Software Requirements Specification for Bridge Corrosion: A Chloride Exposure Prediction Model

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Contents

Revision History

Date	Version	Notes
Jan 27, 2024	1.0	Initial release
Feb 23, 2024	2.0	Add more details according to feedback from peer review

1 Reference Material

This section records information for easy reference.

1.1 Table of Units

Throughout this document SI (Système International d'Unités) is employed as the unit system. In addition to the basic units, several derived units are used as described below. For each unit, the symbol is given followed by a description of the unit and the SI name.

symbol	unit	SI
m	length	metre
mile	distance	mile
kg	mass	kilogram
t	mass	tonne
s	time	second
h	time	hour

1.2 Table of Symbols

The table that follows summarizes the symbols used in this document along with their units. The choice of symbols was made to be consistent with the heat transfer literature and with existing documentation for solar water heating systems. The symbols are listed in alphabetical order.

symbol	**unit**	**description**
a_{splash}	kg/m^3	maximum deposition rate occur from splash
a_{spray}	kg/m^3	maximum deposition rate occur from spray
a_{air}	kg/m^3	maximum deposition rate
b_{splash}	N/A	splash emission rate coefficient
b_{spray}	N/A	spray emission rate coefficient
C_s	$kg/m^3/vehicle$	chloride on the bridge substructure
$C_{s_{air}}$	$kg/m^3/vehicle$	chloride sprayed and splashed per unit air volume per vehicle
δ_{salt}	N/A	ratio of salt over water per unit area of road
d	m	distance between road edge and nearby bridge structure
h_{app}	m	daily water film thickness on the road
h_{film}	m	depth of the water film picked up in each rotation
h_{total}	m	the total snowfall during a winter season
I	m/h	rainfall intensity
K	N/A	ratio of the tire width that is not a groove to the tire width
L	m	drainage length
M_{app}	kg/m^2	deicing salts quantity applied per day
M_{total}	kg/m^2	total amount of deicing salts quantity over winter
MR_{BW}	kg/s	MFR displaced by a single tire due to bow
MR_{CA}	kg/s	MFR displaced by a single tire due to capillary adhesion
MR_{SW}	kg/s	MFR displaced by a single tire due to side waves
MR_{TP}	kg/s	MFR displaced by a single tire due to tread pickup
MR_W	kg/s	general MFR displaced by a single tire due to capillary adhesion
N_{lane}	lane	number of lanes
ρ_{water}	kg/m^3	density of water
SD_{BW}	$kg/m^3/vehicle$	spray density by a single tire due to bow
SD_{CA}	$kg/m^3/vehicle$	spray density by a single tire due to capillary adhesion
SD_{SW}	$kg/m^3/vehicle$	spray density by a single tire due to side waves
SD_{TP}	$kg/m^3/vehicle$	spray density by a single tire due to tread pickup
SD_{total}	$kg/m^3/vehicle$	spray density kicked up by each passing truck
$SD_{total\ cl}$	$kg/m^3/vehicle$	mass of chloride ions per unit air volume
S	N/A	slope as a ratio
T	mm	profile depth
t_1	days	number of days with snowfall

t_2	days	number of days with snow melting
t_{snow}	days	number of days with snow
V	m/s	truck speed
V_{salt}	$t/cm/km$	normalized salt application rate
V_{speed}	km/h	heavy vehicle speed
V'	$miles/h$	heavy vehicle speed
W_{lane}	m	lane width
WD	m	water depth/thickness
x	m	distance between road and object surface
Θ	N/A	ratio of chloride ions sprayed and splashed by trucks over those by light duty vehicles
$\theta_{chloride}$	N/A	molar mass ratio of chloride ions over deicing salts

1.3 Abbreviations and Acronyms

symbol	description
A	Assumption
DD	Data Definition
GD	General Definition
GS	Goal Statement
IM	Instance Model
LC	Likely Change
PS	Physical System Description
R	Requirement
SRS	Software Requirements Specification
BC	Bridge Corrosion
TM	Theoretical Model
NaCl	Sodium Chloride, the main component of deicing salts
CA	Capillary Adhesion
TP	Tread Pickup
BW	Bow Waves
SW	Side Waves
MFR	Mass Flow Rate
ADT	Average Daily Traffic
AADT	Annual Average Daily Traffic
AADTT	Annual Average Daily Truck Traffic

1.4 Mathematical Notation

symbol	description
$\mathbb{R}$	Real number
$\{\mathbb{R}\}$	a set of real number

2 Introduction

In Ontario, most of the bridges in highway are made of reinforced concrete (RC) decks. However, the bridges may face the chloride-induced corrosion which damage its surface. There are many elements influencing this situation, one of the most important one is the deicing salts. The primary used is sodium chloride (rock salt),when they melt the snow and in contact with water, they could have a chemical reaction and release the chloride ions. Those chloride could penetrate the concrete and induce corrosion in the reinforcing steel, then damage the bridges' structure and capacity.
There is a tight connection between chloride exposure, weather conditions and traffic flow. Specifically, the amount of deicing salts applied on the road surface greatly depends on the amount of snowfall, and the amount of water and dissolved chloride ions that end up on nearby objects depends on the traffic patterns. This section outlines the document's purpose, delineates its scope of requirements, describes the intended audience's characteristics, and provides an overview of the document's organization.

2.1 Purpose of Document

This document details the requirements of the software Bridge Corrosion. The responsibilities of the user and software are laid out and the requirements that the software must satisfy are explicitly detailed. This document provides the software requirements specification (SRS) for a project to investigate how the climate and traffic could have impact on the corrosion-induced damage for the reinforced concrete, or to be more specific, how they influence the chloride exposure.

2.2 Scope of Requirements

The entire document is written as the chloride is the main source of corrosion damage to the reinforced concrete, and chloride ions are transported from the road to the exterior surface of bridge substructures through vehicle spray and splash mechanisms. Another scope of the document is the factors that affect bridge corrosion is limit to chloride levels, climatic conditions, and traffic patterns.

2.3 Characteristics of Intended Reader

Readers of this documentation are expected to have a understanding of high school mathematics and chemistry, and the ability to comprehend basic results generated through computational fluid dynamics. The users of Bridge Corrosion may exhibit diverse levels of expertise, as further detailed in Section 3.2.

2.4 Organization of Document

The organization of this document follows the template for an SRS for scientific computing software proposed by Smith et al. [1, 2, 3]. Starting with the reference material including units, symbols and abbreviations, this document next introduce the system that we are going to build from general to specific, including the problem, goal, assumptions, theoretical model and instance models. It also talks about the functional and nonfunctional requirements for this project, which could be referred to in process of development.

3 General System Description

This section provides general information about the system. It identifies the interfaces between the system and its environment, describes the user characteristics and lists the system constraints.

3.1 System Context

Figure 1 shows the system context of the software. The user should input a coordinates to the software, and the software will return the predicted chloride exposure in the past and future to the user. The user and the software also assume the following responsibilities.

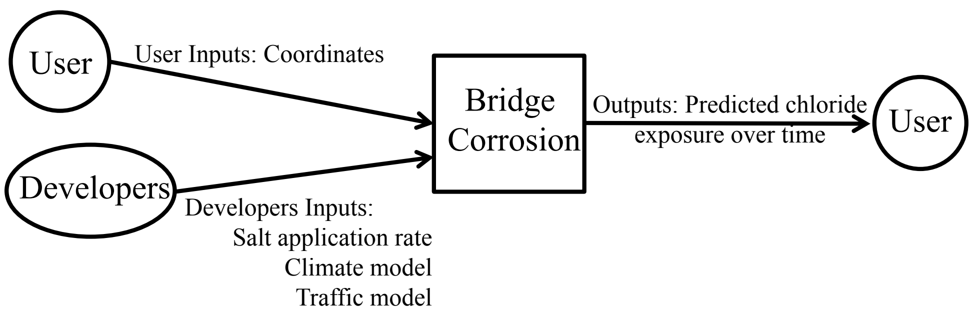


Figure 1: System Context

- User Responsibilities:
  - Provide valid coordinates to the software.
- Bridge Corrosion Responsibilities:
  - Build a database storing the chloride exposure data for every 25 km in the past and future.
  - Search and return the chloride exposure trend at given input coordinate.
  - Provide visualization of the output, such as histograms, line graphs, or grids displaying the data.

3.2 User Characteristics

The end user of Bridge Corrosion should have the basic understanding of geographic coordinates. Additionally, users may benefit from some knowledge of bridge construction or civil engineering principles to better understand the context and implications of the predicted chloride exposure.

3.3 System Constraints

The software must be able to provide output for coordinates inside Ontario.

4 Specific System Description

This section first presents the problem description, which gives a high-level view of the problem to be solved. This is followed by the solution characteristics specification, which presents the assumptions, theories, definitions and finally the instance models.

4.1 Problem Description

This project is intended to investigate how climate, traffic might impact corrosion-induced damage for reinforced concrete bridges by influencing the chloride exposure.

4.1.1 Terminology and Definitions

This subsection provides a list of terms that are used in the subsequent sections and their meaning, with the purpose of reducing ambiguity and making it easier to correctly understand the requirements:

- Mass flow rate: The amount of water displaced by a single tire.
- Spray density: Spray density is the measure of how closely packed the droplets or particles are within the spray plume. It quantifies the amount of material dispersed per unit area. In this document, it is referred to the density of water in the air (mass of water per unit air volume) in the environment.
- Airborne deposition: The process of particles moving from the atmosphere to the earth's surface.
- Deposition rate: The rate at which a substance is deposited onto a surface over a specific period of time.

4.1.2 Physical System Description

The key physical system of Bridge Corrosion, as shown in Figure 2, simulate the situation that a vehicle spray and splash the water, it includes the following elements:

PS1: Capillary adhesion: The absorption of water (present on the road surface) by the tires through surface tension.

PS2: Tread pickup: Water within the grooves of a tire being sprayed and splashed behind the tire by turbulent flow in the grooves.

PS3: Bow wave: Water sent towards the front of the tire because of the physical displacement of water from the road surface due to the vehicle tires.

PS4: Side wave: Water sent in the direction perpendicular to the traffic because of the physical displacement of water from the road surface due to the vehicle tires.

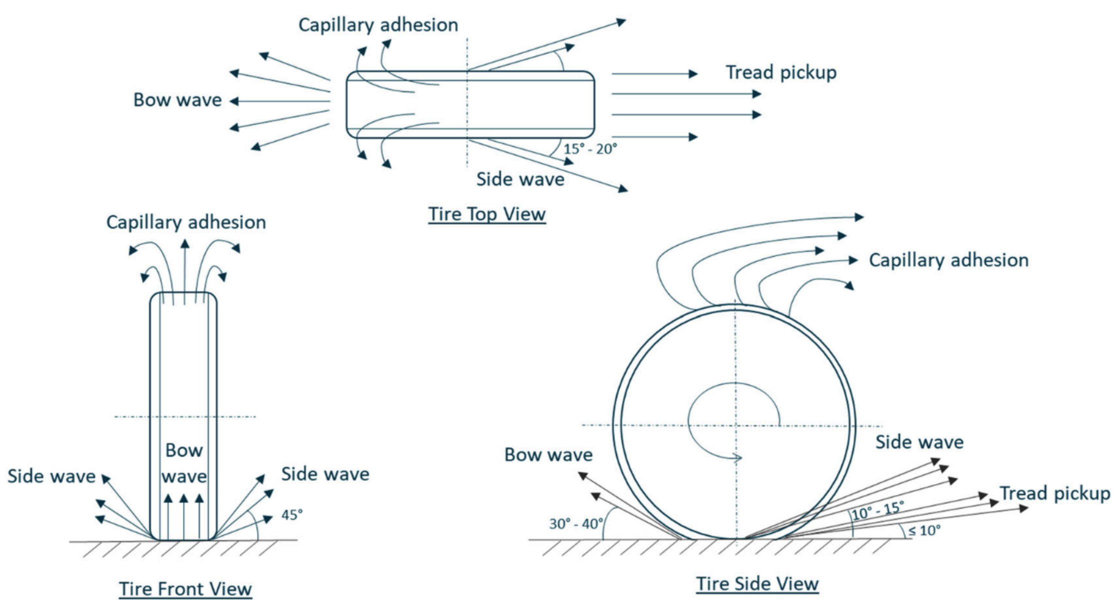


Figure 2: Mechanisms of vehicle spray and splash

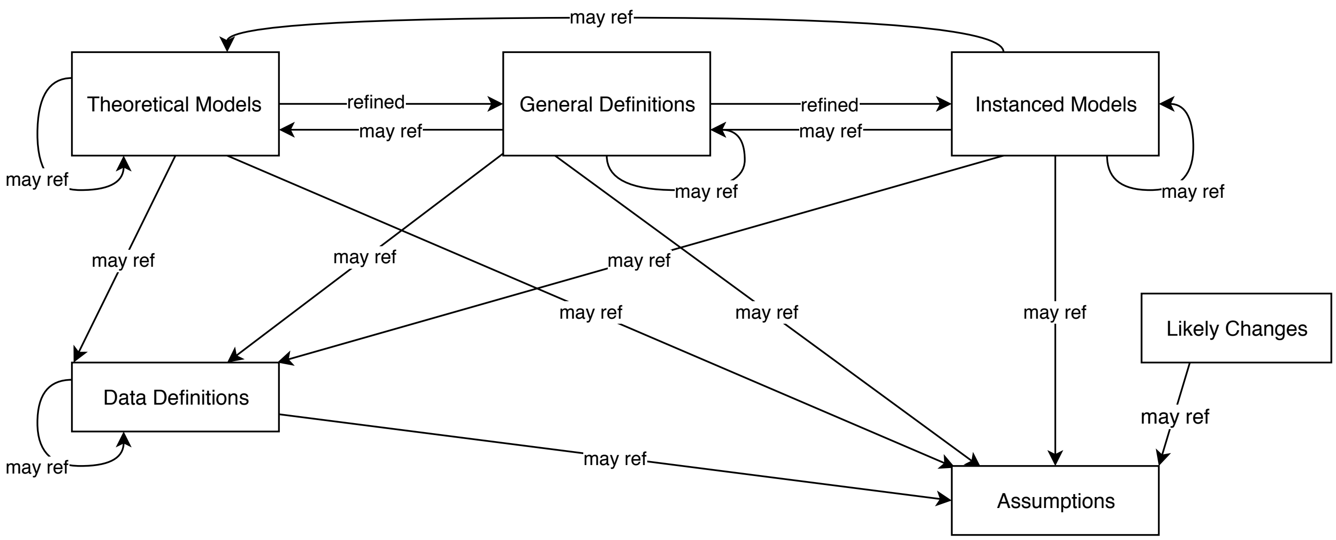
4.1.3 Goal Statements

Given the salt application data, climate data and traffic data across different regions and time period , the goal statements are:

GS1: Predict the chloride exposure for bridges in Ontario in the past and future.

GS2: Allow user to input coordinate and return the prediction for that location.

4.2 Solution Characteristics Specification



The instance models that govern this project are presented in Subsection 4.4.5. The information to understand the meaning of the instance models and their derivation is also presented, so that the instance models can be verified.

4.2.1 Types

Input:

- User input:
  - longitude = $\mathbb{R}$
  - latitude = $\mathbb{R}$
- Dataset input:
  - climate model
    - annual snowfall $h_{total} = \mathbb{R}^{+}$

    - ∗ annual number of days with snowfall $t_1 = \mathbb{R}^+$
    - ∗ annual number of days with snow melting$t_2 = \mathbb{R}^+$
  - traffic model
    - ∗ AADT per lane $AADT = \mathbb{R}^+$
    - ∗ AADTT per lane $AADTT = \mathbb{R}^+$
    - ∗ lane width $W_{lane} = \mathbb{R}^+$
    - ∗ the distance between roadway edge and bridge substructures $d = \mathbb{R}^+$
  - salt application rate $M_{total} = \mathbb{R}^+$

Output:

- predictedChlorideExposure = $\{\mathbb{R}\}$

4.3 Scope Decisions

- The surface chloride exposure data is in a 25-km grid resolution. This is because the climate data extracted from the CanRCM4 model ([13]) is at a resolution of 25 × 25 km.
- If the input coordinate does not have a bridge on it, it would return the value of the nearest bridge.

4.4 Modelling Decisions

4.4.1 Assumptions

This section simplifies the original problem and helps in developing the theoretical model by filling in the missing information for the physical system. The numbers given in the square brackets refer to the theoretical model [TM], general definition [GD], data definition [DD], instance model [IM], or likely change [LC], in which the respective assumption is used.

A1: All the deicing salts are applied on days with snowfall. (RefBy: TM3, GD3, DD1, DD2)

A2: The lane width for all the roads are the same. (RefBy: DD1, LC1)

A3: The main component of deicing salt is NaCl. (RefBy: DD3, DD6)

A4: Same class of the road over which the bridge spans has the same AADT. (RefBy: GD3, LC2)

4.4.2 Theoretical Models

This section focuses on the general equations and laws the project is based on.

Number	TM1
Label	**Water film thickness**
SI Units	m
Equation	$WD = 6 \times 10^{-4} \cdot T^{0.09}(L \cdot I)^{0.6} \cdot S^{-0.33}$
Description	The above equation compute the water film thickness based on the rainfall intensity and pavement surface properties. • WD is the water depth. (m) • T is the texture. (mm) • L is the drainage length. (m) • I is the rainfall intensity. (m/h) • S is the slope. (ratio)
Source	[5]
Ref. By	TM2

Number	TM2
Label	**Max flow rate general**
SI Units	kg/s
Equation	$MR_W = V \cdot b \cdot WD \cdot \rho_{water}$
Description	The above equation is the general equation for mass flow rate, which is the maximum amount of water available for splash and spray. • V is the truck speed. (m/s) • b is the tire width. (m) • WD is the water depth/thickness. (m) • ρ_{water} is the density of water. (kg/m^3)
Source	[5]
Ref. By	GD1
Use	TM1

Number	TM3
Label	**Chloride sprayed and splashed**
SI Units	kg/m^3/vehicle
Equation	$C_{s_{air}} = (SD_{total\ cl} \times \frac{1}{\Theta} \times \frac{ADT-N}{N_{lane}} + SD_{total\ cl} \times \frac{N}{N_{lane}}) \times t_{snow}$
Description	The above equation computes the mass of chloride ions per unit air volume sprayed and splashed by all the vehicles passing near the bridge pier every winter, accounting for all the days with snow in a typical winter season. • $SD_{total\ cl}$ is the mass of chloride ions per unit air volume. ($kg/m^3/vehicle$) • Θ is the ratio of chloride ions sprayed and splashed by trucks to light-duty vehicles. (ratio) • ADT is the average daily traffic. (number of vehicles/day) • N is the average number of heavy-duty vehicles per day. (number of vehicles/day) • N_{lane} is the number of lanes. • t_{snow} is the number of days with snow.
Notes	The first part in the parentheses calculate the chloride exposure by light-duty vehicle, and the second part is for heavy-duty vehicles. The calculation focues on the road lane that is closest to the bridge component, so N_{lane} is included in the denominator.
Source	[4]
Ref. By	GD3
Use	A1, DD6

Number	TM4
Label	**Total airborne deposition at a certain distance**
SI Units	kg/m^3
Equation	$D(x) = a_{spray} \times e^{b_{spray}\ x} + a_{splash} \times e^{b_{splash}\ x}$
Description	The above equation describes the total airborne deposition at a certain distance from the road. • a_{spray} is the maximum deposition rates that occur from spray. (kg/m^3) • a_{splash} is the maximum deposition rates that occur from splash. (kg/m^3) • b_{spray} is the spray emission rate coefficient. • b_{splash} is the splash emission rate coefficient. • x is the distance between the road and the object. (m) • e is the base of natural logarithm.
Source	[12]
Ref. By	IM1

4.4.3 General Definitions

This section collects the laws and equations that will be used in building the instance models.

Number	GD1
Label	**Mass flow rate**
SI Units	kg/s
Equation	$$\begin{cases} MR_{CA} = V_{speed} \times b \times K \times h_{film} \times \rho_{water} & \text{for } CA \\ MR_{TP} = V_{speed} \times b \times (1-K) \times h_{app} \times \rho_{water} & \text{for } TP \\ MR_{BW} = MR_{SW} = 0.5 \times V_{speed} \times b \times (h_{app} & \\ -K \times h_{film} - (1-K) \times h_{app}) \times \rho_{water} & \text{for } BW\ and\ SW \end{cases}$$
Description	The above equations compute the contribution to the amount of water displaced by a single tire(also called mass flow rate) of each splash and spray mechanism, using the following equations in the order presented until the total amount of available water is exhausted. $MR_{CA}, MR_{TP}, MR_{BW}, MR_{SW}$ stands for capillary adhesion, tread pickup, bow waves and side waves correspondingly. • V_{speed} is the heavy vehicle speed. (km/h) • b is the tire width. (m) • K is the ratio of the tire width that is not a groove to the tire width. (ratio) • h_{film} is the depth of the water film picked up in each rotation. (m) • h_{app} is the thickness of melted water per day with snow melting. (m) • ρ_{water} is the density of water. (kg/m^3) The tread pickup will be activated only if there is water remaining after the capillarity adhesion, and the bow and side waves will be activated only if there is water remaining after the capillary adhesion and tread pickup.
Source	[4]
Ref. By	GD2
Use	TM2, DD2

Detailed derivation of mass flow rate

The maximum mass flow rate associated with capillary adhesion (MR_{CA}) is estimated as the number of tire rotations per second multiplied by the volume of water dispersed on each tire rotation multiplied by the density of water, or

$$MR_{CA} = \left[\frac{V_{speed}}{2\pi R}\right] \cdot [2\pi R \times b \times K \times h_{film}] \times \rho_{water} = [V_{speed} \times b \times K \times h_{film}] \times \rho_{water}$$

After capillary action, the tire is able to displace a volume of water within its tread. The maximum flow rate for this mechanism (MR_{TP}) will occur when all the water contained in the tread volume is flung out of the tread during each tire rotation. Thus, it can be computed as the number of tire rotations per second multiplied by the capacity of tire's tread on each rotation multiplied by the density of water:

$$MR_{TP} = V_{speed} \times b \times (1 - K) \times h_{app} \times \rho_{water}$$

Any remaining water for which there is no capacity either underneath the tire contact area or within the tire tread must be displaced to the front of the tire or to the side, causing the bow wave and side wave, respectively. So, the total mass flow rate that can be attributed to bow and side wave mechanisms can be written as:

$$MR_{BW} + MR_{SW} = \rho_{water} \times b \times V_{speed} \times (h_{app} - K \times h_{film} - (1 - K) \times h_{app})$$

So, MR_{BW} and MR_{SW} can be estimated separately as:

$$MR_{BW} = \alpha \times \rho_{water} \times b \times V_{speed} \times (h_{app} - K \times h_{film} - (1 - K) \times h_{app})$$

$$MR_{SW} = \beta \times \rho_{water} \times b \times V_{speed} \times (h_{app} - K \times h_{film} - (1 - K) \times h_{app})$$

where α and β are calibration factors that satisfy $\alpha+\beta = 1$. Until other evidence is available, it will be assumed that $\alpha = \beta = 0.5$.

Number	GD2
Label	**Spray density**
SI Units	kg/m^3/vehicle
Equation	$\begin{cases} SD_{CA} = (-2.69 \times 10^{-5} \times V' + 2.43 \times 10^{-3}) \times MR_{CA} & \text{for } CA \\ SD_{TP} = (1.16 \times 10^{-5} \times V' - 5.25 \times 10^{-5}) \times MR_{TP} & \text{for } TP \\ SD_{BW} = (2.67 \times 10^{-5} \times V' - 4.71 \times 10^{-4}) \times MR_{BW} & \text{for } BW \\ SD_{SW} = (1.65 \times 10^{-5} \times V' - 3.99 \times 10^{-4}) \times MR_{SW} & \text{for } SW \end{cases}$
Description	Spray density is derived by conducting regression analysis to develop relationship between spray density, mass flow rate and vehicle speed, to compute the concentration of water kicked up to the environment. The detailed process could be found in section 6.6.1 in [4] . • V' is the heavy vehicle speed. $(miles/h)$ • $MR_{CA}, MR_{TP}, MR_{BW}, MR_{SW}$ is the mass flow rate for capillary adhesion, tread pickup, bow waves and side waves correspondingly. (kg/s)
Source	[4]
Ref. By	DD4
Use	GD1

Number	GD3
Label	**Chloride sprayed and splashed**
SI Units	kg/m^3/vehicle
Equation	$C_{s_{air}} = (SD_{total\ cl} \times \frac{1}{\Theta} \times (AADT\ per\ lane - AADTT\ per\ lane) + SD_{total\ cl} \times AADTT\ per\ lane) \times t_2$
Description	The cumulative mass of chloride ions per unit air volume sprayed and splashed by all vehicles every winter, can be calculated by first finding the mass of chloride ions per unit air volume sprayed and splashed by all the vehicles per day, and times with the number of says with snow melting. • $SD_{total\ cl}$ is the mass of chloride ions per unit air volume. $(kg/m^3/vehicle)$ • Θ is the ratio of chloride ions sprayed and splashed by trucks to light-duty vehicles. • $AADT\ per\ lane$ is the annual average daily traffic per lane. • $AADTT\ per\ lane$ is the annual average daily truck traffic per lane. • t_2 is the number of days with snow melting.
Notes	This equation simplified TM3 by using AADT and AADTT that are generated from existing database for calculation for light traffic and heavy-duty traffic.
Sources	[7, 8]
Ref. By	IM1
Use	A1, A4, DD6, TM3

4.4.4 Data Definitions

This section collects and defines all the data needed to build the instance models. The dimension of each quantity is also given.

Number	DD1
Label	**Deicing salts quantity**
Symbol	M_{app}
SI Units	kg/m^2
Equation	$$\begin{cases} M_{app} = M_{total}/t_1 \\ M_{app} = \frac{V_{salt} \times h_{total}}{t_1 \times W_{lane}} \end{cases}$$
Description	The equation determine the quantity of deicing salts applied per day with snowfall, with A1. In some case there is absence of the data of M_{total}, the second equation is used. • M_{total} is the total amount of deicing salts applied on the road during the winter season. (kg/m^2) • t_1 is the number of days with snowfall. • V_{salt} is the normalized salt application rate. $(t/cm/km)$ • h_{total} is the total snowfall during a winter season. (m) • W_{lane} is the lane width according to A2. (m).
Sources	[4, 7]
Ref. By	DD5
Use	A1, A2

Number	DD2
Label	**Daily water film thickness**
Symbol	h_{app}
SI Units	m
Equation	$h_{app} = h_{total}/t_{snow}$
Description	The equaition above calculates the thickness of melted water per day with snow melting. • h_{total} is the the total snowfall during a winter season. (m) • t_{snow} is the number of days with snow melting.
Sources	[4, 9]
Ref. By	GD1, DD5
Use	A1

Number	DD3
Label	**Ratio of chloride in deicing salts**
SI Units	none
Equation	$\theta_{chloride} = \frac{\text{mass of } Cl^-}{\text{mass of } NaCl}$
Description	This equation computes the molar mass ratio of chloride to deicing salts, where we assume the main component of deicing salts is NaCl. • Cl^- is the chloride ions whose exposure we want to investigate. • $NaCl$ is the most commonly used salt.
Source	Mass Ratio Calculation
Ref. By	DD6
Use	A3

Number	DD4
Label	**Total spray density**
SI Units	kg/m^3/vehicle
Equation	$SD_{total} = SD_{CA} + SD_{TP} + SD_{BW} + SD_{SW}$
Description	The spray density (i.e. mass of water per unit air volume kicked up by each passing truck), is the sum of the four mechanism. • SD_{CA} is the spray density due to capillary adhesion. • SD_{TP} is the spray density due to tread pickup. • SD_{BW} is the spray density due to bow waves. • SD_{SW} is the spray density due to side waves.
Source	[4]
Ref. By	DD6
Use	GD2

Number	DD5
Label	**Ratio of salt over water**
SI Units	none
Equation	$\delta_{salt} = \frac{M_{app}}{h_{app} \times \rho_{water}}$
Description	This equation computes the ratio of the mass of salt applied per unit area of road to the mass of water per unit area of road. • M_{app} is the quantity of deicing salts applied per day. (kg/m^2) • h_{app} is the thickness of melted water per day. (m) • ρ_{water} is the density of water. (kg/m^3)
Source	[4]
Ref. By	DD6
Use	DD1, DD2

Number	DD6
Label	**Mass of chloride ions**
SI Units	kg/m^3/vehicle
Equation	$SD_{total\ cl} = SD_{total} \times \delta_{salt} \times \theta_{chloride}$
Description	This equation computes the mass of chloride ions per unit air volume kicked up by each truck. • SD_{total} is the mass of water per unit air volume. ($kg/m^3/vehicle$) • δ_{salt} is the salt-to-water mass ratio per unit area of road. (ratio) • $\theta_{chloride}$ is the molar mass ratio of chloride to deicing salts. (ratio)
Source	[4, 7]
Ref. By	TM3, GD3
Use	A3, DD3, DD4, DD5

4.4.5 Instance Models

This section transforms the problem defined in Section 4.1 into one which is expressed in mathematical terms. It uses concrete symbols defined in Section 4.4.4 to replace the abstract symbols in the models identified in Sections 4.4.2 and 4.4.3.

The goal GS1 is solved by IM1. The goal GS2 is solved by IM2.

Number	IM1
Label	**Chloride on the surface**
Input	$C_{s_{air}}, e, d$
Output	C_s
Equation	$C_s = 0.015 \times C_{s_{air}} \times e^{-0.05d} + 0.985 \times C_{s_{air}} \times e^{-0.5d}$
Description	The above equation computes the chloride ions deposition on bridge substructure, taking into account the distance between the edge of the road near the bridge substructure and the bridge substructure. • $C_{s_{air}}$ is the cumulative mass of chloride ions per unit air volume sprayed and splashed by all the vehicles passing near the bridge pier. (kg/m^3) • d is the distance between the road edge and nearby bridge structure. (m) • e is the base of natural logarithm.
Sources	[7, 10, 11, 12]
Ref. By	IM2, LC3
Use	TM4, GD3

Detailed derivation of chloride on the surface

According to [12], the spray emission rate coefficient and splash emission rate coefficient could be taken as -0.05 and -0.5, and the distance between road edge and nearby bridge structure is d, so we have:

$$C_s = a_{spray} \times e^{-0.05d} + a_{splash} \times e^{-0.5d}$$

According to [11, 12] which measured the deposition of deicing salts along a highway in Sweden to define the relation between the mass of deicing salts per unit area and distance from roadside, and used nonlinear fitting techniques to determine the proportions of sprayed and splashed chloride ions:

$$a_{spray} = a_{air} \times 0.015$$

$$a_{splash} = a_{air} \times 0.985$$

Combining the above equation in the scenario of chloride, we have:

$$C_s = 0.015 \times C_{s_{air}} \times e^{-0.05d} + 0.985 \times C_{s_{air}} \times e^{-0.5d}$$

Number	IM2
Label	**Search data for specific coordiinate**
Input	$(longitude, latitude)$
Output	$\{C_{s_1}, C_{s_2} ..., C_{s_n}\}$
Description	This instance model get the longitude and latitude as input, and return a series of the amount of chloride exposure as output. This is the model that the end user of this software will encounter. • $\{C_{s_1}, C_{s_2} ..., C_{s_n}\}$ is a list of chloride exposure data. ($\{kg/m^3\}$) • $(longitude, latitude)$ is the coordinate of a location. (°, °)

4.4.6 Input Data Constraints

Table 1 shows the data constraints on the input output variables. The column for physical constraints gives the physical limitations on the range of values that can be taken by the variable. The column for software constraints restricts the range of inputs to reasonable values. The software constraints will be helpful in the design stage for picking suitable algorithms. The constraints are conservative, to give the user of the model the flexibility to experiment with unusual situations. The column of typical values is intended to provide a feel for a common scenario. The uncertainty column provides an estimate of the confidence with which the physical quantities can be measured. This information would be part of the input if one were performing an uncertainty quantification exercise. In the Bridge Corrosion project, I would talk about not only the input variables mentioned in instance models, but also include those in other models that the software need to process.
The specification parameters in Table 1 are listed in Table 6.

4.4.7 Properties of a Correct Solution

A correct solution must exhibit the chloride exposure values that does not exceed the solubility limits of chloride ions.

Table 1: Input Variables

Var	Physical Constraints	Software Constraints	Typical Value	Uncertainty
b	$0.2 \leq b \leq 0.71$	$b_{min} \leq b \leq b_{max}$	0.56m	10%
d	$d > 0$	$d > 0$	3m	10%
h_{film}	$h_{film} > 0$	$h_{film} > 0$	0.0001m	10%
K	$0 \leq K \leq 1$	$b_{min} \leq K \leq b_{max}$	0.75	10%
t_2	$0 \leq t_2 \leq 365$	$t_{snow} \leq t_2 \leq 365$	70days	10%
t_{snow}	$0 \leq t_{snow} \leq 365$	$0 \leq t_{snow} \leq 365$	65days	10%
V'	$37 \leq V' \leq 65$	$V'_{min} \leq V' \leq V'_{max}$	65miles/h	10%
V_{speed}	$60 \leq V_{speed} \leq 105$	$V_{speed_{min}} \leq V_{speed} \leq V_{speed_{max}}$	105km/h	10%
Θ	$0 \leq \theta < 1$	$0 \leq \theta < 1$	0.61	10%

Table 2: Output Variables

Var	Physical Constraints
C_s	$C_s < 357kg/m^3$ (by Water Quality Guidelines)

5 Requirements

This section provides the functional requirements, the business tasks that the software is expected to complete, and the nonfunctional requirements, the qualities that the software is expected to exhibit.

5.1 Functional Requirements

R1: The user input need to be a coordinate within Ontario (By IM2).

R2: The output need to be a series of data showing the trend of chloride exposure in the past and future at the input location (By IM2).

R3: During the calculation, the software should be capable of handling situations where units do not match in between steps as the developers or users are not able to interrupt/modify the data manually during the calculation.

R4: The output from the previous year should be verifiable against real-world data.

R5: The output should be in two decimal points, showing the mass of chloride ions per unit air volume (By IM1).

5.2 Nonfunctional Requirements

NFR1: **Reliability**: The predictions generated by the software should be accurate and reliable, reflecting real-world conditions and factors influencing chloride exposure.

NFR2: **Usability**: The software interface should be intuitive and user-friendly, allowing users in the section 3.2 to easily input coordinates and look at the predicted chloride exposure in the past and future.

NFR3: **Maintainability**: The code for this software should be designed and structured in a way that it could be easily comprehended and modified by other potential developers.

NFR4: **Portability**: This software should be able to run on recent versions of Google Chrome, Firefox, MS Edge and Safari. The operating system include Windows 7+ and Mac OS X 10.7+.

NFR5: **Scalability**: The software should be scalable to accommodate potential future expansions or updates, ensuring its continued usefulness as new data or techniques become available.

5.3 Rationale

The assumptions made in this document are based on practical considerations to simplify and quantify the data required in the model. In A1, the deicing salts need to be applied on the roads in time to ensure safe driving conditions during winter weather. In A2, it simplifies the model by assuming a standardized lane width across all roads. While lane widths can vary depending on road type and location, assuming a uniform lane width streamlines the analysis and allows for consistent calculations. Additionally, a lane width of 3 meters is commonly used in many road design standards and provides a reasonable approximation for modeling purposes. Similarly, NaCl is one of the most widely used deicing salts due to its effectiveness and affordability, so A3 simplifies the model while still capturing the essence of typical deicing salt compositions. Lastly, AADT is an important parameter for assessing traffic volume on roads and is typically used to classify roads into different categories based on their traffic intensity, A4 simplifies the analysis by providing a standardized measure of traffic volume. By incorporating these assumptions, the model can effectively simulate real-world scenarios and provide valuable insights into the factors influencing bridge corrosion. The The constraints in Table 1 are defined considering real-world scenarios. For example, the speed constraints adhere to established speed limits, ensuring a realistic representation of vehicle speeds. Similarly, the constraints associated with the variable about days are confined within the bounds of the annual calendar, reflecting a practical consideration of time duration within a given year.

6 Likely Changes

LC1: The lane width in some area might not be fixed, and the lane width standards might change in the future, so A2 is likely to be changed.

LC2: A4 might be changed with the population density, urbanization, or transportation preferences in different area, which all may influence traffic volume and distribution.

LC3: The proportions(0.015 and 0.985) in IM1 might change with the site characteristics of a bridge, such as the roadside environment (forested or urban), traffic characteristics (direction and volume), wind direction, and road surface condition.

7 Unlikely Changes

ULC1: The deicing salt need to be applied on days with snowfall to effectively mitigate the formation of ice and ensure safe road conditions, so A1 is unlikely to change.

ULC2: A3 is also unlikely to change, as the main component of deicing salt remain consistent.

8 Traceability Matrices and Graphs

The purpose of the traceability matrices is to provide easy references on what has to be additionally modified if a certain component is changed. Every time a component is changed, the items in the column of that component that are marked with an "X" may have to be modified as well. Table 3 shows the dependencies of theoretical models, general definitions, data definitions, instance models, and likely changes on the assumptions. Table 4 shows the dependencies of theoretical models, general definitions, data definitions, and instance models with each other. Table 5 shows the dependencies of instance models, requirements, and data constraints on each other.

	A1	A2	A3	A4
TM1				
TM2				
TM3	X			
TM4				
GD1				
GD2				
GD3	X			X
DD1	X	X		
DD2	X			
DD3			X	
DD4				
DD5				
DD6			X	
IM1				
IM2				
LC1		X		
LC2				X
LC3				
ULC1	X			
ULC2			X	

Table 3: Traceability Matrix Showing the Connections Between Assumptions and Other Items

	TM1	TM2	TM3	TM4	GD1	GD2	GD3	DD1	DD2	DD3	DD4	DD5	DD6	IM1	IM2
TM1		X													
TM2					X										
TM3							X								
TM4														X	
GD1						X									
GD2											X				
GD3														X	
DD1												X			
DD2					X							X			
DD3													X		
DD4													X		
DD5													X		
DD6			X				X								
IM1															X
IM2															

Table 4: Traceability Matrix Showing the Connections Between Items of Different Sections

	IM1	IM2	R1	R2	R3	R4	R5	NFR1	NFR2	NFR3	NFR4	NFR5
IM1							X					
IM2			X	X					X		X	
R1		X			X					X		
R2						X	X	X				
R3			X									X
R4				X				X				
R5				X								
NFR1		X				X						
NFR2		X		X								
NFR3												X
NFR4												
NFR5										X		

Table 5: Traceability Matrix Showing the Connections Between Requirements and Instance Models

9 Values of Auxiliary Constants

Symbol	**Description**	**Value**	**Unit**
V'_{min}	minimum speed of heavy vehicle	37	miles/h
V'_{max}	maximum speed of heavy vehicle	65	miles/h
$V_{speed_{min}}$	minimum speed of heavy vehicle	60	km/h
$V_{speed_{max}}$	maximum speed of heavy vehicle	105	km/h
b_{min}	minimum tire width	0.2	m
b_{max}	maximum tire width	0.71	m
b_{spray}	spray emission rate coefficient	-0.05	N/A
b_{splash}	splash emission rate coefficient	-0.5	N/A
W_{lane}	lane width	3	m
V_{salt}	salt application rate	0.06	t/cm/km
Θ	ratio of chloride ions sprayed and splashed by trucks over light-duty vehicles	6	N/A

Table 6: Auxiliary Constant

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Appendix — Reflection

The information in this section will be used to evaluate the team members on the graduate attribute of Lifelong Learning. Please answer the following questions:

1. Which of the courses you have taken, or are currently taking, will help your team to be successful with your capstone project.
2. What knowledge and skills will the team collectively need to acquire to successfully complete this capstone project? Examples of possible knowledge to acquire include domain specific knowledge from the domain of your application, or software engineering knowledge, mechatronics knowledge or computer science knowledge. Skills may be related to technology, or writing, or presentation, or team management, etc. You should look to identify at least one item for each team member.
3. For each of the knowledge areas and skills identified in the previous question, what are at least two approaches to acquiring the knowledge or mastering the skill? Of the identified approaches, which will each team member pursue, and why did they make this choice?