longitudinal direction, 2 in transverse. (Designed by the Alberta Research Council) Measures longitudinal and transverse strain in the asphalt pavement layer. (Non-dynamic strains).	Strain (mm/mm).	- Stress/strain	**MnDOT (Minnesota Dept of Transportation)**: **US$480 ea**. Longitudinal and Transverse embedment strain gauge – **US$785** Horizontal Clip Gauge - **US$228**	**MnDOT (Minnesota Dept of Transportation)**: Specs online.
5	Accelerometer: Piezoelectric (most common), LVDT, Variable resistance, capacitive, inductive.	Completely self-contained vibration measuring systems having a built-in amplifier within the housing. Low output impedance allows operation directly into standard read-out equipment without	An AC voltage that is linearly proportional to the linear acceleration along the sensitive axis of the accelerometer.	- Stress/strain	**Hoskin Scientific**: Wide range of uniaxial and triaxial accelerometers. **Columbia Research Labs**: Wide range of piezoelectric accelerometers	**Hoskin**: Heavy duty hermetically sealed units available (titanium casing) **Columbia Research Labs**: Product specs online. Hermetically sealed models available for use

	Sensor name	Description of methodology	Output	Possible Application	Manufacturer/ Models/ Price	Specs/ Installation
		auxiliary signal conditioning. Vibration or Vertical acceleration of pavement surface under dynamic load.			(triaxial, integrated, special purpose, general purpose and miniature). **MnDOT (Minnesota Dept of Transportation)**: Piezo-Accelerometer – **US$270**	in dirty and humid environments.
6	Pressure transducer: Strain-gauge, Piezo-electric	The physical deformation of a strain gauge or piezo-electric material due to external pressure is converted to an analog electrical signal.	A voltage that is linearly proportional to the pressure applied.	- Stress/strain	**Columbia Research Labs**: Wide range of piezo-electric pressure transducers, for different environments/needs (high pressure, high temp, corrosive environment etc.).	**Columbia**: Product specs online. Hermetically (stainless steel) sealed model available.

Appendix B

Web Sites for Equipment Manufacturers

3M, Canoga VDS: Non-Invasive Microloop Model 702
http://multimedia.mmm.com/mws/mediawebserver.dyn?yyyyyygeqJMySazyLazyyydAY3t0truQ-

AerotechTelub – RWIS
http://www.rwis.net/pdf/rwis3.pdf

ANS Inc – frost probes
http://www.approach.nb.ca/products/frost%20probe.asp

AquaPro Sensors – Radio Frequency Sensors
http://www.aquapro-sensors.com/

ASIM Technologies, TT290 Series Infrared vehicle classifiers
http://www.asim.ch/e/traffic/

Avery Weight-Tronix
http://www.wtxweb.com/
Avery Weight-Tronix, Traxle truck scales (suitable for trucks with similar configurations only)
http://www.wtxweb.com/scales/traxle_L.pdf
Avery Weight-Tronix, SteelBridge XT and BridgeMont
http://www.wtxweb.com/scales/mptc_L.pdf (suitable for trucks with similar configurations only)

Banner Engineering Corp, Mini-Array AVC system
http://info.bannersalesforce.com/xpedio/groups/public/documents/prod_broc_flyer/44925.pdf

More information on the above available at:
http://www.bannerengineering.com/products/measure_inspect/miniarray/

Campbell Scientific – Time Domain Reflectometry (TDR)
http://www.campbellsci.com/tdr.html

CAPTELS LS-WIM (Low Speed WIM) Systems
http://www.captels.com/hten/

http://www.cascadecontrols.com/Banner/Measuring%20and%20Profiling%20Toll%20Booth%20(AVC)%20System.htm

Central Weighing Limited, Checklode Freeweigh Cablefree (portable, dynamic weighing),
http://www.central-weighing.co.uk/product_brochures.asp

Columbia Research Labs
http://www.columbiaresearchlab.com/lvdt.htm - LVDT
http://www.columbiaresearchlab.com/Pressure.htm - Pressure Transducers
http://www.columbiaresearchlab.com/Piezo1.htm - Piezoelectric accelerometers

Counters & Accessories, Ltd.
http://www.c-a.co.uk/
Counters & Accessories, Ltd., Loop Profiler
http://www.c-a.co.uk/products/products.asp?ID=28

Dynamax Inc.
http://www.dynamax.com/p13.htm - – Time Domain Reflectometry (TDR)
http://www.dynamax.com/ - THLogger (soil moisture datalogger)

Efkon, TOM 2000 (vehicle classification)
http://www.efkon.com/index.pl/en_vehicle_classification
Efkon, Ecotoll
http://www.efkon.com/index.pl/en_mlff_ecotoll

Electronique Control Mesure, Piezo Sensors, LOREN multi-lane microwave detectors, HESTIA WIM,
(ALSO: Software and GUI)
http://www.ecm-france.com/gb/produits/index.php

Environmental Measurements Ltd
http://www.emltd.net/SW120.pdf – Surface wetness probes
http://www.emltd.net/NRS2.pdf - net radiation sensor
http://www.emltd.net/SKS1110.pdf - solar radiation sensor

FATA DTS, WIM System
http://www.fatadts.it/

Gage Technique:
http://www.gage-technique.demon.co.uk
http://www.gage-technique.demon.co.uk/instruments/piezo-intro.html - Piezometers

Geokon:
www.geokon.com
http://www.geokon.com/products/datasheets/4800.pdf - Pressure cells (Jackout, Pile-Tip, Earth, Contact)

Geo-Log Inc. – Dynaflect
http://www.dynaflect.com/index.htm

Geonor:
http://www.geonor.com/page14.html - Earth pressure cell

Global Water Instrumentation Inc. – Soil Moisture Sensor
http://www.globalw.com/soil_moisture.html

Golden River Traffic, 8-loop and 2-loop traffic classifiers (accurate)
http://www.goldenriver.com/ns/ps_loop.html
Golden River Traffic, 16-loop and 8-loop piezo traffic classifiers
http://www.goldenriver.com/ns/ps_piezo.html
Golden River Traffic, M671/2 WIM
http://www.goldenriver.com/ns/ps_wim.html

Hoskin Scientific
http://www.hoskin.ca/html/sen/st_gauge/st_gauges.html
http://www.hoskin.ca/html/sen/accelerometer/accelerometer.html

Humboldt – Benkleman beam
http://www.humboldtmfg.com/pdf1/80.pdf

Intermountain Environmental Inc. – Soil Moisture Sensors
http://www.inmtn.com/sensorsmoist.htm

International Road Dynamics Inc.
http://products.irdinc.com/index.htm
International Road Dynamics Inc., large selection of Integrated vehicle classifiers & counters.
http://products.irdinc.com/html/counter/index.htm
International Road Dynamics Inc., WIM systems
http://products.irdinc.com/html/counter/wimclass.htm
International Road Dynamics Inc., large selection of In-road sensors
http://products.irdinc.com/html/sensor/inroad.htm
International Road Dynamics Inc., selection of treadles
http://products.irdinc.com/html/treadle/index.htm

Intertraffic (leading online reference database & info bank for the parking, traffic and transport infrastructure industry)
http://www.intertraffic.com/home.asp

Measurement Specialties, Inc.
http://www.msiusa.com/

Metter Toledo WIM System
http://www.mt.com/mt/product_detail/product.jsp?m=t&tr=I1NDU3MzcwMS1QfDQxNTQ1NzM3MDEtUHw2_TM0NTczNzAxLUF8MTc2NTU3MzcwMS1DfDU2NjU1NzM3MDEtQ3wiNz&key=k0Mzg4NjM1_D

MnDOT (Minnisota Dept of Transportation): Office of Materials and Road Research
http://www.mnroad.dot.state.mn.us/research/MnROAD_Project/pavesensors90.asp - all Pavement Sensors used by MnDOT.

MSI, RoadTrax (piezoelectric)
http://www.msiusa.com/sensors/mass_transit_and_traffic.asp

OSI LaserScan
http://www.osi-ls.com/
OSI LaserScan system (Overhead OR Ground based vehicle classification systems)
http://www.roadtraffic-technology.com/contractors/detection/osi/

PEEK Traffic
http://www.peek-traffic.com/Index.asp?LinkID=99997#
PEEK Traffic, Idris (ADR6000)
http://www.its-info.com/datacol_adr6000.htm
PEEK Traffic, ADR3000 Plus (Loop or piezo-electric traffic counter classifier)
http://www.peek-traffic.com/File.asp?FileID=ss96-114-1ADR3000
PEEK Traffic, VideoTrak Plus
http://www.peek-traffic.com/File.asp?FileID=ss96-081-1VideoTrak

Peltron
http://www.sensorsforindustry.com/prod29.htm

Prenart Equipment ApS
http://www.prenart.dk/tdr.php

Slope Indicator:
http://www.slopeindicator.com/instruments/tpc-jackout.html - Jackout pressure cells

Sowacs.com – Time Domain Reflectometry (TDR)
http://www.sowacs.com/sensors/tdr.html#csi
Spectrum – Time Domain Reflectometry (TDR)
http://www.specmeters.com/Soil_Moisture/index.html

SSI – Range of RWIS products
http://www.ssiweather.com/pages/products/rwis/road_runway_weather_information_system.htm

Sterela (WIM, traffic count, also meteorology stations for road-surface temp, air temp, dew point, frost depth, rain detection, windstrength/direction etc.)
http://www.sterela.fr/indexuk.htm
Sterela, SASV (WIM station)
http://www.sterela.fr/english/routier.htm

STI scanners: Side profiling scanner, VS6500
http://www.stiscanners.com/products/vscan/index.html

Surface Systems, Inc
http://www.ssiweather.com/pdf/TDP%20Probe.pdf – Thermistor Probe
http://www.ssiweather.com/pdf/FP2000_Sensor.pdf - pavement sensor FP2000

TagMaster, AVI tags & readers
http://www.tagmaster.se/products/tags.php

TEC Traffic Systems, Marksman 660 vehicle classifier (loop)
http://www.tectraffic.nl/English/VR_Marksman660Classifier.php
TEC Traffic Systems, Kistler WIM
http://www.tectraffic.nl/English/VR_KistlerWIM.php
TEC Traffic Systems, TOM

Technolution, custom-made transport solutions
http://www.technolution.nl/htmluk/defaultuk.htm
Technolution, example of a WIM installation
http://www.technolution.nl/htmluk/ourcompany/References/weigh%20in%20motion_eng.pdf

Telvent
http://www.telvent.com/products/transportation.asp
Telvent, AVC (Automatic Vehicle Classification)
http://www.telvent.com/products/transportation/AVC.pdf

Temperature Systems International – Thermocouples
http://www.tsitoday.com/tmi.html

Thermo Sensors Corporation – Thermocouples
http://www.thermosensors.com/catalog/thermocouples.pdf

Traffic Technology 2000 – ARWIS
http://www.traftech2000.com/lufft/index.htm

Transport Canada – Remote Controlled Weight Stations
http://www.tc.gc.ca/tdc/projects/its/d/its04.htm

Transport Data Systems – Automatic Vehicle Classification and License Plate Capture Systems (overhead and ground based profilers, WIM system)
http://www.transportdatasystems.com/products.htm

Vaisala – Extensive range of products (Road weather)
http://www.vaisala.com/page.asp?Section=5418

Laser Vehicle Detection (overhead profiler)
http://www.tectraffic.nl/English/VD_TOM.php

Appendix C

Market Scan

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1. INTRODUCTION

Intelligent Transportation Systems (ITS) include the application of technology to address transportation issues. Through this Research and Development project funded by Transport Canada, the use of ITS to assist with variable load restrictions will be investigated. Variable load restrictions include Seasonal Load Restrictions (SLR) and Winter Weight Premiums (WWP).

The current asset value of Canada's roads and pavements is in the order of $150 billion, encompassing the national, provincial and municipal road network. Protecting this investment is of critical importance to the movement of goods and the mobility of people. The two biggest sources of deterioration are the environment and loading. It is a principle challenge to design a pavement that will withstand very low temperatures in the winter and very high temperatures in the summer. In addition to resisting environmental effects, the pavements must be able to withstand the effects of heavily loaded trucks, which are an important source of revenue to our national economy.

Pavements are especially vulnerable to deterioration throughout the spring thaw. During this time of year, as the thaw progresses, the pavement structure becomes weak due to saturation and differential thaw. Damage can occur in both the surface asphalt layer but also in the base, sub-base and subgrade layers depending on the degree of saturation and the degree of thawing. Consequently, the pavements will exhibit signs of premature deterioration due to permanent structural damage. This damage can be isolated to cracking or it can be more severe in nature where a full failure occurs which will then require immediate repair. Thus it is critical that seasonal load restrictions be applied to these pavements structures, which are weakened during the spring thaw.

In 1992, the World Bank published a report that stated cost savings ranging from 40 % up to 92 % with an average of 79 % could be achieved where seasonal traffic load restrictions were implemented in countries that had annual freeze-thaw cycles. Although these numbers are not available for Canada, it is reasonable to assume that cost savings are achieved when seasonal load restrictions are applied at the right time. The actual cost savings would be dependent on the pavement material properties and thickness of the respective pavement structural layers.

In April 2000, the Transportation Association of Canada (TAC) Pavements Standing Committee (PSC) met to discuss the issue of current seasonal load restrictions in Canadian provinces. Based on this assessment, it was determined that most agencies do not restrict their primary network; however, restrictions are placed on the secondary and tertiary networks. These restrictions tend to be related to expert judgement and historical records. Typical restrictions are based on the allowable weights and vary from 50 % to 90 % [1]. A number of jurisdictions, including Manitoba, The Northwest Territories and Alberta, permit WWP to reflect the additional bearing capacity of the frozen conditions. In addition, it was determined that many Canadian provinces were interested in developing seasonal load restrictions based on mechanistic principles that relate to actual temperatures and moisture within the pavement structure. This flexibility is especially critical given global warming and continued pressure from the trucking industry to justify SLR restriction periods and to increase truck weights and loads.

In jurisdictions that employ both SLR and WWP, seasonal weight limits can cover up to a seven month period [2].

1.1 Project Scope and Objective

Overall the project involves looking at the opportunity to apply ITS to assist agencies across Canada with management of their seasonal load restrictions and winter weight premiums. The project includes the following tasks:

- Market Scan – review current SLR and WWP policies and practices;

- Parameter Definition – research and determine the pavement and sub-grade parameters that could be monitored;
- Equipment Definition – assess the equipment that is available to quantitatively measure the necessary parameters; and
- Algorithm Definition and System Design – develop the functional definition and system functional requirements to deliver the ITS solution.

This report represents the findings of the Market Scan component of the overall study.

1.2 Definitions and Abbreviations

A number of terms and abbreviations were defined to facilitate discussion and understanding during the study and for this document. Provided below is the terminology and abbreviations formulated for these purposes:

ARWIS - Advanced Road Weather Information Systems

BWR - Basic Weight Regulations

C-SHRP - Canadian Strategic Highway Research Program

CTI - Central Tire Inflation

FHWA - United States Federal Highway Administration

FWD - Falling Weight Deflectometer

GPS - Global Positioning System

RF - Radio Frequency

SLR - Seasonal Load Restrictions

PWGSC - Public Works and Government Services Canada

TDR - Time Domain Reflectometry

WWP - Winter Weight Premiums

2. LOAD RESTRICTION/PREMIUM POLICIES AND PRACTICES

2.1 Justification and Rationale

Roadway design practices vary for primary and secondary roads and consequently the roads have different strength characteristics, different structural capacity and different susceptibility to frost. It is noteworthy that there is a relationship between frost susceptible soils and thaw weakening. With regards to frost susceptibility, there are three conditions that must be met for road strength to be impacted during the spring thaw period. These conditions include:

- The soil must be frost susceptible;
- A water source must be available to the freezing zone; and
- Freezing temperatures must penetrate into the soil [3].

The availability of these three conditions will result in thaw weakening. In addition, thaw weakening can occur in soils that are not frost susceptible, in these cases, it would be expected that the type of soil would impact the amount of thaw weakening that occurs in the structure. This concept will be further explored in the parameter definition task as part of this project.

2.2 Current Imposition System

There are a number of different ways that agencies determine when to implement SLR or WWP ranging from fixed date to analytical. The primary goal in implementing SLR and WWP is to strike the right balance between minimizing road damage and maintenance costs and reducing economic activity by restricting weights for trucks. Start and end dates must be properly administered, as inaccurately determining either the SLR or WWP may disrupt the balance and result in higher maintenance costs or reduced economic activity.

This review summarizes how agencies determine when to implement and when to lift SLR and WWP, but does not address how agencies determine which roads to implement SLR or WWP on. Typically design criteria and strength are the primary factors in the latter case.

2.2.1 CALENDAR-BASED

A calendar based imposition system refers to the practice of selecting fixed start and end dates for the SLR or WWP. These fixed start and end dates are typically determined through consideration of historic data and applying an average duration.

2.2.2 VISUAL OBSERVATIONS/ENGINEERING JUDGEMENT

Agency staff typically have a very good understanding of their networks and how the roads are performing. Diligent monitoring triggered by temperature changes in conjunction with historical information leads to informed decisions for when to trigger SLR or WWP.

2.2.3 QUANTITATIVE

Agencies adopting a quantitative or condition based approach to SLR and WWP may apply a model or thaw index to measured conditions or predictive temperatures. Agencies may also rely on data relating to frost depth, road strength and temperature to quantitatively determine when to impose and lift the SLR or WWP.

2.2.4 REDUCED TIRE PRESSURE

Work has been done throughout Canada and the US on the use of reduced tire pressure to create more 'road friendly' trucks. Reduced tire pressure increases the footprint of the tire, which reduces the horizontal and vertical strain that is applied to the road surface, allowing heavier loads to be carried without increasing the damage to road structures. A Central Tire Inflation (CTI) system allows drivers to monitor and modify tire pressures from their cab [4]. In addition, the use of Global Positioning System (GPS) on the truck and a data logger allows the tracking of vehicle location and associated tire pressure. The British Columbia Ministry of Transportation adopted the use of CTI in 2004 as a means of allowing hauling through part of the SLR period.

2.3 Current Imposition Application by Jurisdiction

A literature search was completed to determine current imposition methods in Canadian jurisdictions. In addition, interviews with Canadian transportation agencies were conducted to confirm/supplement this documentation. The primary focus was to document the practices and policies within Canada and augment that information with a high level overview of what is happening in the US and internationally. The summaries provided below reflect the general policies and practices of the agencies and highlight new practices. Further details on each agency were obtained through the Internet or by contacting the agency representative.

2.3.1 CANADA

The implementation of SLR and WWP vary dramatically across Canada. Some of the differences include:

- What the restriction/premium is;
- How to determine when to implement;
- How to determine when to lift; and,
- How people are informed.

Contact was undertaken with representatives from each Province and Territory across Canada to determine their policy, practice and information dissemination. The following sections include a description of the practices and policies in each Province and Territory with an overall summary included in Table C-1. Tables C-2 and C-3 provide a summary of the load restrictions that was developed as part of the C-SHRP initiative [5].

2.3.1.1 National Roads

Public Works and Government Services Canada (PWGSC) is responsible for the implementation of SLR and WWP on kilometre 133-968 of the Alaska Highway. During the SLR, no overweight permits are issued, however trucks may still carry 100% of their legal limit. The WWP includes an increase in the weight that is acceptable for overweight permits.

As the first 133 km of the Alaska Highway is operated by the British Columbia Ministry of Transportation, PWGSC implements and lifts its SLR and WWP in accordance with the decisions made by the Ministry. In addition, information on the SLR and WWP on the Alaska Highway is provided through the Ministry's web site. PWGSC also provides a daily road report that gets disseminated to the media, lodges and trucking associations.

2.3.1.2 Newfoundland and Labrador

Newfoundland does not use seasonal load restrictions because their sub-grade generally consists of rock and consequently does not experience deterioration during the spring.

Prior to the Trans-Labrador highway being upgraded (when it was just gravel) they would impose spring load restrictions. Now that it's been upgraded they have no SLR or WWP.

2.3.1.3 New Brunswick

New Brunswick Department of Transportation (NBDOT) implements SLR but no WWP. During the spring, some roads are at 100% of legal limit, some at 90% and others at 80%. The 90% limits are typically the arterials and collector facilities.

They recently reviewed their start/end dates over the last 20 years and determined the average start/end dates and that the average period for the SLR is 70 days. 2004 is the first year when they are using the average dates and they chose the closest Monday to the average date. The average start date may be amended using engineering judgment, if there is significantly cooler weather. There are two zones – North and South – and the start dates may differ for each zone.

NBDOT staff use a Benkelman beam or Falling Weight Deflectometer (FWD) to determine current strength. Staff take readings once per week at 40 or more control sections and compare to strength curves for that section. Once the strength readings have hit bottom and are starting to regain strength then they will lift the restrictions.

Information is posted on the web site and an ad is placed in papers to let motorists and operators know about web site. Maintenance staff also post signs on roads.

2.3.1.4 Nova Scotia

In Nova Scotia SLRs are implemented on all roads with some exceptions (exempt roads). Winter weight premiums are not used. Exempt roads are defined based on design criteria and deflection readings. Dynaflect testing is completed on newly constructed roads to determine if the road meets the maximum allowable deflection of 37. Loads are restricted to 6,500 kg for a single axle, 12,000 kg for tandem and tridem.

In order to determine when to implement the SLR, Nova Scotia Transportation and Public Works (NS TPW) staff look at the long range, 10 day, prediction from Environment Canada and consult with maintenance staff. Using the weather data and road condition information, staff qualitatively determine when to impose the seasonal load restriction. Over the last couple of years, the SLR has been implemented across the province at the same time. Sometimes the "Banana Belt" (Yarmouth – Halifax area) will melt earlier and the SLR will be implemented earlier in that region with the rest of the province following a couple of weeks later. NS TPW is also gathering frost depth information to assist in the determination of the start date. Frost probes were used in the past, but have provided unreliable results. NS TPW have installed 2 m deep rods with temperature sensors every 20 cm at three ARWIS locations. They plan to use these deep sensors to provide information on frost depth, which will be used to determine when to impose the SLR. NS TPW plan to include these deep temperature sensors at all future ARWIS locations.

The SLR is lifted using a combination of quantitative and qualitative means. Staff complete Dynaflect testing on controlled sections. Knowing the peak deflection, if the readings are close, then they know that the road is recovering and that the restriction will be lifted shortly. Maintenance engineers provide road condition information to supplement the deflection information. The SLR may be lifted at different times for each zone, if the road appears to be in good condition.

Information is disseminated formally and informally. Trucking agencies will call directly for information. In addition, press releases are issued in advance of implementing the restriction to warn of the upcoming restriction. Once the SLR is in place, ads are run in the newspapers, periodic press releases are issued, information is posted at the scale houses, and the information is posted on a web site.

2.3.1.5 Prince Edward Island

Prince Edward Island (PEI) Transportation and Public Works (TPW) implements SLR but does not allow WWP. Full weather roads are not restricted, however, other secondary roads are restricted to 75% of the legal limit.

Frost tube and Benkelman Beam readings are used to determine when to implement the SLR. In addition, PEI is cognizant of when Nova Scotia and New Brunswick implement their SLR and ensures that the timing for the SLR implementation and lifting are at approximately the same time. SLR may be implemented in two zones, the Western and Eastern zone, although typically they are implemented at the same time.

Weather conditions as well as frost tube and Benkelman Beam readings are also used to determine when to lift the SLR.

Information on SLR is disseminated through the internet, newspaper advertisements and through posting of static signs.

2.3.1.6 Quebec

The ministère des Transports du Québec (MTQ) implements SLR but does not implement WWP. SLR involves an axle weight reduction on non-driving axles that ranges from 6% to 20%.

The province is divided into 3 zones and frost tube readings are used to determine the start and end of the SLR. There are between 80 and 90 frost tubes that are read manually by the maintenance staff and then entered into an internal web site. When the thaw depth reaches 30 cm, the SLR is implemented and it is lifted 5 weeks after the thaw depth reaches 90 cm. MTQ has deployed a pilot project that incorporates automatic frost probe readings and temperature sensors. The temperature sensors are mounted on a 2-3 m rod every 20 cm or to correspond to layer thicknesses.

SLR information is provided through the internet and through newspaper advertisements.

2.3.1.7 Ontario

The Ministry of Transportation of Ontario (MTO) imposes SLR but does not allow WWP. For SLR, weight on any axle is reduced to 5000 kg.

There are three periods for SLR that is defined for different geographic locations of highways. The three dates for SLR are:

- Select Kings Highways – 1st day of March 2003 to the 30th day of April 2003, both inclusive;
- Select Kings Highways - 1st day of March 2003 to the 31st day of May 2003, both inclusive; and
- Selected local roads - 1st day of March 2003 to the 30th day of June 2003, both inclusive.

The District Engineer locally determines when the SLR should be implemented using weather conditions and visual inspections of the highway. The SLR is lifted based on the fixed date.

In conjunction with newspaper ads, MTO posts signs on the affected highways, sends letters to stakeholders, and posts the information on the MTO website. In addition, signs are posted by the Operations Division.

2.3.1.8 Manitoba

Manitoba Transportation and Government Services (MTGS) implements SLR and permits WWP. Level 1 roads (RTAC, A1, B1) are restricted to 90% and Level 2 roads (A1, B1) are restricted to 65% of the legal load limit. MTGS uses strength measurements to classify the roads into the Level 1 and 2 categories. The WWP allows for an addition 10% of the legal load limit for tandem axle groups, up to a maximum of the Gross Vehicle Weight.

MTGS uses a fixed start date for the SLR. Zone 1 (South) is March 18th and Zone 2 (North) is March 25th. These start dates can be delayed depending on the thaw index calculation. Manitoba follows the Minnesota thaw index model.

$Ti_{date}=Ti_{previous\ date}$ + Reference Temperature + Daily Mean $Temperature_{date}$

Where:

TI = Thawing Index

Reference Temperature = 1.7°C beginning March 1 and increasing 0.06°C per day

Daily mean temperature = (maximum + minimum Daily Air Temperatures)/2

The reference temperature increases throughout March in order to account for the increase in radiation. MTGS uses a 5 day forecast from Environment Canada for the mean and max air temperature. Once the cumulative thaw index reaches 15°C, then the SLR is in place. A minimum of 48 hours advance notification is necessary to implement the SLR, so MTGS relies heavily on forecasted weather information.

MTGS uses a fixed end date of May 24th for Zone 1 and Zone 2. This is based on their experience of an average period of 70 days for SLR. If the start date is delayed as a result of the thaw index calculation, the end date will be pushed out accordingly up to a maximum of May 30th.

A fixed date of December 1st is used for the initiation of the WWP and a fixed date of February 28th is used as lifting date of the WWP.

In October MTGS places an ad in newspapers to inform stakeholders of the availability of the list of roads that will be restricted on the fixed starting dates next March. As the date is finalized, MTGS provides information directly to trucking associations and posts information on their web site, in newspapers and in bulletins. The SLR information is available through a fax polling service and a road information line. In addition, district crews install road signs with SLR information.

2.3.1.9 Saskatchewan

Saskatchewan Highways and Transportation (SHT) implements SLR and allows WWP. For SLR, steering wheels are restricted to 10.0 kg/mm width of tire to a maximum weight of 3,000 kg on a wheel, to a maximum of 5,500 kg on the steering axle with the exception of straight trucks on primary highways which are allowed up to a maximum of 7,250 kg on the steering axle with appropriate tire size. Other wheels are restricted to 6.25 kg/mm width of tire on any wheel to a maximum of 1,650 kg per wheel. WWP include an increase in the maximum gross weight on various axle configurations.

Area managers determine when to implement SLR based on thermistor readings, weather conditions and road condition inspections.

SHT has a policy that allows SLR to be implemented for a maximum of 6 weeks. Road condition inspections may result in the SLR being lifted earlier.

WWP are implemented and lifted based on fixed dates. WWP are in place from December 11 to February 28.

SLR and WWP information is disseminated through a hotline, a fax polling system, subscriber based fax broadcast and through the Internet.

SHT has developed partnerships with some trucking companies that allow CTI to be used to reduce the SLR.

2.3.1.10 Alberta

Alberta Transportation implements seasonal load restrictions and winter weight premiums.

SLRs reflect 75% or 90% restrictions of the legal load limits. FWD readings from previous years are used to determine which restriction is imposed on which road. Winter weight premiums include an additional 500 kg for single axles and 1,000 kg for tandems.

Alberta Transportation uses a combination of frost probe readings and weather forecasts to determine when to implement the SLR. Frost probe readings at 20 automated sites and 30 manually read (2 times per week) across the province provide input to staff to help them determine if the roads are thawing. SLR must be in place if there is a 30 cm thaw depth. Looking at the weather forecasts when the thaw depth is less than 30 cm assists with planning and provides the opportunity to notify people in advance of the SLR implementation. Alberta Transportation tracks a thaw line across the province and the SLR is placed on any roads south of the thaw line.

Alberta Transportation uses frost probe readings and FWD to measure strength recovery in order to determine when to lift the SLR. Maintenance staff input on the road condition is also used. They have numerous (over 1000) control sections at which to take the FWD readings.

WWP are implemented once there is 1 m or greater of frozen ground. This is determined using the frost probe readings. WWP are lifted when a substantial portion of the Province is in either a permanent or recurring thaw state (~30 cm of thaw).

Information is disseminated through a web site, fax polling service and through a phone-based system maintained by an outside consultant.

2.3.1.11 British Columbia

British Columbia Ministry of Transportation (BC MOT) implements SLR but does not allow WWP. Loads are predominately restricted to 70% of the legal limit by axle group although some areas are restricted to 50% or 75% of the legal limit. BC MOT also imposes a 100% restriction for over loaded vehicles during the SLR period. During other periods trucks can apply for an overweight permit. In 2004, BC MOT issued a press release (http://www.gov.bc.ca/bvprd/bc/channel.do?action=ministry&channelID=-8394&n) that allows vehicles that are equipped with Central Tire Inflation (CTI) to travel routes that would have a SLR in place at 100% of the legal limit with a reduced tire pressure. Studies done by FERIC [4] have proven that reducing tire pressure makes the vehicles more road friendly and allowing them to travel on roads with a full load during the period when SLR are in effect does not result in increased damage to the road.

MOT Staff remotely obtain frost probe readings throughout the year using a data logger and a modem. Frost probe data, weather patterns, historic data and judgement are used to determine when to implement the start of the SLR. There are eleven districts that post their information to a provincial web site. Restrictions are enforced by the Ministry of Public Safety and Solicitor General who run the weigh scales and control licensing.

Benkelman Beam readings are taken on a weekly basis at a number of control sections to determine when to lift the restrictions. They look at the historical readings for the control section and the seasonal strength curve to determine if the pavement structure strength is recovering.

The forest service is regulated by their own set of rules; however, their facilities generally connect with a provincial road, so by default they are bound by the Ministry's regulations.

2.3.1.12 Nunavut

Nunavut does not implement SLR or WWP. Nunavut is comprised of 25 distinct communities that are not connected by a road network.

2.3.1.13 Northwest Territories

The Northwest Territories Department of Transportation implements SLR and WWP. The SLR is either 100% or 75% of the legal limit and roads are classified based on their pavement design. The WWP allows an additional 500 kg per axle on 5 or 6 axle units and truck trains are allowed an additional 100 kg on their drive axles.

The SLR are implemented based on road inspects and weather conditions. Benkelman Beam readings as well as road inspections are used to determine when the SLR can be lifted.

WWP are implemented after a fixed number of days of cold weather.

Trucking agencies are informed of the SLR and WWP through and Interactive Voice Response information number, through flyers at maintenance camps and weigh scales and also through the internet.

2.3.1.14 Yukon Territory

The Department of Highways and Public Works for the Yukon Government implements SLR and is investigating the possibility of allowing WWP.

Secondary highways are reduced to 75% of their legal limit during the SLR.

Thermistors, with probes every 20 cm on a 2 m rod, are read manually and automatically and used to determine when to implement the SLR. Once signs of thawing are noted, the SLR is implemented.

The SLR is in place for approximately 5 weeks or until the thermistor readings show that there is greater than 1 m of thaw.

People are notified of the SLR through newspaper advertisements, road reports and also by providing information directly to trucking authorities. In addition, the Department of Highways and Public Works also notifies Alaska and other states of the SLR.

2.3.1.15 Summary

Included in Table C-1 is a summary of the SLR and WWP practices across Canada.

Table C-1: Summary of SLR and WWP practices

Jurisdiction	SLR – Imposition Method	SLR – Lifting Method	WWP – Imposition Method	WWP – Lifting Method	Contact
National Roads	Based on BC decision	Based on BC decision	Based on BC decision	Based on BC decision	Pat Whidden (250) 774 6957
Newfoundland/ Labrador	N/A	N/A	N/A	N/A	Will Griffin (709) 729 0359
New Brunswick	Fixed date – refined through temperature	FWD, Benkelman beam readings and road condition information	N/A	N/A	Denis Goguen (506) 453 2802 http://www.gnb.ca/0113/Policy/swr2004-e.asp
Nova Scotia	Weather and road condition information. Adding 2 m temperature sensors at ARWIS sites for frost depth readings.	Dynaflect and road condition information	N/A	N/A	Gerrard Lee (902) 424 5582 www.gov.ns.ca
PEI	Frost tubes, Benkelman Beam	Frost tubes, Benkelman Beam, weather conditions	N/A	N/A	Wilfred McDonald (902) 368 5222 http://www.gov.pe.ca/news/getrelease.php3?number=3520
Quebec	Frost tubes, pilot for temperature sensors	Frost tube + fixed duration	N/A	N/A	Denis Saint- Laurent (418) 643 7740 http://www1.mtq.gouv.qc.ca/en/publications/camionnage/infocam/index.asp
Ontario	Fixed date modified based on temperature and road conditions	Fixed date	N/A	N/A	Becca Lane (416) 235 3513 www.mto.gov.on.ca
Manitoba	Fixed date – modified by Thaw index calculation	Fixed date	Fixed date	Fixed Date	Ray Van Cauwenberghe (204) 945 1934 http://www.gov.mb.ca/tgs/transreg/compreg/spring-restrict.html
Saskatchewan	Thermistor, weather, road condition	Road inspection or max of 6 weeks	Fixed date	Fixed Date	Josh Safronetz (306) 933 5947 http://www.highways.gov.sk.ca/docs/trucking/weight_restriction_transition.asp

Jurisdiction	SLR – Imposition Method	SLR – Lifting Method	WWP – Imposition Method	WWP – Lifting Method	Contact
Alberta	Frost probes (= 30 cm of thaw), weather conditions	FWD, frost probe	> 1 m of freezing	< 30 cm of freezing	Imants Krumins (403) 340 5189 http://www.trans.gov.ab.ca/Content/doctype260/production/RoadBans.pdf
B.C.	Frost probe, weather, historical, judgement	Benkelman beam	N/A	N/A	Mike Oliver (250) 387 3353
Nunavut	N/A	N/A	N/A	N/A	Tom Brigard (867) 975 5381
Northwest Territories	Road inspection	Benkelman Beam, road inspection	# of days of cold weather	Road inspections	Pete Boden (867) 874 5007 http://www.gov.nt.ca/
Yukon Territory	Thermistors	Thermistors	N/A	N/A	Gary Felker (867) 667 5644 http://www.hpw.gov.yk.ca/trans/rr/weight.html

Table C-2: Comparison of Basic and Seasonally Restricted Loads in Canada

Province	Allowable Weights Under Basic Regulations				Spring Load Restrictions			
	Tractor		Trailer		Tractor		Trailer	
	Steering	Drive	Tandem	Tridem	Steering	Drive	Tandem	Tridem
British Columbia[1]	5500 kg	9100 kg	17000 kg (1.2 to 1.85m)	24000 kg (2.4 to 3.7m)	• Restrictions imposed only when and where needed through engineering judgement • Overload permits suspended for numbered highways • Other highways restricted at 70% or 50% of basic axle weight (steering axle exempted)			
Alberta[2]	5500 kg	9100 kg	17000 kg	23000 kg (3.05 to 3.6m)	• 90%, 75% or 50% of basic axle weights			
					Not Restricted	8190 kg (90%) 6825 kg (75%)	15300 kg (90%) 12750 kg (75%)	21600 kg (90%) 18000 kg (75%)
Saskatch-ewan[2]	5500 kg	8200 kg	14500 kg	20000 kg	• Reduction of load per tire from 10 kg/mm width to 6.25 kg/mm width to a maximum load of 1650 kg per tire • Some primary highways are downgraded to secondary highways during May and June			
					Not Restricted	6600 kg	13200 kg	19800 kg
Manitoba	5500 kg (A1 Hwys) 5500 kg (B1 Hwys)	9100 kg (A1 Hwys) 8200 kg (B1 Hwys)	16000 kg (A1 Hwys) (1.0 to 1.85m) 14500 kg (B1 Hwys) (1.0 to 1.85m)	23000 kg (A1 Hwys) (3.05m) 20000 kg (B1 Hwys) (3.05m)	• No restrictions to primary system or gravel roads • Steering axle not restricted • For other axles: • **Level 1** (beginning of thaw for 14 days): • A1 highways 90% of basic load • B1 highways 95% of basic load • **Level 2** (imposed 14 days after Level 1 and removed 1 week before removal of Level 1): • 65% of basic load			
Ontario[3]	5000 kg	10000 kg	17200 kg	23000 kg	• Primary network not restricted • Restrictions on some secondary provincial highways up to 50% of basic load • Commercial vehicles not to exceed 5000 kg • 2-axle tanker truck not to exceed 7500 kg/axle • Maximum of 5 kg/mm tire width			
Quebec	5500 kg	10000 kg	18000 kg	21000 kg to 26000 kg	5500 kg	8000 kg	15500 kg	18000 kg to 22000 kg
New Brunswick	5500 kg	9100 kg	18000 kg	21000 kg (2.4 to 3.0m) 23000 kg (3.0 to 3.6m) 26000 kg (3.6 to 4.8m)	• Three restriction levels: • All weather highways, arterials and most collectors allow 100% of basic load • Specific collectors and locals allow 90% of basic load • All other highways allow 80% of basic load • Tolerance removed for all levels			
	Tolerance 500 kg/axle							
Prince Edward Island	5500 kg	6800 kg	13500 kg	18000 kg (<3.6m) 19500 kg (>3.6m)	• All weather highways, Trans-Canada arterials and some collectors allow 100% of basic load • Other highways allow 75% of basic load • Tolerance removed during thaw			
	Tolerance 500 kg/axle							
Nova Scotia	• Combination 50000 kg + 500 kg/axle tolerance • 5-axle Semi-trailer 41000 kg + 2500 kg tolerance (Schedule C highways and some arterials and collectors) • Other highways 38500 kg gross vehicle + 500 kg/axle tolerance				• Tolerance removed during thaw • Max. gross weight 12000 kg for buses			
					Not Restricted	6500 kg	12000 kg	
New-foundland	No formal policy 9100 kg Single, 12000 kg Tandem				• Arterial and collector roads are all weather • Local roads monitored and restricted as needed			

1. Trailer weights are based on 10 kg/mm of tire width.
2. Values reported for Secondary highway system.
3. Weights based on tire width. Example given is for width of 279.4mm (11 in.).

NOTE: REPLACE MANITOBA WITH THE FOLLOWING:					
Manitoba	5500 kg (A2 Hwys)	9100 kg (A1 Hwys)	16000 kg (A1 Hwys) (1.0 to 1.85m)	23000 kg (A1 Hwys) (3.05m)	• No restrictions to primary system or gravel roads <u>Level 1 Restrictions:</u> • 90% of basic load • Steering axle not restricted <u>Level 2 Restrictions:</u> • 65% of basic load, including steering axle <u>Common to both Restriction Levels:</u> • No restrictions to primary system or gravel roads • Fixed starting and end dates for each of the two climatic zones • Starting date may be delayed as determined by the thawing index.
	3575 kg (B1 Hwys)	8200 kg (B1 Hwys)	14500 kg (B1 Hwys) (1.0 to 1.85 m)	20000 kg (B1 Hwys) (3.05m)	

Table C-3: Seasonally Load Restriction Implementation, Testing and Enforcement in Canada

Province	Start/End Dates	Testing	Exemptions	Enforcement
British Columbia	**Mid-February to Mid-June**	• Frost probes, weather synopsis, Benkelman Beam data for 20+ years, other historical data		• Permanent and portable scales
Alberta	**Start Date:** 30cm thaw and a heat flow model **End Date:** Determined with FWD testing	• FWD	• Milk, farm machinery, bread, water, heating fuel, fertilizer, mail and buses	• 20 staffed weigh scales, 20 self-weighing scales and portable scales
Saskatchewan	**Start Date:** Second or third week in March (weather dependent) **End Date:** Maximum six weeks after start date	• Benkelman Beam		• Permanent and portable scales
Manitoba	**Start Date:** (Level 1) • Southern Zone: March 23 • Northern Zone: April 15 **End Date:** May 31	• Benkelman Beam	• Essential commodities exempted	• Permanent and portable scales
Ontario	• Variable start and end dates. Typically first Monday in March to Mid May (Southern Region)		• Municipal, milk, emergency and public utility vehicles	• Permanent and portable scales
Québec	**North:** March 24 to May 25 **Central:** March 6 to May 12 **South:** March 21 to May 19 • Timing can be advanced or delayed based on frost probe data. Start of restrictions at 300 mm thaw and ending at 5 weeks after 900mm thaw below road surface	• 81 frost probes (1.5m to 3.5m depth) • Measured weekly during freeze, daily during thaw, and then weekly at end of thaw.	• Raw forest products exempted while hauling to primary processing plant. • Single unit trucks with non-detachable dumping mechanism • Road maintenance single unit vehicles	• Permanent and portable scales
New Brunswick	**Southern Zone:** Second week in March to mid-May **Northern Zone:** Third week in March to end of May • Timing varied according to severity of winter and spring conditions	• Dynaflect testing on 40 affected control sections on weekly basis during restriction period.	• Passenger buses and service vehicles.	• Permanent and portable scales
Prince Edward Island	**March 1 to April 30** • Timing varied according to severity of winter and spring conditions	• Dynaflect testing on random sections throughout restriction period.	• Commodities (potatoes, livestock, milk, fish, and live stock feed) .	• Portable scales
Nova Scotia	**Southern Region:** March 2 to April 24 **Central/Northern Regions:** March 2 to April 27	• Dynaflect testing on random control sections (all classes) from mid-February to end of April.	• Public utility and emergency vehicles.	• Portable scales
Newfoundland	**February to April** (Trans-Labrador Highway)			• Permanent and portable scales

2.3.2 UNITED STATES

A review of literature revealed that most of the Northern US states implement SLRs to protect their roadway infrastructure. A substantial amount of SLR research is available from the Minnesota Department of Transportation (MN/DOT) and US Department of Agriculture Forest Service (USFS).

The Minnesota Model for Thaw Index using air temperature was adopted as policy in 1999 and has also been adopted (with modification) by Manitoba Transportation and Government Services. Minnesota has found that implementing a SLR one day late causes six times the damage of lifting the SLR one day early.

The Vermont Agency of Transportation (VTrans) does not implement SLR on their state roads. In Vermont, each town determines whether or not to implement SLR and the restrictions are posted on the state's web site (http://www.dmv.state.vt.us/TownHighwayPages/TownHighwaySearch.asp). Road inspections and weather conditions are used by the towns to determine when to implement and lift the SLR.

The methods used to determine when to implement and when to lift SLRs vary between states and include one or more of the following methods:

- Fixed date;
- Engineering judgement;
- Pavement history;
- Pavement design;
- Road condition inspections;
- Restriction of travel to night time hours only;
- Air and pavement temperature monitoring;
- Frost depth measurements (drive rods, frost tubes and other sensors); and/or
- Deflection testing [6].

The following states rely on engineering judgement and road condition inspections to determine when to implement the SLRs:

- North Dakota;
- Idaho;
- Maine;
- Montana;
- New Hampshire;
- Oregon;
- New York;
- Iowa;
- Wisconsin;
- Michigan; and
- Illinois [6].

The following states also apply the use of analytical methods to determine when to implement the SLR:

- Washington;
- Alaska;
- Minnesota; and
- South Dakota [6].

2.3.3 INTERNATIONAL

Limited information was found on international practices for SLR. Norway implemented SLR up to 1995. At that point, the SLR was limited and additional construction budget applied to maintain the service lives of the primary and secondary roads [6].

3. METHODOLOGY ANALYSIS

There are three primary categories of SLR/WWP imposition methods, namely indirect, deflection and direct condition-based methods. There are benefits and disbenefits for each type of methodology that is applied to determine when to implement and when to lift SLR and WWP. The following subsections provide information on each methodology and provide principle advantages and disadvantages of each.

3.1 Indirect Methods

Indirect methods include the application of models or calculations, the application of engineering judgement or fix calendar dates based on historical averages. Provided below are the methods that fall within this category.

3.1.1 HISTORICAL DATA APPLICATION/CALENDAR-BASED

There are a number jurisdictions that use historical freeze and thaw durations, in whole or in part, to apply their spring load restrictions and winter weight premiums based on calendar dates. A calendar-based imposition is the simplest; however, it is necessarily conservative and does not dynamically take into account year-to-year variations in the thaw period. A calendar-based approach is commonly used to lift SLRs.

Advantages:

- Simple;
- Provides the most amount of warning to trucking agencies;
- Easiest method for transportation companies to plan around; and,
- Limited monitoring and equipment required.

Disadvantages:

- Method does not take into consideration seasonal fluctuations and may miss thaw periods resulting in damage to road structure; and

- May be too conservative and restrict hauling when it is not necessary, thus limiting economic activity.

3.1.2 WEATHER FORECASTS AND THAWING INDEX

The depth of frost and its dissipation is a function, in part, on the magnitude and duration of the temperature differential of the pavement structure and the ambient air temperature. The thawing index is a function of the number of "degree-days" above a reference temperature that would result in the onset of pavement structure thawing. A number of jurisdictions have developed models to determine a thawing index as a function of a reference temperature, which varies by the time of year. The reference temperature takes into account the solar radiation variations in the spring months. SLRs are imposed when weather forecasts predict that the cumulative Thaw Index exceeds a defined threshold, based on the following:

$Ti_{date} = Ti_{previous\ date}$ + Reference Temperature + Daily Mean Temperature$_{date}$

Where:

TI = Thawing Index

Reference Temperature = 1.7^{o}C beginning March 1 and increasing 0.06^{o}C per day (Manitoba)

Daily mean temperature = (maximum + minimum Daily Air Temperatures)/2

The reference temperature increases throughout March in order to account for the increase in radiation. Once the cumulative thaw index reaches 13-15^{o}C (dependent on Agency), then the SLR is implemented. The duration of the spring weight restriction subsequent to its imposition ranges from 7 to 10 weeks, with 8 weeks being the average.

The Thaw Index method is effectively used by a number of jurisdictions including Manitoba and Minnesota.

Advantages:

- Starting restrictions at the right time has significant benefits;

- Accounts for seasonal temperature variations; and

- Maximizes economic activity and minimizes risk of damage to road structure.

Disadvantages:

- In order to provide advance warning, relies on predicted weather patterns, which may or may not occur; and

- Method can be used for determining when to impose SLR; however, cannot be used to determine when to lift SLR.

3.1.3 EXPERT JUDGEMENT AND VISUAL CONDITION SURVEYS

Some jurisdictions rely on visual condition surveys to implement spring-weight restrictions. Visual observations of the road structure for “pumping” near cracks and shoulders or water seeping from the pavement indicate the potential for a weakened bearing capacity. Many North American jurisdictions use visual condition surveys and expert judgement to supplement other direct and indirect methods.

Advantages:

- Little or no equipment costs.

Disadvantages:

- Labour intensive;
- Roadway damage may already have begun by the time appropriate surface conditions arise; and,
- Subjective.

3.2 Deflection Methods

Deflection equipment is used to determine the strength of the road structure. By comparing the spring strength measurements to a seasonal strength curve, agencies can ascertain if the road structure is losing or regaining strength. As the road begins to regain its strength it can carry heavier loads. Provided below is a summary of the predominant deflection methods.

3.2.1 BENKELMAN BEAM

The Benkelman Beam device measures the deflection of a flexible pavement under moving wheel loads. The device measures the rebound of the pavement when an (8,100 kg) 18,000 lb truck is driven from the measurement location. An ASSHTO Standard Test (T-256) has been established for the use of this device. In addition, the Canadian Good Roads Association prepared "A Manual on Pavement Investigations", Ottawa 1959 that outlines standard methodology for Benkelman Beam testing. Standards for using the Benkelman Beam were also described in the “Pavement Evaluation Studies in Canada”, Special Committee on Pavement Design and Evaluation, Canadian Good Roads Association, University of Michigan International Conference on the structural design of Asphalt Pavements Proceedings, 1962. To determine reduced bearing capacity periods, deflection measurements during the spring thaw are compared to the pavement structure strength from other times of the year. Benkelman Beam measurements are used by British Columbia, Saskatchewan and Manitoba.

Figure C-1: Benkelman Beam Device

Source: EnviroMed Analytical Inc.

Advantages:

- Actual measurement of pavement structure bearing capacity;
- Proven and established benchmark – simple testing; and
- Low capital cost.

Disadvantages:

- Manual data collection and dissemination;
- Poor repeatability;
- Safety concerns associated with workers on the roadway; and
- Labour and resource intensive.

3.2.2 FALLING WEIGHT DEFLECTOMETER

The Falling Weight Deflectometer (FWD) is the preferred direct deflection method for determining pavement bearing capacity by both road and airport agencies. The FWD is an impulse-type non-destructive testing device that applies a dynamic load to the pavement surface, similar in magnitude and duration to that of a single heavy moving axle load. A load is applied to a loading plate by dropping a standard weight. The resulting pavement deflection bowl is measured by 7 to 9 geophones spaced at predefined intervals from the loading plate. The response of the pavement structure is measured in terms of vertical deflection seismometers. The unit is towed behind a standard vehicle. Typical units are shown in Figure C-2. FWD devices are used by New Brunswick and Alberta in their SLR programs.

Figure C-2: Typical FWD Devices

Advantages:

- Equipment portability;
- Applies a load with similar magnitude and duration to that of a single axle load; and,
- Replacing Benkelman Beams in many areas because the FWD simulates actual moving wheel loads and has good repeatability [6].

Disadvantages:

- Capital cost of equipment;
- Periodic testing; and,
- Safety concerns associated with stopping vehicle on roadway.

3.2.3 DYNAFLECT

The Dynaflect System is built upon a trailer unit towed behind any vehicle and can be operated from the vehicle by one person. The device consists of a dynamic force generator and a set of motion sensing devices linked to the motion logging system in the towing vehicle. Dynaflect units are used in Nova Scotia, New Brunswick and PEI. In addition, Ontario has used the Dynaflect technology for pavement assessment and/or rehabilitation projects; however, not for SLR imposition.

Figure C-3: Typical Dynaflect Unit

Pavement deflection is measured while the trailer is stopped for a short period of time. The motion sensing devices are lowered into contact with the pavement and the operator reads/logs the results.

Advantages:

- Equipment portability; and,
- Applies a load with similar magnitude and duration to that of a single axle load.

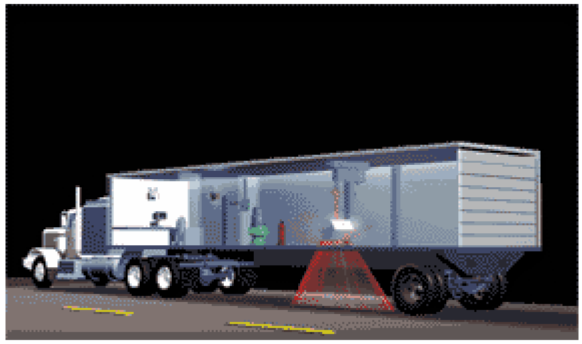
Disadvantages:

- Capital cost of equipment;
- Periodic testing; and,
- Safety concerns associated with stopping vehicle on roadway.

3.2.4 ROLLING WHEEL DEFLECTOMETER

A Rolling Wheel Deflectometer (RWD) device measures the pavement deflection by scanning the pavement surface and deflection during the loading of the design vehicle passing over the area. An example system is depicted in Figure C-4. The RWD technology is relatively new and is not currently used for SLR imposition.

Figure C-4: Rolling Wheel Deflectometer (RWD)



Advantages:

- Use of design wheel speed and type;
- Greater coverage area (continuous versus point testing); and,
- Reduced safety concerns associated with stopped vehicle, i.e., test vehicle does not have to stop undertake deflection test.

Disadvantages:

- Used for research, still under development;
- Periodic testing; and,
- Equipment cost.

3.2.5 GROUND PENETRATING RADAR

Ground Penetrating Radar (GPR) technology transits a very short pulse of radio energy to the road. Echoes are returned from each interface where the electrical properties of the materials change i.e., at the interface between water and ice or between each structural pavement layer. Therefore GPR can be used to determine a frozen/unfrozen interface [6]. None of the surveyed jurisdictions have identified the used of GPR as a primary means of establishing SLRs or WWPs.

Advantages:

- High speed, continuous, position based sampling;
- High resolution (identify layers as thin as 50 mm); and,
- Detect information 1.5-2.0 m deep.

Disadvantages:

- Used for research, still under development; and,
- Cost.

3.3 Direct Condition Monitoring Technologies

Direct condition monitoring technologies are typically installed in the ground and provide direct measurements. The type of data received varies between each type of instrument used, but overall these measurements may then be used to determine frost or thaw depths. There has been very little SLR research conducted using other types of direct condition monitoring equipment that could dynamically measure other road structure conditions such as stress or strain.

3.3.1 FROST TUBES

Frost tubes consist of a tube set into the pavement structure with a liquid that changes colour when frozen. The tube may be manually removed and checked for the depth of the colour change, i.e., frost depth. Readings may be taken manually or the frost tube may be connected to a data logger and a modem and the readings transmitted to a central location. Frost tubes are used by number of jurisdictions to establish SLRs including, Minnesota, Alberta and British Columbia.

Advantages:

- Commonly used to determine start of WWP or start of SLR;
- Remote download capabilities; and,
- Inexpensive.

Disadvantages:

- Experienced maintenance problems; and,
- Measure frost/thaw depth; however, do not indicate the onset of pavement structure recovery.

3.3.2 THERMOCOUPLES/THERMISTORS

Thermocouples and thermistors are two technologies used to measure subsurface temperature. Both are simple devices whose resistance changes with temperature and thus can be used to determine freezing and thaw points. Multi-sensor thermistors and thermocouples are typically installed to measure temperatures at various depths. Upwards of 20 sensors can be mounted on a rod and installed at an incremental spacing. Thermistors are currently used by Saskatchewan and the US Department of Agriculture Forest Service in their SLR programs.

Figure C-5: Thermocouple

Advantages:

- Data loggers can be remotely accessed through dial-up modems; and,
- Relatively low cost.

Disadvantages:

- Contamination from salts or other de-icing materials may alter the actual freezing point of the pavement structure especially in pavement areas that are badly distressed; and,
- Measure temperature; however, cannot be used to indicate the onset of pavement structure recovery.

3.3.3 RESISTIVITY PROBES

Resistivity probes (RP) consist of wire wrapped around dowels that are permanently inset into holes drilled in the pavement structure. Changes in pavement structure temperature and frost significantly change the resistance through the coil. This change in resistance is detected and can be manually or automatically collected.

Advantages:

- Inexpensive; and,
- Can be connected to a data acquisition and dissemination system.

Disadvantages:

- Measure frost/thaw depth; however, do not indicate the onset of pavement structure recovery

3.3.4 TIME DOMAIN DEFLECTORS/TIME DOMAIN REFLECTOMETRY PROBE

The TDR is a probe that is installed vertically in the pavement structure to measure a profile of the soils dielectric properties. The dielectric constant for water is much greater than that of dry or frozen soil, thus a suitable indicator to determine frost depth. The dialectic constants of air, dry soil, ice and water are approximately 1,3-5, 3-4, and 80, respectively [7]. The system sends an electromagnetic wave through the probe and monitors its propagation velocity. From this information, the presence of water, and thus thawing, can be detected. The US Department of Agricultural Forest Service has tested the TDR technology for SLR application.

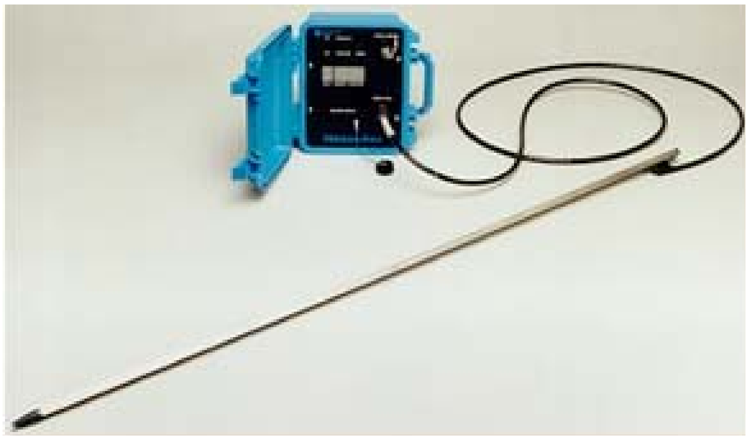
Advantages:

- Continuous monitoring with little or no need for calibration;
- Field data can be remotely download;
- Unaffected by salts for most soils/subgrade; and,
- Studies done by the US Department of Agriculture Forest Service (USFS) have demonstrated that TDRs are more reliable and have fewer maintenance issues than Radio Frequency (RF) soil moisture sensors [8].

Disadvantages:

- Equipment costs; and,
- Slow rates of freezing and low initial water contents can make data interpretation difficult.

Figure C-6: Environmental Sensors Inc. – TDR Unit



3.3.5 FREQUENCY DOMAIN REFLECTOMETRY/RADIO FREQUENCY SENSORS

Frequency Domain Reflectometry (FDR) or Radio Frequency (RF) sensors measure a change in the radio frequency pulse resulting from changes in the dielectric constant of a material, i.e., it measures the change in frequency response of the soil's capacitance due to the soil moisture. The dielectric constant for water is much greater than that of dry or frozen soil, thus a suitable indicator to determine frost depth.

Advantages:

- Suited to homogeneous or bulk materials having a relatively constant granularity or consistency;
- More accurate correlation of data than TDR; and,
- Can be connected to data logging system.

Disadvantages:

- Calibration to specific soil/subgrade type is required - time consuming and expensive;
- Point source;
- Oxidization during operation in field [7]; and,
- Studies done by the US Department of Agriculture Forest Service (USFS) have demonstrated that TDRs are more reliable and have fewer maintenance issues than Radio Frequency (RF) soil moisture sensors [8].

3.3.6 MOISTURE BLOCK (WATERMARK) SENSORS

This device relies on the premise that electrical resistance increases with dryness and therefore can be used to measure soil water tension or suction in thawed conditions, or the depth of frozen conditions.

Figure C-7: Watermark Sensors

Advantages:

- Automatic data logging capabilities; and,
- Low maintenance.

Disadvantages:

- Requires individual calibration; and,
- Drying of subgrade/soil may cause voids in soil and negate moisture readings;
- Point source.

3.3.7 ROAD WEATHER INFORMATION SYSTEM

Road Weather Information Systems (RWIS) provide real-time information on weather and roadway conditions including:

- Roadway surface conditions including water layer thickness and temperature;
- Ground temperature;
- Wind speed, direction and gusts;
- Visibility;
- Total radiation;
- Snow depth;
- Sub-surface temperature;

- Precipitation levels and type; and,
- Metrological parameters including humidity, dewpoint, etc.

The units can be outfitted with a number of air and surface measuring devices including frost probes. A Canadian Standard has been developed for the RWIS technology and is available from Environment Canada. Nova Scotia is beginning to use RWIS stations to provide frost depth information.

Advantages:

- Real-time information;
- Correlation abilities with air and ground temperature changes;
- Existing deployment throughout Canada; and,
- Supports multiple applications (i.e., winter maintenance, automated bridge de-icing, and traveller information).

Disadvantages:

- Existing RWIS stations are typically on primary roads that don't have SLR;
- Cost; and,
- Coverage (point source).

3.3.8 REMOTE CONTROLLED WEIGH STATIONS

Remote Controlled Weigh Stations are being evaluated as a new model for automated weigh stations for commercial vehicles. Information from these stations could possibly provide information into enforcement of seasonal load restrictions or may provide cost savings for co-location of equipment.

The weigh stations could provide:

- weight and dimension measurement;
- vehicle classification;
- compliance verification on weight and dimension;
- safety checks of signals (brake lights, turn signals, headlights);
- detection of overheated brakes; and,
- vehicle data collection.

More advanced stations could also provide:

- credential check using transponder technology;
- credential check using licence plate reader;

- Commercial Vehicle Information Exchange Window (CVIEW) capability for self-serve safety check reporting; and,
- Commercial Vehicle Information Systems and Networks (CVISN) time-in capability for interprovincial and international data exchange, i.e., for safety, security and credential information for use a border crossings, etc.

Advantages:

- Real-time information that could be used for enforcement; and,
- New deployments throughout Canada are possible and it would be easy to add equipment.

Disadvantages:

- Cost; and,
- Coverage (point source).

3.3.9 OTHER SENSOR PRODUCTS

There are a number of other technologies that could be used to measure pavement structure strains and deflection under load. A summary of these technologies and their potential application is included in Table C-4.

Table C-4: Research Methods for Assessment of In-situ Strain and Stress

Technology	Application
Linear Variable Differential Transducers	Measurement of vertical deflections under load
Longitudinal and Transverse Embedment Strain Gauges	Measurement of strains in the asphalt pavement layer
Piezo-Accelerometers	Measurement of vertical accelerations under load
Dynamic Soil Pressure Cells	Vertical pressure data can be used to determine the vertical stress distribution in the base and subgrade layers
Soil Pressure Cells	Measurement of stress distribution in the base and subgrade layers

4. EVALUATION OF AVAILABLE TECHNOLOGIES

An overall evaluation of the available techniques and technologies was undertaken to determine the merits and limitations of each, as well as, their application in setting and terminating spring load restrictions. The criteria and characteristics are summarized in Table C-5 and include:

- **Characteristic monitored** – The measure or determinant that the technique or technology monitors, i.e., pavement stiffness, air and/or ground temperature, moisture content

- **Application** – Based on the device or technique, establish if it could be used for setting and/or terminating of SLR or WWP;

- **Reliability/Effectiveness** – A measure of how effective the technique/device is for setting SLR at the proper time and thus reducing pavement damage and increasing productivity;

- **Data Capture** – The method in which the data is collected whether it is manual or automatic.

- **Remote Download of Data** – The ability to collect data from the specified device without field inspection.

- **Flexibility in Restriction Time** – The ability to change the SLR based on actual weather and field conditions.

- **Cost** – An indication of the relative equipment and labour costs of monitoring.

Table C-5: Evaluation of Available Techniques and Technologies

Application/ Technology	Monitor	Possible Application	Reliability/ Effectiveness	Data Capture	Remote Download of Data	Flexibility in Restriction Time	Relative Cost
Calendar-Based	N/A	SLR Imposition and Lifting	N/A	N/A	N/A	No	Low
Thawing Index	Air temperature	SLR Imposition	Fair	Automatic	Yes	Yes	Low
Expert Judgement/Road Condition Survey	Visual distress and surface moisture	SLR Imposition and Lifting	Poor	Manual	No	Yes	Labour intensive
Benkelman Beam	Pavement structure stiffness	SLR Imposition and Lifting	Fair	Manual	No	Yes	Labour intensive
Falling Weight Deflectometer (FWD)	Pavement structure stiffness	SLR Imposition and Lifting	Good	Automatic	No	Yes	High
Dynaflect	Pavement structure stiffness	SLR Imposition and Lifting	Good	Automatic	No	Yes	High
Rolling Wheel Deflectometer	Pavement structure stiffness	SLR Imposition and Lifting	Good	Automatic	No	Yes	High
Frost Tube	Frost depth	SLR Imposition WWP Imposition and Lifting	Good	Manual	No	Yes	Low
Thermocouples/ Thermistors	Subsurface temperature	SLR Imposition	Good	Real-Time Automatic	Yes	Yes	Low
Resistivity Probe	Moisture content and state	SLR Imposition and Lifting	Good	Real-time Automatic	Yes	Yes	Unknown
TDR	Moisture content and state	SLR Imposition and Lifting	Good	Real-time Automatic	Yes	Yes	Moderate
FDR	Moisture content and state	SLR Imposition	Fair	Real-time Automatic	Yes	Yes	Unknown

Application/ Technology	Monitor	Possible Application	Reliability/ Effectiveness	Data Capture	Remote Download of Data	Flexibility in Restriction Time	Relative Cost
		and Lifting					
Watermark Sensors	Moisture content	SLR Imposition and Lifting	Good	Real-time Automatic	Yes	Yes	Low
RWIS	Air Temperature Dew point temp. Wind Speed Gusts Wind Direction Pressure (Territories and elevations > 5000') Precipitation Pavement Surface Temp, Sub-Surface Temp. **Optional** Visibility & Wx, Visual Images, Total Radiation (solar & IR), Snow Depth, Moisture, Chemical Factor, Freeze Point, Traffic vol/speed	SLR Imposition and Lifting	Good	Real-time Automatic	Yes	Yes	High
Remote Weigh Stations	weight and dimension measurement; vehicle classification; compliance verification on weight and dimension; safety checks of signals (brake lights, turn signals, headlights); detection of overheated brakes; and, vehicle data collection.	Enforcement	Under development	Real-time automatic	Yes	No	Unknown
Linear Variable Differential Transducers, Embedment	Pavement structure deflection and strain	Imposition and Lifting	Under development	Real-time automatic	Yes	Yes	Unknown

Application/ Technology	**Monitor**	**Possible Application**	**Reliability/ Effectiveness**	**Data Capture**	**Remote Download of Data**	**Flexibility in Restriction Time**	**Relative Cost**
Strain Gauges, Piezo-accelerometers, Dynamic and Soil Pressure Cells							

5. CONCLUSIONS

Through the literature review and interviews with agencies, the following have been concluded:

- There are many approaches to implementing and lifting SLR and WWP. Transportation agencies are continuously monitoring and modifying their approach in an effort to strike the right balance between road preservation and minimizing economic impacts of reduced loads.

- The geographic coverage of the road network and the differences in temperature and thaw dates, even across provinces, compounds the problem.

- Currently, there is a significant investment of resources to perform pavement structure condition monitoring for SLR imposition;

- WWP are not commonly implemented;

- A low cost, ITS solution has the opportunity to assist transportation agencies in meeting their mandates and maximizing the life and profitability of the road network.

- A variety of applicable technologies are available for monitoring pavement structure characteristics; and

- Given the number of stakeholders with like objectives and needs with respect to SLR and WWP, there appears to be opportunities for cost efficiencies through not only collaborative research, but prototype deployment and information sharing.

REFERENCES

1. C-SHRP technical brief 21(2000). Seasonal Load Restrictions in Canada and Around the World.

2. Maureen A. Kestler (2003). Techniques for Extending the Life of Low Volume Roads in Seasonal Frost Areas. Transportation Research Board, Washington, D.C.

3. Maureen A. Kestler, Thomas Knight, and Audrey S. Krat (2000). Thaw Weakening and Load Restriction Practices on Low Volume Roads, ERDC/CRREL TR-00-6, Cold Regions Research and Engineering Laboratory, Hanover, NH.

4. Colin Blair (2001). Using road-friendly technologies to extend the haul season on thawing roads. FERIC Advantage, Vol 2, No 48.

5. Jeannette Montufar, Kean Lew, Kai Han, Alan Clayton, Ahmed Shalaby, Robyn McGregor, Dave Palsat, Al MacDonald, Richard Sims (2000). Study for the Harmonization of Spring Weight Restrictions and Winter Weight Premiums for roads in the Prairie Region. Phase 1, Task 1, University of Manitoba Transport Information Group.

6. Jill M. Ovik, John A. Siekmeier, and David A. Van Deusen (2000). Improved Spring Load Restriction Guidelines Using Mechanistic Analysis. Minnesota Department of Transportation.

7. Gordon L. Hanek, Mark A. Truebe, and Maureen A. Kestler. Evaluating Moisture Sensors and Monitoring Seasonal Moisture Variation in Low Volume Roads.

8. Maureen A. Kestler, Gordon Hanek, Mark Truebe, and Peter Bolander (1999). Removing Spring Thaw Load Restrictions from Low-Volume Roads, Development of a Reliable Cost-Effective Method. National Academy Press, Washington, D.C.

Appendix D

Functional Definition

CONTENTS

LIST OF TABLES

1. INTRODUCTION

This document outlines the functional requirements for the Intelligent Transportation System (ITS) developed to assist with the determination of when to implement and lift Spring Load Restrictions (SLR) and Winter Weight Premiums (WWP).

2. FUNCTIONAL REQUIREMENTS

The three primary stages in the determination and implementation/termination of SLR and WWP are:

- Collection of relevant weather and roadway data;
- Analysis of data to make decision; and,
- Dissemination of information.

Each of these three stages are described in further detail in the sections below. In addition, the three stages have been broken down into requirements for basic system and requirements for an advanced system.

2.1 Data Collection

2.1.1 DATA COLLECTION - BASIC

Earlier work identified data requirements for the planning, design and operations and maintenance of asphalt pavement in Canada. Through quantitative analysis efforts to determine when to implement and lift SLR and WWP, a subset of this data has been identified as necessary for the collection and analysis stages. Based on the algorithms that have been selected in Sections 2.2.1 to Section 2.2.4, the list of data that will be collected through in-situ equipment or derived from collected data includes:

- Road Structure
  - Deflection/Strength;
  - Stress/strain;
  - Moisture content in subgrade, sub-base and base;
  - Pavement, base, sub-base thickness;
  - Recovery period (lag time).
- Environmental
  - Pavement Temperature;
  - Air Temperature;
  - Frost depth;
  - Freeze/thaw cycle;

- Thaw depth;
- Thaw indices;
- Solar radiation; and,
- Forecast min/max daily air temperatures (5 days in advance).

- Other
  - Roads that have SLR or WWP;
  - Date of imposition;
  - Date of lifting;
  - Revised legal load limit; and,
  - Fax/email addresses for Trucking Association representative.

All data will be collected and stored, and will be available as current and historic information. Aggregated data such as daily or hourly averages or maximum and minimum temperatures can easily be derived.

This data may be collected by a number of different types of equipment, depending on the preferences of the agency and availability of technology.

The data will be collected in real time and shall be aggregated into configurable resolutions ranging from 5 minutes to 24 hours. All raw data will be stored by the system.

2.1.2 DATA COLLECTION – ADVANCED

The data collection requirements for the Advanced System include the requirements for the Basic System plus the following requirements:

- Road Structure
  - Displacement or relative elevation of pavement structure (up or down);
  - Consolidation settlement.

2.2 Data Analysis

The data that is collected will be further analysed to determine when to implement and lift SLR and WWP.

Through a literature review, there are a trigger points and calculations that have been used regularly for determining when to trigger SLR or WWP and additional trigger points or calculations used to determine when the SLR or WWP should be lifted once implemented.

Discussions with the Technical Steering Committee also resulted in triggers that could be considered.

The various algorithms and triggers are summarized below:

- FERIC reports that for thermistors used in Northwestern BC, when the temperature sensor that is approximately 5 cm below the top of the asphalt surface reaches -0.5°C the implementation of the SLR is triggered [1].

- BC has a 'TPCS SLR Program' by which trucks operating with tire pressure control systems (TPCS) are exempted from weight restrictions on approved routes, after road strength has recovered to a surface rebound of 1.5 mm. This haul resumption rebound applies to all truck configurations and roads, and is calculated as the average plus two standard deviations (x+2s) from a 10-point Benkelman beam test on the weakest part of the route. The haul resumption rebound is based on results from a mechanistic analysis of critical road strains conducted by FERIC, using typical truck configurations and road structures. BC's restrictions are typically lifted after a surface rebound of 1.25 mm is reached so the program offers significant gains to participants.

- The Norwegian restrictions were generally implemented when thaw depth was 20 to 25 cm and was lifted at a thaw depth of 100 to 125 cm [2].

- Various provinces across Canada use measured thaw depths to determine when to implement SLR. A 30 cm thaw depth is generally used as the trigger point. Alberta uses a 1 m frost depth as a trigger point for when to implement WWP and a 30 cm thaw depth as a trigger point for when to lift the WWP. Albert also takes into consideration weather conditions when implementing and lifting WWP. Quebec is trialing a pilot project where the SLR is lifted 5 weeks after the Thaw depth reaches 90 cm.

- Ottawa uses a Dynaflect deflection reading of 0.92mils (thousands of an inch) to trigger SLR implementation and lifting as well as the Thaw Index.

- Minnesota has done research on the use of the Modified Berggren Equation (MBE) that was developed in 1953 for the US Army Corps of Engineers [3].

  $$nF_\ell = \frac{t^2 L_\ell}{48 k_\ell \lambda_\ell^2}$$

  Where:

  n = n-factor to convert an air freezing index to a surface freezing index, dimensionless

  F = air freezing index (°F-days)

  L = volumetric latent heat of fusion (Btu/ft³)

  λ = a dimensionless factor to account for the effects of the initial temperature conditions not being isothermal at 32°F. It is influenced by the thermal properties of the soil as well as the mean annual temperature (MAT), the freezing index, and the length of the freezing season. Its value is always less than 1.0 for freezing conditions

- Surface frost forecasting has been completed using an Artificial Neural Network (ANN) coupled with a surface frost deposition model [4]. Discussions with the Researcher and subsequent literature searches confirmed that frost depth predictions using ANNs have not yet been developed.

- Calculation of a thaw weakening index to assist in predicting weakening in the pavement structure. It is proposed by Dore [5] as:

  TWin = (h/D) x (X/S)

Where:

TWin = Thaw weakening index

h = Total heave resulting from frost action in subgrade soil

D = Thickness of subgrade soil affected by frost action

X = Thawing rate (mm)

S = Settlement rate (mm)

- A modified Minnesota thaw index is currently being used in Manitoba and Ottawa to assist with determining when to implement SLR. The equation is:

  $TI_{date} = TI_{previous\ date}$ + Reference Temperature + Daily Mean $Temperature_{date}$

  Where:

  TI = Thawing Index

  Reference Temperature = 1.7°C beginning March 1 and increasing 0.06°C per day (Manitoba) or 1.5°C beginning February 1 and increasing 0.56°C per week (Ottawa)

  Daily mean temperature = (maximum + minimum Daily Air Temperatures)/2

Fine tuning of the Reference Temperature would be possible if solar radiation information were available to provide a better conversion of forecasted air temperature to pavement temperature.

- Minnesota also developed a freeze index that is used to determine when WWP can be implemented [6]. The equation is:

  $FI = \sum(0^{o}C - T_{mean})$

  Where:

  FI = Freezing Index

  T_{mean} = mean daily temperature, °C = ½ (T1 + T2)

  T_1 = maximum daily air temperature

  T_2 = minimum daily air temperature

Discussions through our steering committee meetings resulted in the creation of the following equation for SLR implementation:

- Use strain, thaw depth, moisture content and forecasted temperature as triggers for when to implement SLR. A look up table would be provided based on the following:

  If Strain ≥ a and thaw depth ≥ b and moisture content ≥ c then SLR;

  If Strain < a and thaw depth ≥ b and moisture content ≥ c then SLR advance warning;

  If Strain ≥ a and thaw depth < b and moisture content ≥ c then SLR advance warning;

  If Strain ≥ a and 5 Day thaw index ≥ b1 and moisture content ≥ c then SLR advance warning;

If Strain < a and 5 Day thaw index ≥ b_1 and moisture content ≥ c then SLR advance warning

Where:

Strain – measured at the bottom of asphalt;

Thaw Depth – measured

Moisture content – measured

5 Day Thaw index – calculated using Thaw Index and 5 day forecasted temperatures

a and c are configurable values calibrated in a lab

b is configurable per area but generally within 20-30 cm

b_1 is configurable per area but generally 13-15^{o}C

The proposed algorithms for SLR and WWP implementation and lifting are described below.

Once the data has been analysed the system will generate an alarm at a workstation to alert someone that the conditions warrant implementation of SLR or WWP. As advance notice is required to notify trucking companies and associations, there will also be alarms as conditions approach the trigger points for SLR.

2.2.1 SLR IMPLEMENTATION

The most commonly used equations are the Thaw Index and the measured depth of thaw. The other equations, such as the MBE, have not been used for operational purposes within Canada. Minnesota completed testing of the MBE [3] and their report published in March 1997 compares computer frost depths using MBE to measured frost depths. Further work done by Minnesota in 2000 [7] to define the Thaw Index and Freezing Index did not include use of this equation. Calculation of a thaw weakening index is considered to be at the leading edge of the quantitative analysis of spring road conditions. The equation that has been proposed is in its infancy and may be subject to further modifications with further research. Therefore, the use of this equation has been included in the Advanced System description.

2.2.1.1 SLR Implementation - Basic

A combination of algorithms is proposed to address the need adequately and to allow for alarm verification. There will initially be two algorithms used for generating SLR implementation alarms. Algorithm 1 will detect an alarm state. Algorithm 2 will be used to assist with providing 5 day advance notice.

1. SLR implementation will be determined based on the following logic statement:

   If Strain ≥ a and thaw depth ≥ b and moisture content ≥ c then SLR;

   -OR-

   If Strain ≥ a and 5 day thaw index ≥ b and moisture content ≥ c then SLR

   Where:

   Strain – measured at the bottom of asphalt (maximum for day);

   Thaw Depth – measured

Moisture content – measured

5 Day thaw index - is a computed thawing Index for specific date (where this date is in the future, forecasted air temperatures are used and converted to pavement temperatures using the reference temperature)

a and c are configurable values calibrated in a lab

b is configurable per area but generally within 20-30 cm

NOTE: That Moisture content is also represented by a % moisture content that exists in the subgrade.

2. Advance warning of SLR implementation will be determined by the following logic statements:

If Strain < a and thaw depth ≥ b and Moisture content ≥ c then SLR advance warning;

-OR-

If Strain ≥ a and thaw depth < b and Moisture content ≥ c then SLR advance warning;

-OR-

If Strain ≥ a and 5 Day thaw index < b_1 and Moisture content ≥ c then SLR advance warning;

-OR-

If Strain < a and 5 Day thaw index ≥ b_1 and Moisture content ≥ c then SLR advance warning

Where:

Strain – measured at the bottom of asphalt (maximum for day);

5 Day thaw index - is a computed thawing Index for specific date (where this date is in the future, forecasted air temperatures are used and converted to pavement temperatures using the reference temperature)

Moisture content – measured

a and c are configurable values calibrated in a lab or developed through field observation

b is configurable per area but generally within 20-30 cm

b_1 is configurable per area but generally 13-15 ^{o}C

5 Day Thaw Index details:

$TI_{date}=TI_{previous\ date}$ + Reference Temperature + Daily Mean $Temperature_{date}$

Where:

$TI_{previous\ date}$ = summation of mean measured pavement temperatures from a specified start date.

Reference Temperature = 1.7°C beginning March 1 and increasing 0.06°C per day (Manitoba) of 1.5°C beginning February 1 and increasing by 0.56° per week (Ottawa)

Daily mean temperature = (maximum + minimum Daily Air Temperatures)/2

This equation is run using measured pavement temperatures from the previous day, along with forecasted air temperatures for the next 5 days. These forecasted air temperatures will be entered into the system by the user. The user will obtain this information from Environment Canada. The reference temperature converts the air temperature to pavement temperature. Alternatively, the TAC conversion could be used.

An alternative for this equation, that would take Solar Radiation measurements into account, would be:

$TI_{date} = TI_{previous\ date}$ + Solar Radiation Factor * Daily Mean $Temperature_{date}$

Where:

TI_{date} = Thawing Index for specific date (where this date is in the future, forecasted air temperatures are used and converted to pavement temperatures by multiplying by a Solar Radiation Factor)

$TI_{previous\ date}$ = summation of mean measured pavement temperatures from a specified start date.

Solar Radiation Factor = calculated based on historic radiation (either last 5 days or based on previous years information) and factor developed through comparative analysis

Daily mean temperature = (maximum + minimum Daily Air Temperatures)/2

2.2.1.2 SLR Implementation – Advanced

If an Advanced System is deployed, the following equation would be run in parallel to the equations defined in Section 2.2.1.1 to determine when to implement SLR.

SLR implementation is determined necessary if the thaw weakening index computed as TWin = (h/D) x (X/S) exceeds a user defined threshold.

Where:

TWin = Thaw weakening index

h = Total heave resulting from frost action in subgrade soil

D = Thickness of subgrade soil affected by frost action

X = Thawing rate (mm/day)

S = Settlement rate (mm/day)

2.2.2 SLR LIFTING – BASIC AND ADVANCED

1. A determination to lift and implement SLR will be based on the following logic statement:

   If Strain ≤ d and thaw depth ≥ e and Moisture content ≤ f then SLR lifting;

Where:

Strain – measured at the bottom of asphalt;

Thaw Depth – measured

Moisture content – measured

d,f are configurable values calibrated in a lab

e is configurable per area but generally within 100-125 cm

NOTE: there are several agencies doing Dynaflect, FWD or Benkelman Beam testing throughout the spring and other periods of the year. There may be value in allowing these measured values to be added to the system, along with the date and time so as to allow a comparison between strain measured at the sensor and the Dynaflect, FWD or Benkelman Beam measurements.

2. Advance warning of SLR lifting will be determined by the following logic statements:

If Strain ≤ d and 5 Day thaw index ≥ e and Moisture content ≤ f then SLR lifting advance warning;

Where:

Strain – measured at the bottom of asphalt;

5 Day thaw index –see Section 2.2.1.1

Moisture content – measured

d,f are configurable values calibrated in a lab

e is configurable per area but generally within 100-125 cm

2.2.3 WWP IMPLEMENTATION – BASIC AND ADVANCED

A combination of algorithms is proposed to address the need adequately and to allow for alarm verification. There will initially be two algorithms used for generating WWP implementation alarms. Algorithm 1 will detect an alarm state. Algorithm 2 will be used to assist with providing 5 day advance notice.

1. WWP implementation will be determined based on the following logic statement:

If Strain ≤j and frost depth ≥ k then WWP;

-OR-

If Strain ≤j and 5 day freeze index ≥ k_1 then WWP

Where:

Strain – measured at the bottom of asphalt (maximum for day);

Frost Depth – measured

5 Day freeze index - is a computed freezing Index for specific date (where this date is in the future, forecasted air temperatures are used and converted to pavement temperatures using the reference temperature)

j, k and k_1 are configurable values calibrated in a lab

2. Advance warning of WWP implementation will be determined by the following logic statements:

If Strain ≤j and frost depth < k then WWP;

-OR-

If Strain ≤j and 5 day freeze index < k_1 then WWP;

-OR-

If Strain >j and frost depth ≥ k then WWP;

-OR-

If Strain >j and 5 day freeze index ≥ k_1 then WWP

Where:

Strain – measured at the bottom of asphalt (maximum for day);

Frost Depth – measured

5 Day freeze index - is a computed freezing Index for specific date (where this date is in the future, forecasted air temperatures are used and converted to pavement temperatures using the reference temperature)

j, k and k_1 are configurable values calibrated in a lab

$FI = \sum(0^{\circ}C - T_{mean})$

Where:

FI = Freezing Index

T_{mean} = mean daily temperature, $^{\circ}C = ½ (T1 + T2)$

T_1 = maximum daily air temperature

T_2 = minimum daily air temperature

This equation is run using measured pavement temperatures from the previous day, along with forecasted air temperatures for the next 5 days. These forecasted air temperatures will be entered into the system by the user. The user will obtain this information from Environment Canada. The reference temperature converts the air temperature to pavement temperature. Alternatively, the TAC conversion could be used.

2.2.4 WWP LIFTING – BASIC AND ADVANCED

1. WWP lifting will be determined based on the following logic statement:

If Strain ≥l and frost depth ≤ m then WWP;

-OR-

If Strain ≥l and 5 day freeze index ≤ m_1 then WWP

Where:

Strain – measured at the bottom of asphalt (maximum for day);

Frost Depth – measured

5 Day freeze index - is a computed freezing Index for specific date (where this date is in the future, forecasted air temperatures are used and converted to pavement temperatures using the reference temperature)

l, m and m_1 are configurable values calibrated in a lab

2. Advance warning of WWP lifting will be determined by the following logic statements:

If Strain ≥l and frost depth > m then warning;

-OR-

If Strain ≥l and 5 day freeze index > m_1 then WWP;

-OR-

If Strain <l and frost depth ≤ m then WWP;

-OR-

If Strain <l and 5 day freeze index ≤ m_1 then WWP

Where:

Strain – measured at the bottom of asphalt (maximum for day);

Frost Depth – measured

5 Day freeze index - is a computed freezing Index for specific date (where this date is in the future, forecasted air temperatures are used and converted to pavement temperatures using the reference temperature)

l, m and m_1 are configurable values calibrated in a lab

$FI = \sum(0^{o}C - T_{mean})$

Where:

FI = Freezing Index

T_{mean} = mean daily temperature, $^{o}C = \frac{1}{2}(T1 + T2)$

T_1 = maximum daily air temperature

T_2 = minimum daily air temperature

This equation is run using measured pavement temperatures from the previous day, along with forecasted air temperatures for the next 5 days. These forecasted air temperatures will be entered into the system by the user. The user will obtain this information from Environment Canada. The reference temperature converts the air temperature to pavement temperature. Alternatively, the TAC conversion could be used.

2.3 Information Dissemination

Agencies across Canada use a diverse set of tools to disseminate information to commercial agencies. Integration of the data into a GIS based central system, will assist with electronic dissemination through the various technologies employed by these agencies, including:

- Web site;
- Email;
- 511;
- Fax polling service; and,
- Interactive Voice Response.

3. PHYSICAL REQUIREMENTS

The high level system functional requirements were described in Section 2. The physical components required to deliver this functionality are described in this section. The physical components have been broken into physical location, field components and central components.

There are two alternatives for how this information can be processed. Field data can be sent to the central system for processing or field data can be processed locally through field controllers which generate alarms and aggregated data for transmission to the central system. The choice of field or central processing is often driven by communication requirements and infrastructure availability. The data processing functionality has been described in both the field and central requirements, although only one location is required. Regardless of where the data processing for each site is performed, there will always be a central processing function to store, archive and visually display information from all of the sites in a central location.

3.1 Field Components

The data that is required to meet the algorithms can be delivered by a variety of equipment. Therefore, wherever possible, agencies can make use of existing infrastructure that they may have or preferences for deliver of information. For example if there are existing Remote Weather Information Systems (RWIS) or planned RWIS deployments, these sites could be augmented with additional sensors to meet all of the requirements.

Table D-1 summarizes the equipment or the calculations that will provide all of the information necessary to deliver the system based on the requirements outlined in Section 2.1.

Table D-1: Equipment Versus Data Summary

	Environmental/Road												Traffic												Deflection/Strength						
	Earth pressure cells	Dynamic soil pressure cell	Frost probes	Thermocouples / thermistor probes	Pavement sensors (passive)	Time domain detectors/ time domain reflectometry probe (TDR)	Frequency domain reflectometry/ radio frequency sensors (FDR)	Soil moisture sensor	Moisture block (watermark) sensors	Net radiation sensor	Solar radiation sensor	Road weather information system (RWIS)	Inductive loop detectors (ILD)	Non-invasive microloops	Piezoelectric sensors	Load-cells	Active infrared detection systems	Microwave sensors	Overhead profiler	Ground-based profiler	Video image detection systems (VID)	Axle treadle	Weigh-in-motion systems (WIM)	Remote control weigh station (RCWS)	Linear variable differential transducers	Linear variable differential transformers (LVDT)	Strain gauges	Strain gauge: biaxial embedment	Accelerometer	Pressure transducer	Comments
Road Structure																															
Deflection/strength																															Deflection will be manually entered into the system based on FWD or BB readings that are completed by the agency. Deflection may be able to be derived from measured strains.
Stress/strain	✓	✓																									✓	✓	✓	✓	
Relative elevation of pavement structure (up or down)																									✓	✓					
Moisture content in subgrade, sub-base and base						✓	✓	✓	✓																						
Consolidation settlement																															Calculated from displacement.
Pavement, base, sub-base thickness																															This information will be available from the design process.
Recovery period (lag time)																															Difference between start and end of SLR.
Saturation						✓	✓	✓	✓																						
Environmental																															
Pavement temperature					✓							✓																			
Air temperature												✓																			
Frost depth			✓	✓	✓	✓	✓	✓	✓																						
Freeze/thaw cycle																															Calculated based on frost/thaw depth over time.
Thaw progression																															Calculated based on thaw depth over time.
Thaw depth			✓	✓	✓	✓	✓	✓	✓																						
Solar radiation										✓	✓	✓																			
Forecast min/max daily air temperatures (5 days in advance)																															Provided by Environment Canada. In the future it may be possible to have a system-to-system interface.
Other																															
Roads that have SLR or WWP																															Determined in advance by the agency based on its assessment of road design and road condition.
Date of imposition																															Calculated by the system using predefined algorithms.
Date of lifting																															Calculated by the system using predefined algorithms.
Revised legal load limit																															Determined in advance by the agency based on its assessment of road design and road condition.
Fax/e-mail address for trucking association representative																															Collected by the agency and configured in the system.

In addition, as there is a correlation between pavement temperature and strain, the system will also include a check and backup for the strain measurements. A table will be configured in the system, based on laboratory results, that correlates pavement temperature to strain.

All equipment would be installed in accordance with the equipment manufacturer's recommendations.

If the final design architecture identifies a need for distributed processing then some sort of Advanced Field Controller (AFC) would be deployed that comprises the necessary communication interfaces to consolidate the various sensor devices and perform local processing of data. Software specific to this application would be developed in conjunction with the central software requirements.

National Transportation Communications for ITS Protocol (NTCIP) standards will be used wherever possible for communication to field devices.

3.2 Central Components

The central system components will comprise the necessary software and hardware elements to collect, analyze and disseminate the SLR and WWP information. The software will be developed to poll each of AFCs or field device controllers for information (either processed or raw depending on where the processing is completed) and to display the information graphically on a GIS based map. The alarms that are generated for warning or for SLR implementation and lifting and WWP implementation and lifting will be graphically displayed here for review and acceptance by a user. The central system will also generate the information for dissemination through e-mail and facsimile and to external systems that may deploy other technologies such as interactive voice and 511. This will allow data to be graphically disseminated which will be helpful for users to illustrate where there are restrictions in place.

Data will be stored and archived for use by the planning and design departments.

REFERENCES

1. C.R. Webb and L.M. Kelly, “Monitoring frost levels in thawing roadbeds to maximize the hog hauling season”, FERIC Advantage Report, Vol 1, No 37, November 2000

2. Geir Refsdal, “The lifting of axle load restrictions during spring thaw – A Norwegian Experiment”, 5th International Conference on the Bearing Capacity of Roads and Airfields, Norwegian Public Roads and Administration, 1998, p. 103-108

3. Richard Berg, “Calculating Maximum Frost Depths at Mn/ROAD Test Cells”, Report No MN/RC-97/21, Minnesota Department of Transportation, March 1997

4. William Gallus, “Improved Frost Forecasting through Coupled Artificial Neural Network Time-series Prediction Techniques and a Frost Deposition Model”, FHWA-HRT-04-109, October 2004, p. 19-26

5. Guy Dore and Cedric Imbs, “Development of a new mechanistic index to predict pavement performance during spring thaw”, Cold Regions Engineering, 2004, p. 348-359

6. David A. Van Deusen and Jill M. Ovik, “Spring Load Restrictions Improving Minnesota’s Policy”, TR News 211, November-December 2000

7. Jill M. Ovik, John A. Siekmeier, and David A. Van Deusen, “Improved Spring Load Restriction Guidelines Using Mechanistic Analysis”, MN/RC-2000-18, July 2000

Appendix E

Software Requirements Specification

CONTENTS

LIST OF FIGURES

1. INTRODUCTION

1.1 Purpose

As temperatures drop below 0 degrees Celsius, frost begins to form in pavement soil sub-layers. As the water above the water table freezes, it draws moisture upward through capillary forces and expands causing an increase in volume commonly referred to as "heave". During the spring thaw, it is possible that the soil under the roadway will become temporarily saturated with water as surrounding soil remains frozen, inhibiting the efficient draining of moisture from roadway sub-layers.

During the periods of spring thaw soil saturation, roadways may lose a significant percentage of their load bearing strength. For this reason, many agencies impose "Spring Load Restrictions" (SLR) limiting the total weight load that may be carried by a vehicle during the restriction period.

Conversely, during the winter months when the water in the pavement structure is frozen, some agencies allow increased truck loading under the assumption that the pavement structure has increased bearing capacity and as an incentive to help shift spring trucking loads into the winter months. This practice is commonly referred to as the application of "Winter Weight Premiums" (WWP).

Through the use of appropriately located weather related and in-situ field devices that monitor various surface and sub-surface conditions, it is possible to deploy a system that warns of the onset of roadway freeze and thaw conditions and provides a centralized monitoring station to aid agencies with the activation and termination of SLR and WWP.

The purpose of this document is to clearly define the software requirements of an SLR/WWP automated monitoring system, herein referred to as the "Roadway Conditions Watch" application or RCWatch for short.

The intended audience of this document includes both the agencies that would ultimately be responsible for owning and operating an RCWatch system, as well as the contractor(s) that would develop and deliver RCWatch based upon the requirements specified herein.

This Software Requirements Specification (SRS) is the baseline for verification and validation of a delivered RCWatch product.

1.2 Scope

The SRS describes the software components of RCWatch that provide the roadway condition monitoring and notification functions for a centralized operations centre. Depending on physical implementation and the capabilities of off-the-shelf field equipment, RCWatch will comprise software that runs on one or more centrally located computers and may additionally include software running on a distributed network of field controllers.

The principal function of the software is to collect and analyze surface and sub-surface data to identify periods for which to implement Spring Load Restrictions and Winter Weight Premiums.

The SRS is formatted based on the IEEE Standard 830-1998 for Software Requirements Specifications which has a primary focus on functional requirements and does not specify a particular software or hardware design.

1.3 Definitions

The following terms are used throughout this document and are presented here for clarity.

ANL	Data Analysis Function of RCWatch
C-2-C	Center to Center
COC	Central Operations Centre
DA	Data Archive Function of RCWatch
DC	Data Collection Function of RCWatch
GIS	Geographical Information System
GUI	Graphical User Interface
ID	Information Dissemination Function of RCWatch
O&M	Operations and Maintenance
RCWatch	Roadway Conditions Watch application software
SLR	Spring Load Restrictions
SRS	Software Requirements Specification
TC	Transducer Communications Function of RCWatch
Weather Area	The agency will set up control areas that represent a number of roads in their general vicinity. Each of these control areas will be equipped with one set of sensors and is referred to as a Weather Area.
WWP	Winter Weight Premiums

1.4 References

The following document forms a part of this specification to the extent specified herein. In the event of conflict between the documents referenced and the contents of this specification, the contents of this specification shall supersede.

IBI Group, SLR & WWP Functional Definition, November 2004.

1.5 Document Overview

This Software Requirements Specification presents the required functionality and operational characteristics of RCWatch. The remaining sections of this document provide specific details of the functional capabilities and requirements necessary to proceed with software design and development.

Section 2 describes the general factors affecting the RCWatch software product and provides a brief overview of the external entities that exist within the context of RCWatch.

Section 3 outlines the engineering requirements for RCWatch; including capability requirements, interface requirements, data requirements, and any performance requirements and other constraints imposed by specific hardware, facilities, safety or security considerations.

2. GENERAL DESCRIPTION

This section of the SRS describes the general factors that affect the product and its requirements. It does not state specific requirements but rather helps to make those requirements easier to understand.

2.1 Product Perspective

The primary business process supported by RCWatch is the collection and analysis of surface and sub-surface data for a defined roadway network for the purpose of determining the appropriate periods during which the SLR and WWP programs are to be implemented.

RCWatch will aid operating agencies by automating the process of roadway conditions monitoring and the dissemination of these conditions to various other departments and external agencies as required.

2.1.1 EXTERNAL ENTITIES

Figure 1 contains the Context Diagram of the application software, which defines the scope and logical boundaries of RCWatch. The diagram depicts RCWatch as a single element connected (either logically or physically) to external entities that can comprise hardware, software and human operators.

2.1.1.1 User

The User is any system operator designated by the RCWatch owner to monitor and control the RCWatch application. There may be one or more Users of RCWatch at any given time. The term '***User'*** is used throughout this document when referring to any person that interacts with the system, including daily system operators, supervisors and engineers.

2.1.1.2 Weather Transducers

The Weather Transducer block represents the various field devices that directly collect the surface and sub-surface data required by RCWatch. The network of field devices and their associated communications infrastructure are considered to be outside the scope of the RCWatch effort. However, the RCWatch scope will include any software that needs to be developed for distributed field data collection, based upon the overall hardware and communications architecture design.

2.1.1.3 Environment Canada

Environment Canada will provide necessary weather data to the RCWatch application for use in the determination of SLR and WWP implementation periods. As a minimum, RCWatch will include capabilities for manual entry of this data but will optionally allow for an automated exchange of data.

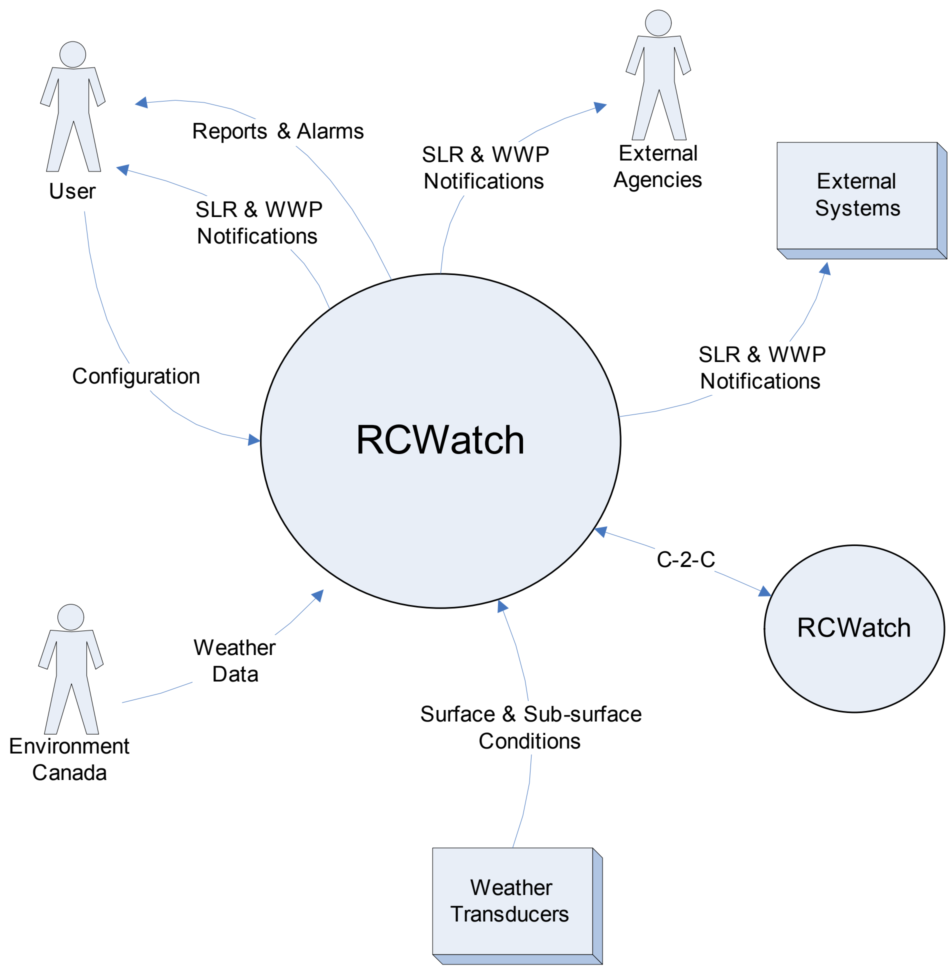


Figure E-1: RCWatch Context Diagram

2.1.1.4 External Agencies & Systems

The RCWatch application will generate data in a suitable format for dissemination to relevant external departments and agencies. RCWatch will include options for the dissemination technologies such as e-mail and facsimile. Additionally, the application will provide necessary hooks for future integration and data exchange with external systems such as an Interactive Voice, 511 or Advanced Traffic Management Systems

2.1.1.5 Other RCWatch

The RCWatch application will be capable of center-to-center coordination with other RCWatch installations.

2.2 Product Functions

The primary functions provided by the RCWatch software are graphically depicted in Figure 2. A bubble represents each function, and the external ‘actors’ or entities with which the software must interact are represented by stick figures. The lines that join the actors to the functions simply indicate that some level of interaction exists between the actor and the particular RCWatch capability.

The arrows that are drawn from one function to another indicate the existence of some level of functional reliance. A function that <<extends>> another function can be viewed as a function that adds value to the primary goal(s) of the other functions. A function that <<includes>> another function can be viewed as a function that requires the work of that other function for the realization of its primary goal(s). Arrows originate from the function that either includes or extends the work of the targeted functions.

The primary RCWatch functions are described below. As previously stated, this requirements document does not impose any particular physical design. An RCWatch function is simply a collection of related requirements and does not necessarily represent a software process or executable.

DATA COLLECTION

The Data Collection function of RCWatch will collect all relevant data from the configured field sensor devices. The function will ensure that the data is retrieved at regular intervals appropriate for the various sensors and for the other functions of the application. The Data Collection function will run on computer(s) in the Central Operations Centre (COC). Data Collection will also accept relevant weather data (either manually or through an automated interface) from Environment Canada.

TRANSDUCER COMM

The Transducer Comm function comprises all the necessary software drivers to directly interact with the field devices. The drivers will implement the communication protocols specific to each sensor sub-system. Depending on the physical architecture of the deployed system, the Transducer Comm function may run solely on computer(s) in the COC or may be spread across computer(s) at the COC and distributed controllers strategically locate in the field.

DATA ANALYSIS

The Data Analysis function of RCWatch will utilize the raw field data collected by the Data Collection function to determine the appropriate periods for which the SLR and WWP programs are to be implemented. The function will incorporate a number of industry approved algorithms to aid in the decision making process.

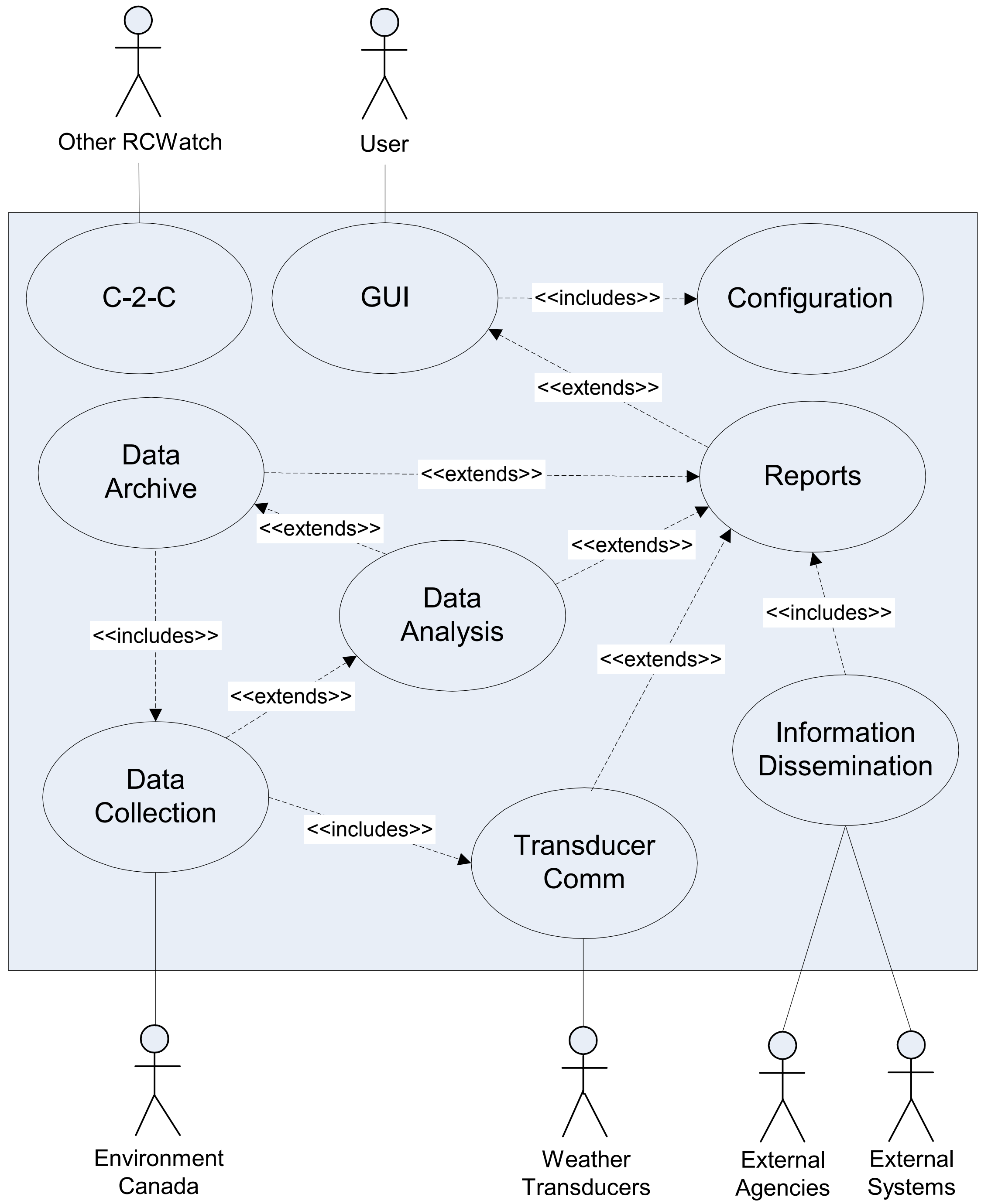


Figure E-2: RCWatch Functional Decomposition

DATA ARCHIVE

All raw data collected by the system will be saved to a relational database by the Data Archive function.

REPORTS

The Reports function of the application will be responsible for generating canned system reports for viewing and/or printing (e.g. equipment status reports, SLR & WWP historical reports, and various data reports).

GUI

The GUI will be a GIS based graphical interface that will allow the users to interact with the RCWatch application to monitor roadway conditions, generate reports, and initiate SLR and WWP programs. The GUI function will allow for multiple and simultaneous users of RCWatch and will be designed to accommodate access to the application whether the user is local or remote to the system (using appropriate network communication standards).

INFORMATION DISSEMINATION

RCWatch will include an Information Dissemination function that provides capabilities to send information to external agencies and systems through a number of dissemination technologies. The function will accommodate the concept of “service subscribers” such that individuals or agencies may be configured by dissemination service type and information content.

CONFIGURATION

The Configuration function provides the necessary tools to view and modify the various parameters that control the overall operation and configured field devices of RCWatch.

C-2-C

The C-2-C function will allow different RCWatch installations to coordinate with each other for the purpose of SLR/WWP program implementation and termination. This feature could allow neighbouring agencies sharing common roadways to implement cooperative policies for SLR and WWP. The C-2-C option is a future capability and will not be incorporated with the initial system delivery. This document does not elaborate any further on these requirements.

2.3 User Characteristics

The typical users of RCWatch can be classified by the following categories:

O&M	The Operations & Maintenance (O&M) user will be the primary user of the RCWatch system. The O&M user will monitor all aspects of system operation and will ultimately be responsible for the implementation of the SLR and WWP programs. The O&M user may also access current and historical information for the purpose of general analysis and reporting.
Planning	This Planning user will typically access historic information and review the performance of roadways over the past year(s). The Planning user would determine which roads are to get which particular restriction(s).
Design	This Design user will typically access historic information for input into their pavement design models. There is a quantitative model NCHRP 1-37A 2004 (for example) that uses measured data to determine pavement design criteria.
Enforcement	The Enforcement user plays a key role in ensuring trucks are complying with the SLR and WWP programs. These users would typically have read-only access to the RCWatch application.
Public	The Public user comprise of various trucking agencies, associations and companies that need to modify their loads and/or their shipping routes in accordance with the SLR and WWP programs. These users will typically receive the required information through a number of sources including the internet, e-mail, IVR, and facsimile.
Engineer	The Engineer user interacts with RCWatch to configure the application parameters, enable and disable sub-system operation, and to troubleshoot hardware, software and communication problems directly related to the RCWatch application. The Engineer will completely understand the system architecture and functionality, but may only have a broad understanding of the agency operations and management processes.

2.4 Constraints, Assumptions & Dependencies

System Availability

RCWatch is expected to operate 24 hours per day, 7 days per week. The RCWatch application may be shut down for short periods (in the order of hours) during off-peak operational hours to facilitate maintenance and software upgrades.

Multiple, Simultaneous Users

RCWatch will support multiple simultaneous users of the application.

3. SPECIFIC REQUIREMENTS

This section of the SRS provides comprehensive detail for all RCWatch software requirements. The information contained herein will form the basis from which the software design will be created and validated.

3.1 Functional Requirements

3.1.1 DATA COLLECTION

The Data Collection function (or DC) of RCWatch collects relevant data from the configured field sensor devices and accepts other relevant weather data from Environment Canada.

Data Tags

R-1. All data collected by the DC function shall be tagged in a manner that allows them to be characterized into one of the following categories:

a. "valid" – if there is no specific reason to be suspicious of the data value;

b. "invalid" – if the data value falls outside valid boundaries for the data type (e.g. a value in units of percent reported as %110 is invalid);

c. "suspect" – if the data falls outside expected boundaries for the data type (e.g. a strain reading that seems excessively large given the current pavement temperature);

d. "unknown" – if the data is normally subject to validation checks but the validation checks can not be performed for any reason;

e. "derived" – if the data is derived from other information maintained by the system;

f. "missing" – if the data could not be collected during a collection cycle.

NOTE: Data tags are not required to be text based – the requirement is for the categories above to be assigned (e.g. through an enumeration) to a data item.

Temperature Data

R-2. The DC function shall collect pavement temperature from each configured pavement temperature sensor at a user configurable periodic rate.

R-3. The DC function shall collect air temperature from each configured air temperature sensor at a user configurable periodic rate.

R-4. There shall be a single user configurable parameter defining the data collection rate for the temperature (air and pavement) data in units of minutes from 5 minutes to 60 minutes.

R-5. All temperature data received from sensors shall be converted to units of degrees Celsius if not directly reported as such by the sensor.

R-6. There shall be minimum and maximum user configurable temperature parameters that define the expected valid range for pavement temperatures in units of degrees Celsius.

R-7. There shall be minimum and maximum user configurable temperature parameters that define the expected valid range for air temperatures in units of degrees Celsius.

R-8. The DC function shall validate all temperature data received from sensors using the system parameters defined in R-6 and R-7.

a. If the temperature value received from the sensor falls within the expected valid range for temperatures of that type, the data value shall be tagged as “valid”.

b. If the temperature value received from the sensor falls outside the expected valid range for temperatures of that type, the data value shall be tagged as “suspect”.

R-9. If the DC function is unable to obtain a temperature value from a sensor for a collection cycle, the temperature value shall be set to an arbitrary value (e.g. zero) and shall be tagged as “missing”.

R-10. The DC function shall collect forecasted daily minimum and maximum air temperature data from an external agency for up to 5 days in advance (i.e. Environment Canada).

a. The software shall provide for manual input of forecasted daily minimum and maximum air temperature data for user definable geographical areas.

b. The software “should” provide for an automated interface between RCWatch and Environment Canada to facilitate the automated collection of forecasted daily temperature data for each user definable geographical area.

Strain Data

R-11. The DC function shall collect strain data from each configured strain sensor at a user configurable periodic rate.

R-12. There shall be a single user configurable parameter defining the data collection rate for strain data in units of minutes from 5 minutes to 60 minutes.

R-13. All strain data received from sensors shall be converted to units of millimetres per millimetre (or alternatively left unitless) if not directly reported as such by the sensor.

R-14. The DC function shall support a user configurable table that correlates roadway strain with roadway surface temperature.

a. Each entry of the table shall contain a temperature range defined by a lower limit and an upper limit in units of degrees Celsius.

b. For each temperature range, there shall be a strain range defined by a lower limit and an upper limit in units of millimetres.

R-15. The DC function shall try to validate all strain data received from the sensors using the temperature-strain correlation table.

a. The function shall determine the appropriate range for the strain data based upon the last received pavement temperature providing the temperature value is “valid” and is no older than 60 minutes.

b. If the reported strain value falls within the range stored in the correlation table, the strain data shall be considered “valid” and shall be tagged accordingly.

c. If the reported strain value falls outside the range stored in the correlation table, the strain data shall be considered “suspect” and shall be tagged accordingly.

d. If the strain range cannot be obtained from the correlation table for any reason, the data received from the sensor shall be considered “unknown” and shall be tagged accordingly.

R-16. If the DC function is unable to retrieve strain data from a particular sensor for a particular collection cycle, the function shall try to obtain a suitable value from the temperature-strain correlation table.

a. The function shall determine the appropriate range for the strain data based upon the last received pavement temperature providing the temperature value is “valid” and is no older than 60 minutes.

b. If the function is able to obtain a strain range from the correlation table, the strain value for the sensor for the collection cycle shall be set to the value that is the median of the strain range from the table, and shall be tagged as “derived”.

c. If the function is unable to obtain a strain range from the correlation table for any reason, the strain value for the sensor for the collection cycle shall be set to an arbitrary value (e.g. zero) and shall be tagged as “missing”.

Deflection Data

It is the intention for the system that when a suitable formula is derived allowing deflection data to be computed from strain data that the collection and storage of deflection data will become an automated process. Until then, the following requirements will apply:

R-17. The DC function shall compute a deflection value in units of millimetres for every strain value collected and shall associate the deflection data with the corresponding strain sensor.

a. Until a suitable formula is available for the derivation of deflection data from strain data, the DC function shall simply compute an arbitrary value for deflection (e.g. zero) and shall tag the data with the “missing” tag.

R-18. The DC function shall allow for manual entry of deflection data, superseding any computed value.

a. Manual deflection data entered by the user shall be tagged as “valid”.

Pavement Displacement Data

R-19. The DC function shall collect displacement data from each configured pavement elevation sensor at a user configurable periodic rate.

R-20. There shall be a single user configurable parameter defining the data collection rate for pavement displacement data in units of minutes from 5 minutes to 60 minutes.

R-21. All displacement data received from sensors shall be converted to units of millimetres if not directly reported as such by the sensor.

R-22. There shall be minimum and maximum user configurable parameters that define the expected valid range for pavement displacement in units of millimetres.

R-23. The DC function shall validate all pavement displacement data received from sensors using the system parameters defined in R-22.

a. If the displacement value received from the sensor falls within the expected valid range for pavement displacements, the data value shall be tagged as “valid”.

b. If the displacement value received from the sensor falls outside the expected valid range for pavement displacements, the data value shall be tagged as “suspect”.

R-24. If the DC function is unable to obtain a pavement displacement value from a sensor for a collection cycle, the displacement value shall be set to an arbitrary value (e.g. zero) and shall be tagged as “missing”.

Moisture Content Data

R-25. The DC function shall collect moisture content data from each configured moisture content sensor at a user configurable periodic rate.

R-26. The data collected from each sensor (or group of sensors) shall comprise a moisture content reading for the roadway sub-grade as a minimum, and may optionally include sub-base and base layer values.

R-27. There shall be a single user configurable parameter defining the data collection rate for moisture content data in units of minutes from 5 minutes to 60 minutes.

R-28. All moisture content data received from sensors shall be converted to a percentage value if not directly reported as such by the sensor.

R-29. The DC function shall validate all moisture content data received from sensors.

a. If the moisture content value received from the sensor is greater than or equal to 0% and less than or equal to 100%, the data value shall be tagged as “valid”;

b. If the moisture content value received from the sensor is less than 0% or greater than 100%, the data value shall be tagged as “invalid”;

c. If the “valid” moisture content value received from the sensor for the sub-base differs from the “valid” values for the base and sub-grade by an amount greater than a user configurable threshold, all three data values shall be tagged as “suspect”.

R-30. If the DC function is unable to obtain a moisture content value from a sensor for a collection cycle, the moisture content value shall be set to an arbitrary value (e.g. zero) and shall be tagged as “missing”.

Solar Radiation Data

R-31. The DC function shall collect solar radiation data from each configured solar radiation sensor at a user configurable periodic rate.

R-32. There shall be a single user configurable parameter defining the data collection rate for solar radiation data in units of minutes from 5 minutes to 60 minutes.

R-33. All solar radiation data received from sensors shall be converted to units of Watts/m^2 if not directly reported as such by the sensor.

R-34. There shall be minimum and maximum user configurable parameters that define the expected valid range for solar radiation in units of Watts/m^2.

R-35. The DC function shall validate all solar radiation data received from sensors using the system parameters defined in R-34.

a. If the solar radiation value received from the sensor falls within the expected valid range for solar radiation, the data value shall be tagged as “valid”.

b. If the solar radiation value received from the sensor falls outside the expected valid range for solar radiation, the data value shall be tagged as “suspect”.

R-36. If the DC function is unable to obtain a solar radiation value from a sensor for a collection cycle, the solar radiation value shall be set to an arbitrary value (e.g. zero) and shall be tagged as “missing”.

R-37. The DC function shall compute a moving average Historic Solar Radiation (HSR) once per day for each solar radiation sensor location as the average of the past 5 years (inclusive) worth of solar radiation for that same day as follows:

$$\mathbf{HSR = (\textstyle\sum_{(CurrentYear\text{-}4\,-\,CurrentYear)}(\,SR_{avg})\,)\,/\,5}$$

Where,

SR_{avg} = The average solar radiation for the particular day for a particular year ranging from the current year-4 through the current year, computed as the sum of all “valid” solar radiation values recorded for that day divided by the total number of values in the summation.

a. If there are no “valid” solar radiation values for a particular day, the SR_{avg} for that day shall not be included in the HSR summation and the divisor of the equation shall be adjusted accordingly (e.g. if only 3 SR_{avg} values are used, the summation is divided by 3 rather than 5).

b. If there are no “valid” solar radiation values for any of the required days, the HSR for the current year shall be tagged as “missing”, otherwise if HSR is computed in any way it shall be tagged as “valid”.

Frost & Thaw Depth Data

R-38. The DC function shall collect frost/thaw depth data from each configured frost/thaw depth sensor at a user configurable periodic rate.

R-39. There shall be a single user configurable parameter defining the data collection rate for frost/thaw depth data in units of minutes from 5 minutes to 60 minutes.

R-40. All frost/thaw depth data received from sensors shall be converted to units of millimetres if not directly reported as such by the sensor.

R-41. There shall be minimum and maximum user configurable parameters that define the expected valid range for frost/thaw depth in units of millimetres.

R-42. The DC function shall validate all frost/thaw depth data received from sensors using the system parameters defined in R-41.

a. If the frost/thaw depth value received from the sensor falls within the expected valid range for frost/thaw depth, the data value shall be tagged as “valid”.

b. If the frost/thaw depth value received from the sensor falls outside the expected valid range for frost/thaw depth, the data value shall be tagged as “suspect”.

R-43. If the DC function is unable to obtain a frost/thaw depth value from a sensor for a collection cycle, the frost/thaw depth value shall be set to an arbitrary value (e.g. zero) and shall be tagged as “missing”.

Thaw Indices

R-44. The DC function shall compute a Thaw Index (TI_{dateN}) once per day for the previous day for each weather zone as follows (assumes today’s day is represented by dateN+1)

$$\mathbf{TI_{dateN} = \sum_{(dateREF - dateN)}(PT_{mean})}$$

Where,

dateREF = A user configurable reference date typically set to March 1st.

For example, if today’s date is March 10th, then the Thaw Index for March 9th can be computed as the summation of all measured mean pavement temperatures from March 1st (the reference date) through March 9th.

NOTE: Thaw index can only be computed for dates on or past the reference date.

$\mathbf{PT_{mean}}$ **=** The computed mean pavement temperature in units of degrees Celsius for a particular date N computed from the measured minimum and maximum temperature values for the day as:

(Max Temp Date N + Min Temp Date N) / 2

R-45. If the mean temperature for a particular date required in the summation of the Thaw Index is not available (e.g. missing data) but there is a “valid” mean temperature data for the previous day and the next day, then the missing mean temperature value shall be computed as the average of the previous and next day’s values and used in the summation accordingly.

a. Any Thaw Index computed with derived data as above shall be tagged as "derived".

R-46. If one or more mean temperature values for a particular date required in the summation of the Thaw Index is not available and can not be derived as specified in R-45 then the Thaw Index value for the particular day shall be set to an arbitrary value and tagged as "missing".

R-47. All Thaw Indices computed from "valid" data shall be tagged as "valid".

R-48. The DC function shall compute a forecasted 5–Day Thaw Index ($TI5D_{dateN}$) once per day for that day for each weather zone as follows (assumes today's day is represented by dateN):

$$\mathbf{TI5D_{dateN} = TI_{dateN-1} + \sum_{(dateN - dateN+4)}(SR_{ref} * T_{mean})}$$

Where,

$TI_{dateN-1}$ = The actual Thaw Index computed at this location for the previous day. If there is no previous day data, then $TI_{dateN-1} = 0$.

SR_{ref} = The solar radiation reference factor computed for a particular date N as follows:

$$\mathbf{HSR_{dateN} * SR_{fact}}$$

Where:

HSR_{dateN} is the Historic Solar Radiation value computed for the day,

and

SR_{fact} is a user configurable number that has been developed based on field measurements and trend analysis to correlate air temperature, solar radiation and pavement temperature.

T_{mean} = The forecasted mean air temperature in units of degrees Celsius for a particular date N computed as:

(Forecast Max Temp Date N + Forecast Min Temp Date N) / 2

R-49. In the absence of appropriate solar radiation data, the DC function shall compute the 5–Day Thaw Index for dateN as follows:

$$\mathbf{TI5D_{dateN} = TI_{dateN-1} + \sum_{(dateN - dateN+4)}(T_{ref}) + \sum_{(dateN - dateN+4)}(T_{mean})}$$

Where,

T_{ref} = The reference temperature in °C computed for a particular date N as follows:

Before reference date parameter (e.g. March 1st) → $T_{ref} = 0$

After reference date → T_{ref} = a + (Number days since $DATE_{ref}$) * b

Where "a" is a user configurable parameter (typically set to 1.7) and "b" is a user configurable parameter (typically set to 0.06 for Manitoba and possibly 0 elsewhere)

R-50. Each 5-Day Thaw Index value shall be tagged as follows:

a. "valid" – if computed using the available solar radiation data;

b. "derived" – if computed using the reference temperature method;

c. "missing" – if neither the solar radiation data nor the forecasted temperature data are available.

Freeze Indices

R-51. The DC function shall compute a Freeze Index (FI_{dateN}) once per day for the previous day for each weather zone as follows (assumes today's day is represented by dateN+1)

$$FI_{dateN} = \sum_{(dateREF - dateN)} (PT_{mean})$$

Where,

dateREF = A user configurable reference date.

NOTE: Thaw index can only be computed for dates on or past the reference date.

PT_{mean} = The computed mean pavement temperature in units of degrees Celsius for a particular date N computed from the measured minimum and maximum temperature values for the day as:

(Max Temp Date N + Min Temp Date N) / 2

R-52. If the mean temperature for a particular date required in the summation of the Freeze Index is not available (e.g. missing data) but there is a "valid" mean temperature data for the previous day and the next day, then the missing mean temperature value shall be computed as the average of the previous and next day's values and used in the summation accordingly.

a. Any Freeze Index computed with derived data as above shall be tagged as "derived".

R-53. If one or more mean temperature values for a particular date required in the summation of the Freeze Index is not available and can not be derived as specified in R-52 then the Freeze Index value for the particular day shall be set to an arbitrary value and tagged as "missing".

R-54. All Freeze Indices computed from "valid" data shall be tagged as "valid".

R-55. The DC function shall compute a forecasted 5–Day Freeze Index ($FI5D_{dateN}$) once per day for that day for each weather zone as follows (assumes today's day is represented by dateN):

$$FI5D_{dateN} = FI_{dateN-1} + \sum_{(dateN - dateN+4)} (FPT_{mean})$$

Where,

$FI_{dateN-1}$ = The actual Freeze Index computed at this location for the previous day. If there is no previous day data, then $FI_{dateN-1} = 0$.

FPT_{mean} = The forecasted mean pavement temperature in units of degrees Celsius for a particular date N computed as:

(Forecast Max Temp Date N + Forecast Min Temp Date N) / 2

Thaw Weakening Indices

R-56. The DC function shall compute a Thaw Weakening Index (TW_{in}) for a sensor area whenever new pavement displacement data is available for the sensor area.

a. The thaw weakening index **TW_{in}** shall be computed as follows:

$$TW_{in} = (h / D) * (X / S)$$

Where,

H = Total heave resulting from frost action, or in other words, the measured pavement displacement value in millimetres.

D = Thickness of sub-grade soil affected by frost action, or in other words, the measured thaw depth in millimetres minus the sum of (thickness of asphalt + base depth + sub-base depths), also in millimetres.

X = Thawing rate in units of millimetres /day. (Determined through experimentation)

S = Settlement rate in millimetres/day. (Determined through experimentation)

b. The value for "**h**" shall be the most current pavement displacement value collected for the particular location. If the most current value is not tagged as "valid" then the TWin value shall not be computed.

c. The value for "**D**" shall be determined using the most current thaw depth value collected for the particular location. If the most current value is not tagged as "valid" then the TWin value shall not be computed.

d. Asphalt thickness, base depth and sub-base depth values shall be user configurable system parameters on a per sensor location basis.

e. Thawing rate and Settlement rate shall be user configurable system parameters on a per sensor location basis.

3.1.2 TRANSDUCER COMM

The Transducer Comm (TC) function performs all communication activities directly with the field sensors. Depending on the physical architecture of the deployed system, the Transducer Comm function may run solely on computer(s) in the COC or may be spread across computer(s) at the COC and distributed controllers strategically locate in the field.

R-57. The TC function shall implement all necessary drivers and communication protocols as required to directly communicate with each field sensor device or sub-system.

R-58. The TC function shall perform all validity checks (e.g. checksum verification) supported by the communication protocols to ensure correctness of received data.

R-59. The TC function shall record all communication errors encountered by recording the following minimum information in the system database:

a. Date and time of error;

b. Identifier of the sensor involved;

c. Descriptive text detailing the error condition.

R-60. The TC function shall perform periodic sanity checks on all field equipment to the extent supported by the protocols associated with such equipment. For example, a temperature sensor may be connected to an intelligent field controller – the TC function should periodically check the operational status of the field controller in addition to the regular collection of temperature data from its sensors.

3.1.3 DATA ARCHIVE

All raw data collected by the system or produced through computation will be archived by the Data Archive (DA) function.

R-61. The DA function shall employ a suitable industry standard relational database such as Microsoft Access, MySQL or Oracle (for example), that supports the structured query language (SQL) standard.

R-62. The database and physical storage shall be sized to allow for a minimum of 5 years worth of on-line data storage for all data archived by the DA function.

R-63. All temperature data collected from field sensors shall be stored in the database with the following minimal information per record:

a. Date and time at which datum was collected;

b. Identifier of sensor from which the datum was collected;

c. Datum value;

d. Datum tag (“valid”, “suspect”, etc.).

R-64. All temperature forecast data collected (manually or automatically) from external agencies shall be stored in the database with the following minimal information per record:

a. Date and time at which the forecast data was collected;

b. Forecast data values;

R-65. All "valid" temperature data collected from field sensors shall be aggregated each hour to produce an average value that is stored in the database with the following minimal information per record:

a. Date and hour of day for which the average temperature applies;

b. Identifier of sensor from which the temperature data was collected;

c. Average hourly temperature in degrees Celsius, or an arbitrary value (e.g. zero) if the average could not be computed;

d. Datum tag ("valid", "missing", etc.). The tag shall be set to "missing" if the average could not be computed for any reason, otherwise the tag shall be set to "valid";

NOTE: Since temperature data may be collected at a rate ranging from every 5 minutes to once every hour, hourly averages are computed using all data collected during the specific hour, which may include 1 or more values.

R-66. All "valid" temperature data (pavement and air) collected from field sensors shall be aggregated each day to produce an average value, a minimum daily value and a maximum daily value that are stored in the database with the following minimal information per record:

a. Date for which the temperature data applies;

b. Identifier of sensor from which the temperature data was collected;

c. Average daily temperature in degrees Celsius, or an arbitrary value (e.g. zero) if the average could not be computed;

d. Average daily temperature tag ("valid", "missing", etc.). The tag shall be set to "missing" if the average could not be computed for any reason, otherwise the tag shall be set to "valid";

e. Minimum daily temperature in degrees Celsius, or an arbitrary value (e.g. zero) if the minimum could not be generated;

f. Minimum daily temperature tag ("valid", "missing", etc.). The tag shall be set to "missing" if the minimum could not be determined for any reason, otherwise the tag shall be set to "valid";

g. Maximum daily temperature in degrees Celsius, or an arbitrary value (e.g. zero) if the minimum could not be generated;

h. Maximum daily temperature tag (“valid”, “missing”, etc.). The tag shall be set to “missing” if the maximum could not be determined for any reason, otherwise the tag shall be set to “valid”;

R-67. All “valid” daily minimum and maximum temperature computations shall be aggregated each week to produce an average minimum daily value and an average maximum daily value for the week that are stored in the database with the following minimal information per record:

a. Week of the year for which the minimum and maximum temperatures apply;

b. Identifier of sensor from which the temperature data was originally collected;

c. Average minimum weekly temperature in degrees Celsius, or an arbitrary value (e.g. zero) if the average minimum could not be generated;

d. Average minimum weekly temperature tag (“valid”, “missing”, etc.). The tag shall be set to “missing” if the average minimum could not be determined for any reason, otherwise the tag shall be set to “valid”;

e. Average maximum weekly temperature in degrees Celsius, or an arbitrary value (e.g. zero) if the average maximum could not be generated;

f. Average maximum weekly temperature tag (“valid”, “missing”, etc.). The tag shall be set to “missing” if the average maximum could not be determined for any reason, otherwise the tag shall be set to “valid”;

R-68. All strain data collected or derived shall be stored in the database with the following minimal information per record:

a. Date and time the datum was collected;

b. Identifier of sensor from which the strain data was collected;

c. Strain value;

d. Data tag (“valid”, “derived”, “suspect”, etc.).

R-69. All deflection data collected or manually entered shall be stored in the database with the following minimal information per record:

a. Date and time the datum was collected;

b. Identifier of strain sensor for which the data is associated;

c. Deflection value;

d. Data tag (“valid”, “derived”, etc.).

R-70. All pavement displacement data collected shall be stored in the database with the following minimal information per record:

a. Date and time the datum was collected;

b. Identifier of sensor from which the datum was collected;

c. Datum value;

d. Datum tag (“valid”, “suspect”, etc.).

R-71. All moisture content data collected shall be stored in the database with the following minimal information per record:

a. Date and time the datum was collected;

b. Identifier(s) of sensor from which the datum was collected;

c. Moisture content value for base level;

d. Moisture content tag for base level (“valid”, “suspect”, etc.);

e. Moisture content value for sub-base level;

f. Moisture content tag for sub-base level (“valid”, “suspect”, etc.);

g. Moisture content value for sub-grade level;

h. Moisture content tag for sub-grade level (“valid”, “suspect”, etc.).

R-72. All solar radiation data collected shall be stored in the database with the following minimal information per record:

a. Date and time the datum was collected;

b. Identifier of sensor from which the datum was collected;

c. Datum value;

d. Datum tag (“valid”, “suspect”, etc.).

R-73. All historical solar radiation data computed shall be stored in the database with the following minimal information per record:

a. Date of the datum;

b. Identifier of sensor the datum applies to;

c. Historical Solar Radiation datum value;

d. Datum tag (“valid”, “missing”, etc.).

R-74. All frost/thaw depth data collected shall be stored in the database with the following minimal information per record:

a. Date and time the datum was collected;

b. Identifier of sensor from which the datum was collected;

c. Frost/Thaw datum value;

d. Datum tag (“valid”, “suspect”, etc.)

R-75. All “valid” frost depth data shall be analyzed each day to produce a daily average, minimum, and maximum value that are stored in the database with the following information per record:

a. Date of the frost depth data;

b. Identifier of the sensor the frost depth data was collected from;

c. Daily average frost depth or an arbitrary value (e.g. zero) if the average could not be determined;

d. Average frost depth value tag set to “missing” if the average could not be determined for any reason, otherwise the tag shall be set to “valid”;

e. Minimum frost depth value, or an arbitrary value (e.g. zero) if the minimum could not be determined;

f. Minimum frost depth value tag set to “missing” if the minimum could not be determined for any reason, otherwise the tag shall be set to “valid”;

g. Maximum frost depth value, or an arbitrary value (e.g. zero) if the maximum could not be determined;

h. Maximum frost depth value tag set to “missing” if the maximum could not be determined for any reason, otherwise the tag shall be set to “valid”.

R-76. All valid maximum daily frost depth values shall be analyzed annually to determine an annual maximum frost depth that is stored in the database with the following information per record:

a. Year for which the frost depth data applies;

b. Identifier of sensor from which the frost depth data was collected;

c. Maximum frost depth value, or an arbitrary value (e.g. zero) if the maximum could not be determined;

d. Maximum frost depth value tag (“valid”, “missing”, etc.). The tag shall be set to “missing” if the maximum could not be determined for any reason, otherwise the tag shall be set to “valid”;

R-77. All “valid” thaw depth data shall be analyzed each day to produce a daily average, minimum, and maximum value that are stored in the database with the following information per record:

a. Date for which the thaw depth data applies;

b. Identifier of sensor from which the thaw depth data was collected;

c. Daily average thaw depth or an arbitrary value (e.g. zero) if the average could not be determined;

d. Average thaw depth value tag set to “missing” if the average could not be determined for any reason, otherwise the tag shall be set to “valid”;

e. Minimum thaw depth value, or an arbitrary value (e.g. zero) if the minimum could not be determined;

f. Minimum thaw depth value tag set to “missing” if the minimum could not be determined for any reason, otherwise the tag shall be set to “valid”;

g. Maximum thaw depth value, or an arbitrary value (e.g. zero) if the maximum could not be determined;

h. Maximum thaw depth value tag set to “missing” if the maximum could not be determined for any reason, otherwise the tag shall be set to “valid”.

R-78. All Thaw and Freeze Index values shall be stored in the database with the following information per record:

a. Date for which the thaw (or freeze) index data applies;

b. Identifier of sensor from which the data was collected for the computation of the index;

c. Thaw (or Freeze) Index value in units of degrees Celsius;

d. Thaw (or Freeze) index value tag (“valid”, “missing”, etc.);

e. 5-Day Thaw (or Freeze) Index value in units of degrees Celsius;

f. 5-Day Thaw (or Freeze) index value tag (“valid”, “missing”, etc.).

R-79. All Thaw Weakening Index values shall be stored in the database with the following information per record:

a. Date for which the thaw weakening index data applies;

b. Identifier of sensor from which the data was collected for the computation of the thaw weakening index;

c. Thaw Weakening Index value (no units);

d. Thaw weakening index value tag (“valid”, “missing”, etc.);

3.1.4 DATA ANALYSIS

The Data Analysis (ANL) function of RCWatch will utilize the raw field data collected by the Data Collection function to determine the appropriate periods for which the SLR and WWP programs are to be implemented.

3.1.4.1 Algorithm Management

The following requirements apply to the algorithm management capabilities of the ANL function.

R-80. The ANL function shall support the following algorithm states:

a. Advanced warning for SLR implementation;

b. SLR implementation;

c. Advanced warning for SLR termination;

d. SLR termination;

e. Advanced warning for WWP implementation;

f. WWP implementation;

g. Advanced warning for WWP termination;

h. WWP termination;

R-81. The ANL function shall provide a mechanism to allow users to “build” data comparison statements for a particular sensor area, comprising a data type identifier, comparison operator and either another data type or a threshold value.

a. There shall be a data type identifier representing every data value collected or computed by the software. (e.g. temperature, thaw depth, etc.);

b. The user shall be able to select from the following comparison operators: “greater than or equal to”, “equal to”, or “less than”;

c. The user shall be allowed to define an unlimited number of unique threshold values on a per sensor basis.

Example: The user may choose to define a threshold “Thaw Weakening Index Threshold” for a particular sensor. Subsequently, he/she builds a data comparison statement by selecting the “Thaw Weakening Index” data type, the “greater than” comparison operator, and the “Thaw Weakening Index Threshold” threshold.

i.e. Comparison Statement = $TW_{in} \geq$ Thaw Weakening Index Threshold

R-82. The ANL function shall provide a mechanism to allow users to “build” algorithm statements by combining together one or more data comparison statements with a logical AND combiner.

a. Each algorithm statement shall be tagged with a unique identifier.

Example: The user may define two comparison statements as follows:

Strain > $THRESHOLD_a$

Moisture Content > $THRESHOLD_b$

Subsequently, the user defines an algorithm statement “ALGORITHM X” by combining the above two comparison statements as follows:

Strain ≥ T_a AND Moisture Content ≥ T_b

R-83. The ANL function shall provide a separate algorithm definition table for each of the supported algorithm states defined in R-80, each of which defines the algorithms to run for the particular state determination and how the outputs of those algorithms are to be combined to form a single determination result.

a. Each record of the table shall contain an algorithm statement identifier.

b. It shall be possible to specify whether or not the results of all algorithm statements are to be combined using a logical AND or a logical OR operation to determine a single result.

R-84. If the algorithms of a particular table are specified as requiring a logical AND operation to form the result, then the ANL function shall determine that the state determination (e.g. SLR implementation) is TRUE if and only if all enabled algorithms produce a determination that the state is TRUE.

a. If one or more enabled algorithms can not be executed for any reason (e.g. insufficient data) the result of that algorithm shall default to a FALSE output and thus the overall determination state shall be FALSE.

R-85. If the algorithms of a particular table are specified as requiring a logical OR operation to form the result, then the ANL function shall determine that the state determination is TRUE if any enabled algorithm produces a determination that the state is TRUE.

Example: The user may configure “ALGORITHM X” (from the example above) for the SLR Implementation state as the sole algorithm statement. Thus, the system will determine that SLR Implementation is required if the output of the algorithm statement is true, or in other words;

IF Strain ≥ T_a AND Moisture Content > T_b THEN SLR Implementation = TRUE

R-86. The ANL function shall provide a separate algorithm schedule table associated with each algorithm definition table that defines when the algorithms listed in the definition table are to be run.

a. Each record of the table shall contain an execution period defined by a start date and end date.

b. For each start and end date period, there shall be a parameter that defines the frequency at which the algorithms are executed on a daily basis (e.g. every hour, once per day, etc.).

c. When the algorithm executes, the data value required by the algorithm (e.g. moisture content) shall be the most recently available data value for that particular sensor and data type.

d. If any of the data required for a particular algorithm statement is not available or not tagged as "valid" for an execution cycle, the algorithm shall not be executed for the cycle.

R-87. The ANL function shall continuously execute all state determination algorithms for each configured roadway area in accordance with the corresponding algorithm tables for definition and schedule, with the following exceptions:

a. The algorithms for the determination of SLR Advance Warning shall not be executed for a particular roadway segment if there is currently an SLR Advance Warning or SLR Implementation for the roadway segment. (i.e. as previously detected by system or declared by user);

b. The algorithms for the determination of SLR Implementation shall not be executed for a particular roadway segment if there is currently an SLR Implementation for the roadway segment. (i.e. as previously detected by system or declared by user);

c. The algorithms for the determination of WWP Advance Warning shall not be executed for a particular roadway segment if there is currently an WWP Advance Warning or WWP Implementation for the roadway segment. (i.e. as previously detected by system or declared by user);

d. The algorithms for the determination of WWP Implementation shall not be executed for a particular roadway segment if there is currently a WWP Implementation for the roadway segment. (i.e. as previously detected by system or declared by user)

e. The algorithms for the determination of SLR termination or advance SLR termination warning shall not be executed for a particular roadway segment unless the SLR program is active for that segment.

f. The algorithms for the determination of WWP termination or advance WWP termination warning shall not be executed for a particular roadway segment unless the WWP program is active for that segment.

3.1.4.2 Spring Load Restrictions Program Implementation Advanced Warning

R-88. The ANL function shall initially be configured with the following algorithm statements for the SLR Implementation Advanced Warning state:

Strain < T_a & Thaw Depth ≥ T_b & Moisture Content ≥ T_c

Strain ≥ T_a & Thaw Depth < T_b & Moisture Content ≥ T_c

Strain < T_a & 5-Day Thaw Index ≥ T_{b1} & Moisture Content ≥ T_c

Strain ≥ T_a & 5-Day Thaw Index < T_{b1} & Moisture Content ≥ T_c

a. "Ta", "T_b", "T_{b1}" and "T_c" shall be user configurable parameters on a per sensor basis.

R-89. The algorithm table for the SLR Implementation Advance Warning state shall be configured with the above algorithm statements using a logical OR operation. (In other words, if any of the above statements are TRUE, the software will determine it appropriate to provide an advance warning for SLR implementation).

3.1.4.3 Spring Load Restrictions Program Implementation

R-90. The ANL function shall initially be configured with the following algorithm statements for the SLR Implementation state:

(Thaw Weakening Index) Twin ≥ T_x

Strain ≥ T_a and Thaw Depth ≥ T_b and Moisture Content ≥ T_c

Strain ≥ T_a & 5-Day Thaw Index ≥ T_{b1} & Moisture Content ≥ T_c

a. "T_a", "T_b", "T_{b1}", "T_c" and "T_x" shall be user configurable parameters on a per sensor basis.

R-91. The algorithm table for the SLR Implementation state shall be configured with the above algorithm statements using a logical OR operation. (In other words, if any of the above statements are TRUE, the software will determine it appropriate to implement SLR).

3.1.4.4 Spring Load Restrictions Program Termination Advance Warning

R-92. The ANL function shall initially be configured with the following algorithm statements for the SLR Termination Advance Warning state:

Strain < T_d & 5-Day Thaw Index ≥ T_e & Moisture Content < T_f

a. "T_d", "T_e" and "T_f" shall be user configurable parameters on a per sensor basis.

3.1.4.5 Spring Load Restrictions Program Termination

R-93. The ANL function shall initially be configured with the following algorithm statements for the SLR Termination state:

Strain < T_d and Thaw Depth ≥ T_e and Moisture Content < T_f

a. "T_d", "T_e" and "T_f" shall be user configurable parameters on a per sensor basis.

3.1.4.6 Winter Weight Premiums Program Implementation Advanced Warning

R-94. The ANL function shall initially be configured with the following algorithm statements for the WWP Implementation Advanced Warning state:

Strain < T_j and Frost Depth > T_k

Strain < T_j and 5-Day Freeze Index < T_{k1}

Strain ≥ T_j and Frost Depth ≥ T_k

Strain ≥ T_j and 5-Day Freeze Index ≥ T_{k1}

a. "T_j", "T_k", and "T_{k1}" shall be user configurable parameters on a per sensor basis.

R-95. The algorithm table for the WWP Implementation Advance Warning state shall be configured with the above algorithm statements using a logical OR operation. (In other words, if any of the above statements are TRUE, the software will determine it appropriate to provide an advance warning for WWP implementation).

3.1.4.7 Winter Weight Premiums Program Implementation

R-96. The ANL function shall initially be configured with the following algorithm statements for the WWP Implementation state:

Strain < T_j and Frost Depth ≥ T_k

Strain < T_j and 5-Day Freeze Index ≥ T_{k1}

a. "T_j", "T_k", and "T_{k1}" shall be user configurable parameters on a per sensor basis.

R-97. The algorithm table for the WWP Implementation state shall be configured with the above algorithm statements using a logical OR operation. (In other words, if any of the above statements are TRUE, the software will determine it appropriate to implement WWP).

3.1.4.8 Winter Weight Premiums Program Termination Advanced Warning

R-98. The ANL function shall initially be configured with the following algorithm statements for the WWP Termination Advanced Warning state:

Strain ≥ T_l and Frost Depth ≥ T_m

Strain ≥ T_l and 5-Day Freeze Index ≥ T_{m1}

Strain < T_l and Frost Depth < T_m

Strain < T_l and 5-Day Freeze Index < T_{m1}

a. "$\mathbf{T_l}$", "$\mathbf{T_m}$", and "$\mathbf{T_{m1}}$" shall be user configurable parameters on a per sensor basis.

R-99. The algorithm table for the WWP Termination Advance Warning state shall be configured with the above algorithm statements using a logical OR operation. (In other words, if any of the above statements are TRUE, the software will determine it appropriate to provide an advance warning for WWP termination).

3.1.4.9 Winter Weight Premiums Program Termination

R-100. The ANL function shall initially be configured with the following algorithm statements for the WWP Termination state:

Strain ≥ T_l and Frost Depth < T_m

Strain ≥ T_l and 5-Day Freeze Index < T_{m1}

a. "$\mathbf{T_l}$", "$\mathbf{T_m}$", and "$\mathbf{T_{m1}}$" shall be user configurable parameters on a per sensor basis.

R-101. The algorithm table for the WWP Termination state shall be configured with the above algorithm statements using a logical OR operation. (In other words, if any of the above statements are TRUE, the software will determine it appropriate to terminate WWP).

3.1.4.10 Recovery Period

R-102. The ANL function shall compute a Recovery Period value for each area in which an SLR program is implemented on an annual basis.

R-103. The Recovery Period shall initially be computed as follows:

Recovery Period Year N = Duration of SLR Implementation for Year N

R-104. The ANL function shall record all Recovery Data values in the database with the following minimal information:

a. Year;

b. Details of the roadway or geographical area associated with the SLR;

c. Recovery period in days (as computed by system);

d. Recovery period in days (as manually entered by user);

R-105. It shall be possible for the user to manually enter a value for Recovery Period to be stored in the database.

3.1.4.11 SLR & WWP Program Data Logging

R-106. RCWatch shall save all SLR and WWP program details in the database with the following minimum pieces of information:

a. Date and time of program details;

b. The program state to be one of: SLR Advanced Warning, SLR Implementation, SLR Termination Warning, SLR Termination, WWP Implementation Advanced Warning, WWP Implementation, WWP Termination Warning or WWP Termination;

c. The roadway segment associated with the program state;

d. The initial source of the program state to be one of: USER or ALGORITHM;

e. For USER sources, the following additional information shall be recorded:

   i. User name

f. For ALGORITHM sources, the following additional information shall be recorded:

   i. A list of all algorithms that were enabled at the time of the determination;
   ii. An indication of whether or not the algorithm results were combined using a logical AND or a logical OR operation;
   iii. For each algorithm used, the final outcome of the algorithm (TRUE or FALSE);
   iv. For each algorithm used, the measured values and system parameters at the time of the determination.

g. User acceptance to be one of: NONE, ACCEPTED or REJECTED

h. Date and time program is accepted/rejected by official user and name of user;

R-107. When the ANL function determines a state determination is TRUE based on the algorithm outputs, a program record shall be created in the database as follows :

a. Date and time of program details: the date and time the algorithm determination was made.

b. The program state: one of SLR Advanced Warning, SLR Implementation, SLR Termination, WWP Implementation or WWP Termination;

c. The roadway segment associated with the program state;

d. The initial source of the program state: ALGORITHM;

e. The following additional ALGORITHM information:

   i. A list of all algorithms that were enabled at the time of the determination;
   ii. An indication of whether or not the algorithm results were combined using a logical AND or a logical OR operation;
   iii. For each algorithm used, the final outcome of the algorithm (TRUE or FALSE);
   iv. For each algorithm used, the measured values and system parameters at the time of the determination.

f. User acceptance: NONE

g. Date and time program is accepted/rejected by official user and name of user: N/A

3.1.5 REPORTS

The Reports function of the application will be responsible for generating pre-formatted system reports for viewing and/or printing (e.g. equipment status reports, SLR & WWP historical reports, and various data reports).

R-108. All reports shall be generated using an approved leading industry 3rd part software package such as Crystal Reports.

R-109. All reports shall be printable on standard 8.5"x11" paper.

R-110. The Reports function shall support the following canned reports as a minimum:

a. Raw Data Reports: a report of a specific raw data item over a specified period of time.

b. Recovery Period Report: a report of the roadway recovery periods over a specified period of time.

c. Algorithm Report: a report of the SLR and WWP algorithm operations.

d. Equipment Status Report: a report of equipment operational status.

e. User Action Report: a report of selected user activity within the application.

f. System Log: a report of all system event logs.

R-111. When a specific report is selected and generated based on parameters specific to the report (e.g. date range), the report shall be displayed on screen for the user to review.

a. While viewing any report, it shall be possible to send the report content to any system configured printer.

3.1.5.1 Raw Data Reports

R-112. The Raw Data Reports shall report on the various raw data values collected and/or computed by RCWatch and shall allow the user to tailor the report content through the following filters:

a. Start Date: the earliest date, specified as a year/month/day value, for which data will be selected for the report;

b. End Date: the latest date, specified as a year/month/day value, for which data will be selected for the report;

c. Report Type: "Tabular" or "Plot";

d. Data Collection Area: a list of all data collection zones in RCWatch, corresponding to the location of the various field sensors. It shall be possible to select one or more data collection area.

e. Data Validity: "All Data", "Valid Data Only", or "Valid & Derived Data";

f. Data Type: one of the following, depending on Report Type as indicated:

    i. Raw Air Temperature (available for Tabular or Plot)
    ii. Hourly Averaged Air Temperature (available for Tabular or Plot)
    iii. Daily Averaged Air Temperature (available for Tabular or Plot)
    iv. Daily Minimum/Maximum Air Temperature (Tabular only)
    v. Weekly Averaged Minimum/Maximum Air Temperature (Tabular only)
    vi. Forecasted Air Temperature (available for Tabular or Plot)
    vii. Raw Pavement Temperature (available for Tabular or Plot)
    viii. Hourly Averaged Pavement Temperature (available for Tabular or Plot)
    ix. Daily Averaged Pavement Temperature (available for Tabular or Plot)
    x. Daily Minimum/Maximum Pavement Temperature (Tabular only)
    xi. Weekly Averaged Minimum/Maximum Pavement Temperature (Tabular only)
    xii. Raw Strain Data (available for Tabular or Plot)
    xiii. Raw Deflection Data (available for Tabular or Plot)
    xiv. Raw Roadway Displacement (available for Tabular or Plot)
    xv. Raw Moisture Content Data (available for Tabular or Plot)
    xvi. Raw Solar Radiation (available for Tabular or Plot)
    xvii. Historic Solar Radiation (available for Tabular or Plot)
    xviii. Raw Frost Depth Data (available for Tabular or Plot)
    xix. Daily Averaged Frost Depth Data (available for Tabular or Plot)
    xx. Daily Minimum/Maximum Frost Depth Data (Tabular only)
    xxi. Annual Maximum Frost Depth Data (available for Tabular or Plot)
    xxii. Raw Thaw Depth Data (available for Tabular or Plot)
    xxiii. Daily Averaged Thaw Depth Data (available for Tabular or Plot)
    xxiv. Daily Minimum/Maximum Thaw Depth Data (Tabular only)
    xxv. Thaw Indices (Tabular only)

R-113. The “Data Type” filter shall grey out any selection that is not permitted based upon the selected Report Type.

R-114. When the Report Type is selected as “Plot”, it shall be possible to select more than one data type for the Data Type filter allowing the user to correlate the effects of one data type with another. The following combinations shall be permitted:

a. Hourly averaged air and pavement temperature;

b. Any combinations of the raw data for air temperature, pavement temperature, strain, deflection, displacement, moisture content, solar radiation, frost/thaw depth.

R-115. When the Report Type is selected as “Tabular”, it shall be possible to select more than one data type for the Data Type filter allowing the user to correlate the effects of one data type with another. The following combinations shall be permitted:

a. Hourly averaged air and pavement temperature;

b. Any combinations of the raw data for air temperature, pavement temperature, strain, deflection, displacement, moisture content, solar radiation, frost/thaw depth.

R-116. All “Tabular” reports shall have a heading that identifies the Start and End Date and shall list the selected data in tabular form.

R-117. Each Collection Area of a tabular report shall be clearly delineated and shall contain the following columns of information:

a. Date/Time: The date and time at which the data was collected from the field/external agency or computed/derived by RCWatch. The data shall be ordered chronologically in ascending order within a particular data collection area.

b. Data Value(s): the corresponding data value based upon the selected Data Type(s). There may be one or more column headings in accordance with the number of selected Data Types. Each column heading shall appropriately describe the data associated with the column (.e.g. Air Temp, Strain, etc.).

c. Data Tag(s): the tag associated with the data in a descriptive textual form (e.g. “valid”, “missing”, etc.). There shall be one data column adjacent to each Data Value column for which it is associated.

R-118. All “Plot” report shall have a heading that identifies the Start and End Dates and shall graphically show the selected data as follows:

a. Y-Axis of the plot shall represent the magnitude(s) of the value(s) selected;

b. X-Axis of the plot shall be the timeline corresponding to the Start and End date range of the report;

c. When more than one data type or data from more than one collection area is plotted on the same report, each plot shall be uniquely coloured.

d. A legend that defines the colour scheme for the plot shall be provided, mapping each colour to the associated data type and collection area.

3.1.5.2 Recovery Period Report

R-119. The Recovery Period Report shall report on the time taken for a particular roadway to regain full strength on an annual basis, allowing the user to tailor the report content through the following filters:

a. Start Date: the earliest year for which data will be selected for the report;

b. End Date: the latest year for which data will be selected for the report;

c. Roadway Section: a list of all configured roadway sections in RCWatch. There shall also be a selection for “All Roadways”. It shall be possible to select one or more items from this filter.

R-120. The report shall be tabular in nature, ordered chronologically in ascending order and for each roadway selected, shall show the recorded Recovery Period for each year within the selected date range.

3.1.5.3 Algorithm Report

R-121. The Algorithm Report shall report on the general operation of the SLR and WWP algorithms and shall allow for the user to tailor the report content through the following filters:

a. Start Date: the earliest year for which data will be selected for the report;

b. End Date: the latest year for which data will be selected for the report;

c. Algorithm: “SLR” or “WWP”;

d. Roadway Section: a list of all configured roadway sections in RCWatch. There shall also be a selection for “All Roadways”. It shall be possible to select one or more items from this filter.

R-122. The report shall be tabular in nature, delineated and clearly marked by Roadway Section and showing the following columns of information for each Roadway Section:

a. Date and time: the specific date and time at which an SLR/WWP event occurred, which may be the result of an algorithm execution or a user implementation or the termination of an SLR/WWP program. The report shall be ordered chronologically in ascending order.

b. Event Type: “Operator Action” or “Algorithm Determination”;

c. The particular event that was triggered (i.e. SLR Advanced Warning, SLR Implementation, SLR Termination, WWP Implementation, WWP Termination);

d. If the Event Type for a row of the report is “Operator Action”, the following additional pieces of information shall be reported for the row:

   i. The name of the operator that implemented the action;
   ii. Any free form notes the were entered by the operator and stored with the event;

e. If the Event Type for a row of the report is “Algorithm Determination”, the following additional pieces of information shall be reported for the row:

   i. A list of all algorithms that were enabled at the time of the determination, each identified by a descriptive name;
   ii. The specific outcome of each algorithm (TRUE or FALSE);
   iii. An indication of whether or not the algorithm results were combined using a logical AND or a logical OR operation;

3.1.5.4 Equipment Status Report

R-123. The Equipment Status Report shall report on the general operation of the various field devices configured to and managed by the RCWatch application using the following report filters:

a. Start Date: the earliest year for which data will be included in the report;

b. End Date: the latest year for which data will be included in the report;

R-124. The report shall be tabular in nature and shall show the following columns of information, ordered chronologically in ascending order:

a. Date and time: the specific date and time at which an equipment operational event occurred;

b. Equipment ID: identification of the particular piece of equipment;

c. Event: a description of the operational event that occurred (e.g. “device failed to respond”, “power supply fault reported by device”, etc.)

NOTE: The particular operational events that will be reported will be dependent upon the status reporting capabilities of the individual field devices and the corresponding information logged by the Transducer Comm function.

3.1.5.5 User Action Report

R-125. The User Action Report shall report on selected user actions within the RCWatch application using the following report filters:

a. Start Date: the earliest year for which data will be selected for the report;

b. End Date: the latest year for which data will be selected for the report;

R-126. The report shall be tabular in nature and shall show the following columns of information, ordered chronologically in ascending order:

a. Date and time: the specific date and time at which the user action occurred;

b. User Name: identification of the RCWatch user;

c. Action: a description of the user action, to include the following as a minimum:

   i. User logon and logoff;
   ii. Parameter modifications – including the name of the parameter, the previous value and the modified value;
   iii. SLR implementation / termination – including the roadway or roadway segment for which the SLR was applied.
   iv. WWP implementation / termination – including the roadway or roadway segment for which the WWP was applied.

3.1.5.6 System Log

R-127. All RCWatch applications shall record details regarding internal software events in the system database or other suitable storage location (e.g. an operating system’s event log facility).

R-128. All software events shall be categorized as being one of the following levels of severity as a minimum:

a. Informational: this category shall be reserved for logs that inform of normal and non-critical system events (e.g. application start date/time);

b. Warning: this category shall be reserved for logs that inform of abnormal but non-critical system events (e.g. multiple contiguous invalid logon attempts for a particular user);

c. Error: this category shall be reserved for logs that inform of critical system events (e.g. failure to save data to a file due to lack of disk space).

R-129. It shall be up to the software developer's discretion as to the amount of application logging that is provide with the RCWatch system, however, the level of logging shall be sufficient to allow for proper diagnosing of system operation by an Engineer level user.

R-130. The System Log shall report on selected RCWatch software application logs using the following report filter:

a. Start Date: the earliest year for which data will be selected for the report;

b. End Date: the latest year for which data will be selected for the report;

R-131. The report shall be tabular in nature and shall show the following columns of information, ordered chronologically in ascending order:

a. Date and time: the specific date and time at which the system event occurred;

b. Event Severity: classification of the severity of the event;

c. Event Description: a detailed description of the system event.

3.1.6 GRAPHICAL USER INTERFACE

The RCWatch Graphical User Interface (GUI) will be based on an industry standard windowing interface (e.g. Microsoft Windows™, XWindows, etc.) utilizing client-server architecture to interact with the core RCWatch application. The primary GUI display will comprise a map background of the covered roadway network from which the user can monitor weather data and SLR/WPP program events.

3.1.6.1 General Architecture

R-132. The RCWatch application shall comprise a number of stand-alone elements, designed and built using industry standard client/server architectures.

R-133. The GUI component of RCWatch shall be one of the stand-alone applications.

a. Multiple simultaneous instances of the GUI application shall be supported by RCWatch.

b. The client/server architecture shall ensure that all GUI instances are synchronized in terms of the information provided to the user.

R-134. When configured properly, RCWatch shall be capable of running and performing all of its primary tasks independent of the GUI application.

R-135. The GUI application shall communicate with the other RCWatch applications using standard Internet based protocols and software remoting techniques allowing for the application to execute on the same computer, on the same physical network, or on a completely autonomous external network.

R-136. The GUI shall support both English and French text.

a. It shall be possible to start the GUI in either English or French mode based upon an application configuration setting.

3.1.6.2 User Access

Operator access to the various functions of RCWatch will be restricted based upon the assigned access rights of the operator. Operators with differing levels of experience and seniority will be assigned different levels of system access accordingly. RCWatch will provide a means for operator access level assignment based on the requirements detailed below.

R-137. Access to the RCWatch user interface shall only be granted to users who enter a valid username and password.

R-138. When the user invokes the GUI application, a logon dialog shall be presented to the user with fields for username and password.

a. Passwords and usernames shall be case sensitive;

b. Passwords displayed in any dialog screen or echoed to the user shall be shown as series of asterisk characters.

R-139. All user logon and logoff events shall be recorded in the RCWatch system database with the username and the date & time of the event as a minimum.

R-140. The GUI shall provide a mechanism allowing any user to change his/her password by requiring the user to first enter their current password credentials.

R-141. All users shall be assigned to one of the following user groups:

a. Guest: users assigned to this group shall only be allowed to view data within the system.

b. Operator: users assigned to this group shall be allowed to view data within the system and to enter or modify the following elements:

   i. Raw and derived weather data;
   ii. SLR implementation and termination;
   iii. WWP implementation and termination.

c. Engineer: users assigned to this group shall be allowed unrestricted access to the system.

3.1.6.3 General Layout

R-142. The Graphical User Interface shall completely fit (i.e. for proper viewing and function) on a display with a resolution as low as 1024 x 768 pixels.

R-143. The GUI shall include the following primary elements a minimum:

a. Menu Bar: a standard windowing style menu bar containing the various menu items detailed in R-144;

b. Application View: a standard windowing style view comprising the main window portion of the application and containing a scalable Geographical Information System (GIS) based Map display. (See 3.1.6.8 for details)

c. Status Bar: a standard windowing style status bar containing the various information panes detailed below.

R-144. The GUI "should" contain additional shortcut features (e.g. tool bar buttons) where appropriate to ease access to selected menu item functions (e.g. map navigation).

3.1.6.4 Menu Bar

R-145. The Menu Bar shall include a 'File' menu item with the following menu options:

a. Password: This item shall be enabled for all users. When selected shall present user with a dialog screen allowing the user to change his/her logon password;

b. System Configuration: This item shall be disabled for any user that is not a member of the "Engineer" user group. When selected shall present users with the main dialog screen for access to the various system configuration items (See 3.1.8).

c. Exit: This item shall be enabled for all users and when selected allows the user to exit the GUI application.

R-146. The Menu Bar shall include a 'Map View' menu item with the following menu options:

a. Pointer: This item shall be enabled for all users. Selecting this item shall change the current cursor to the Pointer cursor, identified by an arrow, allowing the user to select items from the map display. (See 3.1.6.7 Map Navigation for details)

b. Zoom In: This item shall be enabled for all users. Selecting this item shall change the current cursor to the Zoom In cursor, identified by a magnifying glass with a '+' sign, allowing the user to zoom in the map display. (See 3.1.6.7)

c. Zoom Out: This item shall be enabled for all users. Selecting this item shall change the current cursor to the Zoom Out cursor, identified by a magnifying glass with a '-' sign, allowing the user to zoom out the map display. (See 3.1.6.7)

d. View Full Map: This item shall be enabled for all users. Selecting this item shall cause the entire map to be displayed in the map background portion of the screen. (See 3.1.6.7)

e. Pan: This item shall be enabled for all users. Selecting this item shall change the current cursor to the Pan cursor, identified by a small hand, allowing the user to pan the map display. (See 3.1.6.7)

f. Show Field Devices: This item shall be enabled for all users and shall be a standard "checked" style menu item (i.e. with check mark symbol) as follows:

i. If not checked, selecting this item shall cause it to be checked in the menu list and shall cause the field devices to be displayed on the map background display (See 3.1.6.8).

ii. If checked, selecting this item shall cause it to be un-checked in the menu list and shall cause the field devices to be hidden from the map background display.

R-147. The Menu Bar shall include a ‘SLR/WWP’ menu item with the following menu options:

a. Spring Load Restrictions: This item shall be enabled for all users. When selected shall display the main SLR dialog screen (See 3.1.6.8);

b. Winter Weight Premiums: This item shall be enabled for all users. When selected shall display the main WWP dialog screen (See 3.1.6.10);

R-148. The Menu Bar shall include a ‘Reports’ menu item with the following menu options:

a. Raw Data Reports: This item shall be enabled for all users. When selected shall display the reports dialog for the Raw Data Reports (See 3.1.5.1);

b. Recovery Period Report: This item shall be enabled for all users. When selected shall display the reports dialog for the Recovery Period Report (See 3.1.5.2);

c. Algorithm Reports: This item shall be enabled for all users. When selected shall display the reports dialog for the Algorithm Report (See 3.1.5.3);

d. Equipment Status Report: This item shall be enabled for all users that are either members of the “Operator” or “Engineer” user group. When selected shall display the reports dialog for the Equipment Status Reports (See 3.1.5.4);

e. User Action Report: This item shall be enabled for all users that are either members of the “Operator” or “Engineer” user group. When selected shall display the reports dialog for the User Action Report (See 3.1.5.5);

f. System Log: This item shall be enabled only for users that are members of the “Engineer” user group. When selected shall display the System Log dialog (See 3.1.5.6).

R-149. There shall be a ‘Help’ menu item that shall contain the following options:

a. About: This item shall be enabled for all users. When selected shall display a screen that contains the software revision number of the GUI application.

b. Contents: This item shall be enabled for all users. When selected shall display the help documentation for the RCWatch application (see 3.1.6.6).

3.1.6.5 Status Bar

R-150. The Status Bar shall contain a “User Name” information pane that shall display the name of the user that is currently logged in to the specific instance of the GUI application.

R-151. The Status Bar shall contain a "Map Coordinates" information pane containing the X and Y coordinates representing the current cursor position on the Map display, specified using an approved standard GIS coordinate system.

3.1.6.6 Help Documentation

The GUI will include online documentation based on the requirements listed below.

R-152. The on-line help documentation shall contain a clickable table of contents for easy navigation between topics.

R-153. The help documentation shall cover the following topics as a minimum:

a. General System Use & Navigation;

b. SLR Program Implementation;

c. WWP Program Implementation;

d. System Configuration.

R-154. The help documentation shall support hyperlinks and embedded graphics.

R-155. The help documentation shall be accessible through either the main menu bar of the GUI or at any time through the "F1" keyboard key.

3.1.6.7 Map Navigation

The Map background can be navigated in a number of different ways as detailed in the following requirements:

R-156. When the cursor type is the 'Pointer' cursor, and the map is zoomed in to a level such that the scroll bars are displayed, the user shall be able to pan the map display in both the vertical and horizontal directions by clicking and dragging the scroll bars with the left mouse button, or by clicking the arrows in the scroll bars.

R-157. When the cursor type is the 'Zoom In' cursor, the user shall have the ability to zoom the map to a finer level of detail by clicking on a location on the map background with the left mouse button and dragging the cursor across the map background while holding the mouse button down to form a rectangular shape. When the mouse button is released, the map shall be redisplayed to show the region selected by the rectangle and filling the entire map background display area.

R-158. When the cursor type is the 'Zoom Out' cursor, the user shall have the ability to zoom the map out to a more coarse level of detail by clicking on any location on the map, which shall cause the map to be redisplayed at a zoom level that is approximately 33% less than the current level and centered about the location at which the user clicked on the map background.

R-159. When the cursor type is the 'Pan' cursor, and the map is zoomed in to a level such that the scroll bars are displayed, the user shall be able to pan the map display in any direction by clicking and dragging the map background with the left mouse button.

3.1.6.8 GIS Map Content

The main view of the RCWatch GUI will be a GIS Map display conforming to the following requirements.

Roadway Representation

R-160. The map background shall be GIS based and shall have a geographical extent that covers all major roadways managed by the operating agency.

R-161. The map shall be oriented on the screen such that north is towards the top of the screen.

R-162. As a minimum, the map shall display all major highways and limited access roadways managed by the operating agency and subject to either or both the SLR or WWP programs.

a. Each major highway and limited access roadway shall be displayed with highway shield icon overlays spaced at regular intervals that clearly identify the roadway by number (e.g. 401);

b. The two directions of the roadways shall be clearly delineated;

c. If other roadways are displayed on the map background they shall be easily distinguished from the major highways and limited access roadways by some feature such as colour.

R-163. It shall be possible to configure roadway segments that are each assigned a unique name.

SLR and WWP Program Indicators

R-164. The GUI shall display a unique indicator (distinguished by colour) on the map background for each of the following program scenarios, as indicated by the state of the program stored in the system database (See R-106):

a. System determined SLR Implementation or Advance Warning prior to user acceptance;

b. System determined SLR Termination or Advance Warning prior to user acceptance;

c. System determined WWP Implementation or Advance Warning prior to user acceptance;

d. System determined WWP Termination or Advance Warning prior to user acceptance;

e. Accepted SLR Implementation or Advance Warning;

f. Accepted WWP Implementation or Advance Warning;

R-165. Program indicator lines shall be drawn as follows:

a. Each indicator line shall be drawn with a suitable thickness (20-50 pixels for example) such that it is clearly distinguishable on the map display;

b. Each indicator line shall be offset by a suitable distance (20-50 pixels for example) from the roadway segment and shall extend the full length of the roadway segment;

c. Each indicator line shall be terminated at each of its ends with a flag symbol that contains the letters “SLR” for an SLR warning or implementation or “WWP” for a WWP implementation.

R-166. It shall be possible to click the flags of a particular indicator line with the left mouse button to view the specific details of the program. (See 3.1.6.11)

R-167. The GUI shall ensure that all roadway segments are shown with appropriate indicator lines based upon the most current program record in the database for the roadway segment.

a. Indicator lines shall be drawn or removed from the map background in accordance with the program records for each roadway segment within 5 seconds following any change to said program records.

Roadway Popup Menu

R-168. It shall be possible to click on a roadway with the left mouse button to display a popup style menu that clearly lists the roadway number and segment name (if configured) and provides the following options, based upon the program state of the roadway:

a. If there is no roadway segment defined for this section of roadway, there shall not be any menu options presented to the user.

b. If a roadway segment has been define for this section of roadway and there are no current programs or warnings in effect for the segment (i.e. there is no indicator line currently displayed), the following options shall be presented to the user:

i. Implement SLR Warning
ii. Implement SLR
iii. Implement WWP Warning
iv. Implement WWP

c. System determined SLR Implementation Advance Warning for roadway segment prior to user acceptance:

i. Accept SLR Implementation Warning
ii. Reject SLR Implementation Warning
iii. View SLR Implementation Advanced Warning Details

d. System determined SLR Implementation for roadway segment prior to user acceptance:

i. Accept SLR Implementation
ii. Reject SLR Implementation
iii. View SLR Implementation Details

e. System determined SLR Termination Advance Warning for roadway segment prior to user acceptance:

    i. Accept SLR Termination Warning
    ii. Reject SLR Termination Warning
    iii. View SLR Termination Advanced Warning Details

f. System determined SLR Termination for roadway segment prior to user acceptance:

    i. Accept SLR Termination
    ii. Reject SLR Termination
    iii. View SLR Termination Details

g. Accepted SLR Implementation Warning for the roadway segment:

    i. Implement SLR
    ii. View SLR Implementation Warning Details

h. Accepted SLR Implementation for the roadway segment:

    i. Terminate SLR
    ii. View SLR Details

i. Accepted SLR Termination Warning for the roadway segment:

    i. Termination SLR
    ii. View SLR Termination Warning Details

j. System determined WWP Implementation Advance Warning for roadway segment prior to user acceptance:

    i. Accept WWP Implementation Warning
    ii. Reject WWP Implementation Warning
    iii. View WWP Implementation Advanced Warning Details

k. System determined WWP Implementation for roadway segment prior to user acceptance:

    i. Accept WWP Implementation
    ii. Reject WWP Implementation
    iii. View WWP Implementation Details

l. System determined WWP Termination Advance Warning for roadway segment prior to user acceptance:

    i. Accept WWP Termination Warning
    ii. Reject WWP Termination Warning
    iii. View WWP Termination Advanced Warning Details

m. System determined WWP Termination for roadway segment prior to user acceptance:

    i. Accept WWP Termination
    ii. Reject WWP Termination
    iii. View WWP Termination Details

n. Accepted WWP Implementation Warning for the roadway segment:

    i. Implement WWP
    ii. View WWP Implementation Warning Details

o. Accepted WWP Implementation for the roadway segment:

    i. Terminate WWP
    ii. View WWP Details

p. Accepted WWP Termination Warning for the roadway segment:

    i. Termination WWP
    ii. View WWP Termination Warning Details

Equipment Indicators

The various field devices that are deployed for the collection of weather data will be displayed on the map background and will be selectable by the user to display detailed information regarding the operational status of the equipment and values of the weather data collected.

R-169. Each location in the field for which there is equipment installed for the collection of weather data shall be represented on the map display by an icon symbolizing a microcontroller or similar computing device.

R-170. The field equipment icons shall be displayed or hidden in accordance with the "Show Field Devices" menu option state (i.e. checked or un-checked). See 3.1.6.4.

a. All field equipment icons shall be displayed on the map in their geographically correct location.

R-171. Each equipment icon shall be drawn with the following dominant colour:

a. GREEN: when the equipment is operating properly.

b. RED: when the equipment is reporting one or more error conditions or can not be communicated with by RCWatch.

R-172. Each equipment icon shall display standard "hover text" whenever the mouse cursor is placed over the icon.

a. The hover text displayed shall be a user configurable string as part of the equipment configuration record in the RCWatch database.

R-173. It shall be possible to click on an equipment icon to display a popup menu with the following options:

a. Show Equipment Details: when this item is selected, a screen shall be displayed that contains the details of the equipment located at the specific field site, including the following as a minimum:

   i. A unique identifier for the equipment site;
   ii. A list of all field devices located at the site, complete with unique equipment identifier and description of the equipment (i.e. purpose, measurement capabilities, etc.);
   iii. The operational state of each piece of equipment, to be one of OK or FAILED as a minimum;
   iv. For any FAILED piece of equipment, details (if known) pertaining to the failure (e.g. "Device is not communicating with RCWatch");
   v. The date and time at which the current operational state was last set;
   vi. As long as the equipment details window is open, the operational state of each piece of equipment shall be updated automatically whenever its state changes.

b. Show Data: when this item is selected, a screen shall be displayed that contains the current data values collected from the various equipment at that location.

   i. Each data value shall be displayed with appropriate heading describing the type of data (i.e. Pavement Temperature, Solar Radiation, etc.).
   ii. Each data value shall be displayed with appropriate units of measure.
   iii. Each data value shall be displayed with the date and time at which the data value was collected from the field equipment.
   iv. As long as the data window is open, each data value shall be updated automatically when new data is received from the field equipment.

R-174. Each Equipment Details and Data window displayed on the map background shall be connected to their associated field equipment icon with a black line.

R-175. It shall be possible to leave multiple Equipment Details and Data windows open on the map background.

a. Each window shall have a "Close" button to close the window.

b. It shall be possible to drag and drop each window to a new location on the map.

R-176. When the map background is panned or zoomed, all open Equipment Details and Data windows shall be redrawn such that they maintain the same relative position to their associated field equipment icon.

3.1.6.9 SLR Dialog

The SLR Dialog screen provides an interface for the user to monitor, create and terminate SLR programs for the various roadway segments configured within RCWatch. The screen can be accessed through the main menu of RCWatch.

R-177. The SLR Dialog shall contain scrollable tabular list of all SLR database records with the following columns of information as a minimum:

a. Date and time of last update for the database record;

b. Roadway segment;

c. SLR program details, to be: “SLR Implementation Advance Warning”, “SLR Implemented”, “SLR Termination Advance Warning” or “SLR Terminated”;

d. Source, to be one of “User” for user created programs or “Algorithm” for system recommended programs;

e. User Acceptance, to be one of “Accepted” for programs created by a user or recommended by an algorithm and subsequently accepted by a user, “Rejected” for programs recommended by an algorithm and subsequently accepted by a user, or “None” for programs recommended by an algorithm and not yet accepted nor rejected by a user;

f. User Name, to be the name of the user that created, accepted or rejected the program, or to be blank for algorithm detected programs that have yet to be accepted or rejected;

R-178. It shall be possible to sort the list of SLR programs by any of its information columns in both ascending and descending order.

R-179. The default sorting for the list shall be:

a. Descending by date and time;

b. For all records with the same date and time, ascending by roadway segment;

c. For all records with the same date and time and roadway segment, ascending by SLR program;

R-180. It shall be possible to filter the list of SLR programs using one or more of the following filters:

a. Date Range: shall allow the list to be filtered such that only those programs that have an update date/time within the data range are shown. The default range for this filter shall be from the oldest date for which there is a database record to the current date;

b. Roadway Segment: shall allow the list to be filtered such that only those programs that correspond to the selected roadway segment(s) are shown. The default option for the filter shall be to show all roadway segments.

c. SLR State: shall allow the list to be filtered to show either “All SLR Program States”, “SLR Implementation Advance Warning Only”, “SLR Implementation Only”, “SLR Termination Advance Warning Only” or “SLR Termination Only” states. The default selection for this filter shall be “All SLR Program States”;

d. User Acceptance: shall allow the list to be filtered to show either “All”, “Accepted Only”, “Rejected Only” or “None Only” user acceptance states. The default selection for this filter shall be “All”;

R-181. All rows that contain a record with a user acceptance state of “None” shall be displayed in a different colour from that of the other records (e.g. Red text).

R-182. It shall be possible for the user to select a record in the SLR programs list with the mouse.

a. When a record is selected, it shall be highlighted.

R-183. The SLR dialog screen shall include the following buttons and functionality:

a. Close: this button shall always be enabled and shall close the dialog screen when selected;

b. Details: this button shall only be enabled whenever there is a highlighted (selected) record in the list and shall display details of the record when selected (see 3.1.6.11);

c. Accept: this button shall only be enabled when there is a highlighted (selected) record in the list that corresponds to an algorithm recommendation that has not yet been accepted or rejected and shall result in the record being accepted when selected (see 3.1.6.12);

d. Reject: this button shall only be enabled when there is a highlighted (selected) record in the list that corresponds to an algorithm recommendation that has not yet been accepted or rejected and shall result in the record being rejected when selected (see 3.1.6.13);

e. Terminate: this button shall only be enabled when there is a highlighted (selected) record in the list that corresponds to an accepted SLR Implementation program or SLR Termination Advanced Warning and shall result in the record being terminated when selected (see 3.1.6.14);

f. Create: this button shall always be enabled and shall allow the user to create a new program entry (see 3.1.6.15);

3.1.6.10 WWP Dialog

The WWP Dialog screen provides an interface for the user to monitor, create and terminate WWP programs for the various roadway segments configured within RCWatch. The screen can be accessed through the main menu of RCWatch.

R-184. The WWP Dialog shall contain scrollable tabular list of all WWP database records with the following columns of information as a minimum:

a. Date and time of last update for the database record;

b. Roadway segment;

c. WWP program details, to be: “WWP Implementation Advance Warning”, “WWP Implemented”, “WWP Termination Advance Warning” or “WWP Terminated”;

d. Source, to be one of “User” for user created programs or “Algorithm” for system recommended programs;

e. User Acceptance, to be one of “Accepted” for programs created by a user or recommended by an algorithm and subsequently accepted by a user, “Rejected” for programs recommended by an algorithm and subsequently accepted by a user, or “None” for programs recommended by an algorithm and not yet accepted nor rejected by a user;

f. User Name, to be the name of the user that created, accepted or rejected the program, or to be blank for algorithm detected programs that have yet to be accepted or rejected;

R-185. It shall be possible to sort the list of WWP programs by any of its information columns in both ascending and descending order.

R-186. The default sorting for the list shall be:

a. Descending by date and time;

b. For all records with the same date and time, ascending by roadway segment, and;

R-187. It shall be possible to filter the list of WWP programs using one or more of the following filters:

a. Date Range: shall allow the list to be filtered such that only those programs that have an update date/time within the data range are shown. The default range for this filter shall be from the oldest date for which there is a database record to the current date;

b. Roadway Segment: shall allow the list to be filtered such that only those programs that correspond to the selected roadway segment(s) are shown. The default option for the filter shall be to show all roadway segments.

c. WWP State: shall allow the list to be filtered to show either “All WWP Program States”, “WWP Implementation Advance Warning Only”, “WWP Implementation Only”, “WWP Termination Advance Warning Only” or “WWP Termination Only” states. The default selection for this filter shall be “All WWP Program States”;

d. User Acceptance: shall allow list to be filtered to show either “All”, “Accepted Only”, “Rejected Only” or “None Only” user acceptance states. The default selection for this filter shall be “All”;

R-188. All rows that contain a record with a user acceptance state of “None” shall be displayed in a different colour from that of the other records (e.g. Red text).

R-189. It shall be possible for the user to select a record in the WWP programs list with the mouse.

a. When a record is selected, it shall be highlighted.

R-190. The WWP dialog screen shall include the following buttons and functionality:

a. Close: this button shall always be enabled and shall close the dialog screen when selected;

b. Details: this button shall only be enabled whenever there is a highlighted (selected) record in the list and shall display details of the record when selected (see 3.1.6.11);

c. Accept: this button shall only be enabled when there is a highlighted (selected) record in the list that corresponds to an algorithm recommendation that has not yet been accepted or rejected and shall result in the record being accepted when selected (see 3.1.6.12);

d. Reject: this button shall only be enabled when there is a highlighted (selected) record in the list that corresponds to an algorithm recommendation that has not yet been accepted or rejected and shall result in the record being rejected when selected (see 3.1.6.13);

e. Terminate: this button shall only be enabled when there is a highlighted (selected) record in the list that corresponds to an accepted WWP Implementation program or WWP Termination Advanced Warning and shall result in the record being terminated when selected (see 3.1.6.14);

f. Create: this button shall always be enabled and shall allow the user to create a new program entry (see 3.1.6.15);

3.1.6.11 Program Details Screen

The Program Details screen provides the user with a complete record of a particular SLR or WWP program.

R-191. The screen can be accessed from the roadway segment pop-up menus, SLR and WWP program indicator flags drawn on the map, and through the “Details” button of the SLR or WWP Dialog screens.

R-192. The content of the screen shall reflect the method by which the screen is displayed as follows:

a. If accessed from a roadway pop-up menu, it will reflect the current program associated with that roadway segment;

b. If accessed from an SLR or WWP indicator flag, it will reflect the SLR or WWP program associated with the flag;

c. If accessed from the SLR or WWP Dialog screen, it will reflect the current program highlighted in the list of that screen.

R-193. The content of the screen shall include all information stored in the database for the corresponding program record, including any free form notes associated with the record.

R-194. It shall be possible for the user to edit and save the free form notes associated with the record from this screen.

R-195. The dialog shall include the following buttons:

a. Accept: this button shall only be active for programs recommended by the system that have yet to be accepted or rejected by the user. (See 3.1.6.12);

b. Reject: this button shall only be active for programs recommended by the system that have yet to be accepted or rejected by the user. (See 3.1.6.13);

c. Terminate: this button shall only be active for programs created by or accepted by the user. (See 3.1.6.14);

3.1.6.12 Program Acceptance

The Program Acceptance dialog allows the user to accept a system recommended program.

R-196. Acceptance of a system recommended program shall be performed through the Program Details screen (See 3.1.6.11).

R-197. When the user accepts a system recommended program, the database record for the program shall be updated as follows:

a. User acceptance field shall be set to ACCEPTED;

b. Date and time program is accepted/rejected field shall be set equal to the current date and time;

c. Name of user accepting the program shall be set equal to name of user invoking the program acceptance dialog.

3.1.6.13 Program Rejection

The Program Rejection dialog allows the user to reject a system recommended program.

R-198. Rejection of a system recommended program shall be performed through the Program Details screen (See 3.1.6.11).

R-199. When the user rejects a system recommended program, the database record for the program shall be updated as follows:

a. User acceptance field shall be set to REJECTED;

b. Date and time program is accepted/rejected field shall be set equal to the current date and time;

c. Name of user rejecting the program shall be set equal to name of user invoking the program rejection dialog.

3.1.6.14 Program Termination

The Program Termination dialog allows the user to terminate an active program.

R-200. Termination of an active program shall be performed through the Program Details screen (See 3.1.6.11).

R-201. When a user terminates an active program, a corresponding program record shall be created in the database as follows :

a. Date and time of program details: the date and time the program was terminated.

b. The program state: either SLR Termination or WWP Termination accordingly;

c. The roadway segment associated with the program state;

d. The initial source of the program state set to USER;

e. The following additional USER information:

i. User name set equal to name of user invoking the program termination dialog.

f. User acceptance field: ***not relevant***;

g. Date and time program is accepted/rejected and name of user: ***not relevant***;

3.1.6.15 Program Creation

The Program Creation dialog allows the user to create an active program.

R-202. The screen can be accessed from the roadway segment pop-up menus and through the “Details” button of the SLR or WWP Dialog screens.

R-203. The screen shall contain the following fields of information that may be selected or entered by the user:

a. Date and time field allowing user to enter date/time at which program is to start;

b. Program Type selector allowing user to chose from one of SLR Advance Warning, SLR or WWP;

c. Roadway Segment selector allowing user to chose from one or more of the configured roadways within RCWatch;

d. Free form notes. (e.g. for an SLR Advance Warning, the user may enter notes regarding the expected start date of the actual SLR implementation).

R-204. The initial content of the screen shall reflect the method by which the screen was displayed as follows:

a. If accessed from a roadway pop-up menu “Implement SLR Warning”, the Program Type shall be selected as “SLR Advance Warning” and the roadway segment shall be selected as the roadway segment associated with the pop-up menu;

b. If accessed from a roadway pop-up menu “Implement SLR”, the Program Type shall be selected as “SLR” and the roadway segment shall be selected as the roadway segment associated with the pop-up menu;

c. If accessed from a roadway pop-up menu “Implement WWP”, the Program Type shall be selected as “WWP” and the roadway segment shall be selected as the roadway segment associated with the pop-up menu;

d. If accessed from the SLR Dialog screen, the Program Type shall be selected as “SLR”;

e. If accessed from the WWP Dialog screen, the Program Type shall be selected as “WWP”

R-205. When a user creates a program, a corresponding program record shall be created in the database for each impacted roadway segment as follows :

a. Date and time of program details: the date and time the program was created.

b. The program state: either SLR Advance Warning, SLR Implementation or WWP Implementation accordingly;

c. The roadway segment associated with the program state;

d. The initial source of the program state set to USER;

e. The following additional USER information:

   i. User name set equal to name of user invoking the program creation dialog.

f. User acceptance field: ***not relevant***;

g. Date and time program is accepted/rejected and name of user: ***not relevant***;

3.1.7 INFORMATION DISSEMINATION

The Information Dissemination (ID) function provides capabilities to send information to selected external agencies and users through various dissemination technologies.

3.1.7.1 External Users/Agencies

R-206. The ID function shall allow for external users/agencies to subscribe to one or more of the information services supported by RCWatch.

a. Each external user/agency shall be identified by a unique name;

b. Each external user/agency requiring services of the ID function shall be associated with one or more of the following technologies:

   i. E-Mail
   ii. Facsimile

c. For each external user and each service subscribed to, it shall be possible to configure the desired information content for dissemination to that user via the specific service as follows:

   i. SLR Implementation & Termination Advance Warnings
   ii. SLR Implementation & Termination
   iii. WWP Implementation & Termination Advance Warnings
   iv. WWP Implementation & Termination

R-207. The e-Mail service shall use the SMTP mail protocol (or approved equivalent) for the dissemination of information to e-mail subscribers.

R-208. The facsimile service shall utilize an approved 3rd party fax software application (e.g. ZetaFax) for the dissemination of information to facsimile subscribers.

R-209. When the RCWatch user creates or accepts a system recommended implementation of an SLR or WWP Implementation or Termination Advance Warning, the ID function shall send an e-mail to all e-mail subscribers and a facsimile to all facsimile subscribers configured to receive these notifications containing the following minimum pieces of information:

a. Statement of program warning. Example: “Spring Load Restrictions Implementation Advanced Warning issued on MM/DD/YYYY”;

b. Statement identifying the roadway(s) or roadways segment(s) associated with the warning. Example: “The following roadways are impacted: …”.

R-210. When an RCWatch user creates or accepts a system recommended implementation of an SLR or WWP program, the ID function shall send an e-mail to all e-mail subscribers and a facsimile to all facsimile subscribers that are configured for such notifications containing the following minimum pieces of information:

a. Statement of program implementation. Example: “Spring Load Restrictions Implemented on MM/DD/YYYY”;

b. Statement identifying the roadway(s) or roadways segment(s) associated with the SLR or WWP program. Example: “The following roadways are impacted: …”;

c. Any free form notes that were entered by the operator and stored as part of the event record in the database.

R-211. When an RCWatch user terminates or accepts a system recommended termination of an SLR or WWP program, the ID function shall send an e-mail to all e-mail subscribers and a facsimile to all facsimile subscribers that are configured for such notifications containing the following minimum pieces of information:

a. Statement of program termination. Example: “Spring Load Restrictions Implemented on MM/DD/YYYY have been Terminated as of MM/DD/YYYY”;

b. Statement identifying the roadway(s) or roadways segment(s) associated with the SLR or WWP program. Example: “The following roadways are impacted: …”.

c. Any free form notes that were entered by the operator and stored as part of the event record in the database.

3.1.7.2 External Systems

External systems comprise other stand-alone information and traffic management systems (e.g. 511, Interactive Voice Response, and Advanced Traffic Management) that may benefit from the knowledge of SLR and WWP implementations. Furthermore, these external systems may use their own dissemination technologies to present this information to a larger group of users. For example, an agency operating an advanced traffic management system may benefit from the raw weather data (e.g. pavement temperatures) collected from RCWatch or may be asked to assist the RCWatch operator by posting messages on their dynamic message signs such as “Spring Load Restrictions Apply” or similar.

R-212. The ID function shall offer a “publish/subscribe” service allowing external systems to receive specific data from RCWatch.

R-213. The publish/subscribe service shall utilize standard Internet protocols for communications with external systems and shall use an XML (extensible mark-up language) schema for messaging content.

R-214. The publish/subscribe service shall include a security mechanism for authenticating subscription requests from external systems.

a. All external systems must supply appropriate credentials, including an assigned username and password as a minimum, before a subscription to data is granted by RCWatch.

R-215. The following information shall be published by the ID function as a minimum:

a. SLR Advanced Warning Notifications (Implementation and Termination);

b. SLR Implementation & Termination Notifications;

c. WWP Implementation & Termination Notifications;

d. WWP Advanced Warning Notifications (Implementation and Termination);

e. Weather Data Summaries.

R-216. All subscribers of SLR or WWP Advanced Warning notifications shall have the following minimum data pushed to them whenever an SLR or WWP Advanced Warning is triggered for a roadway:

a. SLR or WWP Advanced Warning notification (e.g. SLR Implementation Warning);

b. Date of warning;

c. List of effected roadways;

R-217. All subscribers of SLR or WWP implementation notifications shall have the following minimum data pushed to them whenever an SLR or WWP program is implemented by an RCWatch operator:

a. SLR or WWP Implementation notification;

b. Date of implementation;

c. List of effected roadways;

R-218. All subscribers of SLR or WWP termination notifications shall have the following minimum data pushed to them whenever an SLR or WWP program is terminated by an RCWatch operator:

a. SLR or WWP Termination notification;

b. Date of original implementation;

c. Date of termination;

d. List of effected roadways;

R-219. Subscribers for Weather Data Summaries shall be allowed to subscribe to one or more of the following weather data items:

a. Raw Air Temperature

b. Hourly Averaged Air Temperature

c. Daily Averaged Air Temperature

d. Raw Pavement Temperature

e. Hourly Averaged Pavement Temperature

f. Daily Averaged Pavement Temperature

g. Raw Strain Data

h. Raw Roadway Displacement

i. Raw Moisture Content Data

j. Raw Solar Radiation

k. Raw Frost Depth Data

l. Daily Averaged Frost Depth Data

m. Raw Thaw Depth Data

n. Daily Averaged Thaw Depth Data

R-220. The ID function shall push weather data to subscribers of weather data items whenever the specific weather data item becomes available within RCWatch.

R-221. All weather data item messages shall contain a minimum of the following information:

a. Datum tag (e.g. "Hourly Averaged Pavement Temperature");

b. Datum timestamp: the date and time at which the data was collected or computed;

c. Datum list: a list of data values and geographical location pairs. The geographical location shall be specified in an approved standard GIS representation.

3.1.8 CONFIGURATION

R-222. The Configuration function shall provide all necessary dialog screens allowing the user to view and modify all configurable system parameters, including but not limited to the following parameter groups:

a. Roadways

b. Roadway segments

c. Field sensors and all associated communication parameters

d. Sensor/Roadway Segment mapping

e. Sensor polling rates

f. Sensor data validation parameters

g. Strain/Temperature correlation tables

h. User database and access levels

i. Thaw Index calculation thresholds and parameters

j. Algorithm Definition tables

k. Algorithm Schedule tables

l. Algorithm Parameters

m. Information Dissemination Subscriber database

R-223. The Configuration function shall ensure that only valid values for each particular parameter may be entered by the user.

R-224. The Configuration function shall log all parameter changes to the database with the following minimum information:

a. Data and time of change;

b. Parameter identifier;

c. User name that performed the change;

d. Previous value(s) of the parameter;

e. New value(s) of the parameter;

3.2 Performance & Other Requirements

R-225. The RCWatch GUI shall be capable of running on a minimum of 5 operator workstations simultaneously, providing a level of response that is no worse than 90% of the response realized by an operator with a single instance of the RCWatch GUI running.

R-226. The RCWatch application software shall be available 24 hours per day, 365 days per year, subject to the availability and/or periodic maintenance of the various hardware components on which the software executes.