Module Interface Specification for Bridge Corrosion

Cynthia Liu

April 7, 2024

1 Revision History

Date	Version	Notes
Mar. 8, 2024	0	Initial Release
April. 5, 2024	0.1	Edit according to feedback from peer review and Dr. Smith

2 Symbols, Abbreviations and Acronyms

See SRS Documentation at SRS.

[Also add any additional symbols, abbreviations or acronyms —SS]

Contents

3 Introduction

The following document details the Module Interface Specifications for Bridge Corrosion which investigate how climate, traffic might impact corrosion-induced damage for reinforced concrete bridges by influencing the chloride exposure.

Complementary documents include the System Requirement Specifications and Module Guide. The full documentation and implementation can be found at here.

4 Notation

The structure of the MIS for modules comes from [HoffmanAndStrooper1995], with the addition that template modules have been adapted from [GhezziEtAl2003]. The mathematical notation comes from Chapter 3 of [HoffmanAndStrooper1995]. For instance, the symbol := is used for a multiple assignment statement and conditional rules follow the form $(c_1 \Rightarrow r_1|c_2 \Rightarrow r_2|...|c_n \Rightarrow r_n)$.

The following table summarizes the primitive data types used by BC.

Data Type	**Notation**	**Description**
character	char	a single symbol or digit
integer	$\mathbb{Z}$	a number without a fractional component in (-∞, ∞)
natural number	$\mathbb{N}$	a number without a fractional component in [1, ∞)
real	$\mathbb{R}$	any number in (-∞, ∞)
empty	$\varnothing$	when the input is empty or the variable does not exist
GeoDataFrame	GeoDataFrame	todo

The specification of BC uses some derived data types: sequences, strings, and tuples. Sequences are lists filled with elements of the same data type. Strings are sequences of characters. Tuples contain a list of values, potentially of different types. In addition, BC uses functions, which are defined by the data types of their inputs and outputs. Local functions are described by giving their type signature followed by their specification.

5 Module Decomposition

The following table is taken directly from the Module Guide document for this project.

Level 1	**Level 2**
Hardware-Hiding Module	
Behaviour-Hiding Module	Input Module Control Module Data Searching Module Output Visualization Module Data Model Reading Module Constant Module Deicing Salts Calculation Module Melted Water Thickness Calculation Module Single Water SAS Calculation Module Single Chloride Ions SAS Calculation Module All Chloride Ions SAS Calculation Module Deicing Salts Deposition Calculation Module Chloride Exposure Database Generation Module
Software Decision Module	File I/O Module Plotting Module

Table 1: Module Hierarchy

6 MIS of Control Module

This module provides the main program and the GUI of the software. It is related to R1 and R2 in the SRS.

6.1 Module

main

6.2 Uses

- Input Module (Section 7)
- Data Searching Module (Section 8)
- Output Visualization Module (Section 9)

6.3 Syntax

6.3.1 Exported Constants

None

6.3.2 Exported Access Programs

Name	In	Out	Exceptions
main	-	-	-

6.4 Semantics

6.4.1 State Variables

None

6.4.2 Environment Variables

None

6.4.3 Assumptions

None

6.4.4 Access Routine Semantics

main():

- transition: Control and execute the other modules as follow:
  - Get and verify the input from user. (Section 7)
  - Search the corresponding data in Data Searching Module if the input is valid. (Section 8)
  - Visualize the resulting data by using Output Visualization Module. (Section 9)
- output: out := None
- exception: exc := None

6.4.5 Local Functions

None

7 MIS of Input Module

This module get the input from user and verify if it is within the physical and software constraints, it is related to R1 in SRS.

7.1 Module

input_check

7.2 Uses

None

7.3 Syntax

7.3.1 Exported Constants

None

7.3.2 Exported Access Programs

Name	In	Out	Exceptions
read_geoinfo	filename: String	-	FileNotFoundError
convert_longitude	long: String	long: $\mathbb{R}$	ValueError
convert_latitude	lat: String	lat: $\mathbb{R}$	ValueError
is_within_ontario	long: $\mathbb{R}$, lat: $\mathbb{R}$	Boolean	InputOutofOntarioError

7.4 Semantics

7.4.1 State Variables

- lon: $\mathbb{R}$ # longitude get from user.
- lat: $\mathbb{R}$ # latitude get from user.
- boundary: GeoDataFrame # the data read from geojson file

7.4.2 Environment Variables

- Keyboard: takes input from the keyboard by typing.
- File: the geojson file that contain the shape of Ontario.

7.4.3 Assumptions

This module use the open source geojson file that contain the Ontario boundary, by drawing polygons with the vertex coordinate. The coordinates for those vertexes are assumed to be reliable.

7.4.4 Access Routine Semantics

read_geoinfo($filename$**)**:

- transition: access the data from geojson file
- exception: exc := FileNotFoundError: $\nexists\ filename$

convert_longitude($long$**)**:

- output: out := long: $\mathbb{R}$
- exception: exc := ValueError: $\neg\ isNumeric(long)$

convert_latitude($long$**)**:

- output: out := lat: $\mathbb{R}$
- exception: exc := ValueError: $\neg\ isNumeric(lat)$

is_within_ontario($long, lat$**)**:

- output: out := Boolean
- exception: exc := InputOutofOntarioError: $\neg((long, lat) \in Ontario)$

7.4.5 Local Functions

isNumeric(e):

- output: out := Boolean # check if the input e is a string of float

InputOutofOntarioError:

- output: out := Exception # raise this exception if the input is out of Ontario

8 MIS of Data Searching Module

This module finds the data needed in the database, it is related to R2 in SRS.

8.1 Module

search

8.2 Uses

Input Module (Section 7), Chloride Exposure Database Generation Module (Section 18)

8.3 Syntax

8.3.1 Exported Constants

None

8.3.2 Exported Access Programs

Name	In	Out	Exceptions
read_file	filename: String	data: sequence of $\mathbb{R}$	FileNotFoundError
find_closest	long: $\mathbb{R}$, lat: $\mathbb{R}$	index: $\mathbb{N}$	-
search	long: $\mathbb{R}$, lat: $\mathbb{R}$	result: sequence of $\mathbb{R}$	-

8.4 Semantics

8.4.1 State Variables

- data: sequence of $\mathbb{R}$ # the sequence of all data read from chloride exposure database
- result: sequence of $\mathbb{R}$ # the sequence of predicted chloride exposure data that the user want

8.4.2 Environment Variables

- File: the database file that contain the yearly chloride exposure data within Ontario.

8.4.3 Assumptions

All locations within Ontario, if it is not on water, must contain valid data.

8.4.4 Access Routine Semantics

read_file($filename$):

- output: out := data # sequence of $\mathbb{R}$ read from the file
- exception: exc := FileNotFoundError = $\nexists$ $filename$

find_closest($long, lat$): If the input coordinate is not the exact one in database, find the grid that it belongs to and return the index of center coordinate.

- output: out := index: $\mathbb{N}$

search($long, lat$):

- output: out := result = search(find_closest($long, lat$)) # sequence of $\mathbb{R}$, the chloride exposure result
- exception: exc := None

8.4.5 Local Functions

None

9 MIS of Output Visualization Module

This module provides the visualization of the resulting chloride exposure trend, it is related to R2 and R3 in SRS.

9.1 Module

visualization

9.2 Uses

Data Searching Module (Section 8)

9.3 Syntax

9.3.1 Exported Constants

None

9.3.2 Exported Access Programs

Name	In	Out	Exceptions
draw	result: sequence of $\mathbb{R}$	-	-

9.4 Semantics

9.4.1 State Variables

None

9.4.2 Environment Variables

Screen: The graphs are displayed on the screen.

9.4.3 Assumptions

None

9.4.4 Access Routine Semantics

draw(*result*):

- transition: display the graphs using the result from Data Searching Module.
- output: out := None
- exception: exc := None

9.4.5 Local Functions

None

10 MIS of Data Model Reading Module

This module loads the climate and traffic data from the external file and store it in the data format that could be used for calculation.

10.1 Module

calculation_loadT

10.2 Uses

None

10.3 Syntax

10.3.1 Exported Constants

None

10.3.2 Exported Access Programs

Name	In	Out	Exceptions
new calculation_load	filename: String	calculation_loadT	FileNotFoundError

10.4 Semantics

A data structure designed to store the data from climate and traffic model.

10.4.1 State Variables

- long: sequence of $\mathbb{R}$ # longitude get from climate and traffic model
- lat: sequence of $\mathbb{R}$ # latitude get from climate and traffic model
- AADT: sequence of $\mathbb{R}$ # annual average daily traffic per lane
- AADTT: sequence of $\mathbb{R}$ # annual average daily truck traffic per lane
- t1: sequence of $\mathbb{R}$ # number of days with snowfall
- h_total: sequence of $\mathbb{R}$ # the total snowfall during a winter season
- t2: sequence of $\mathbb{R}$ # number of days with snow melting

10.4.2 Environment Variables

File: the file with all climate model data and traffic model data

10.4.3 Assumptions

None

10.4.4 Access Routine Semantics

calculation_load:

- transition: Read and store the data from the climate model and traffic model file
- output: out := self
- exception: exc := FileNotFoundError = $\nexists$ *filename*

10.4.5 Local Functions

None

11 MIS of Constant Module

This module stores the constants used for calculation.

11.1 Module

constantT

11.2 Uses

None

11.3 Syntax

11.3.1 Exported Constants

Name	Value	Note
salt_application_rate	0.07	salt application rate
W_lane	3.75	lane width
V_speed	100	heavy vehicle speed
b	0.56	tire width
K	0.75	ratio of the tire width that is not a groove to the tire width
h_film	0.0001	depth of the water film picked up in each rotation
water_density	997	density of water
V	62.1371	truck speed
chloride_ratio	0.61	molar mass ratio of chloride ions over deicing salts
d	3.5	distance between road edge and nearby bridge structure
ldv_ratio	6	ratio of chloride ions sprayed and splashed by trucks over light-duty vehicles

11.3.2 Exported Access Programs

None

11.4 Semantics

11.4.1 State Variables

None

11.4.2 Environment Variables

None

11.4.3 Assumptions

None

11.4.4 Access Routine Semantics

None

11.4.5 Local Functions

None

12 MIS of Deicing Salts Calculation Module

This module provides the calculation for the quantity of deicing salts applied per day with snowfall

12.1 Module

calculation_step1

12.2 Uses

Constant Module (Section 11), Data Model Reading Module (Section 10)

12.3 Syntax

12.3.1 Exported Constants

None

12.3.2 Exported Access Programs

Name	In	Out	Exceptions
calculate_step1	h_total: sequence of $\mathbb{R}$, t1: sequence of $\mathbb{R}$	M_app: sequence of $\mathbb{R}$	-

12.4 Semantics

12.4.1 State Variables

None

12.4.2 Environment Variables

None

12.4.3 Assumptions

None

12.4.4 Access Routine Semantics

calculate_step1($h\_total, t1$):

- transition: None

- output: out := $\frac{salt\_application\_rate * h\_total}{(W\_lane * t1)}$, where salt_application_rate and W_lane are constant value get from Constant Module, h_total and t1 are read from Data Model Reading Module
- exception: exc := None

12.4.5 Local Functions

None

13 MIS of Melted Water Thickness Module

This module provides the calculation for the daily water film thickness on the road

13.1 Module

calculation_step2

13.2 Uses

Data Model Reading Module (Section 10)

13.3 Syntax

13.3.1 Exported Constants

None

13.3.2 Exported Access Programs

Name	In	Out	Exceptions
calculate_step2	h_total: sequence of $\mathbb{R}$, t2: sequence of $\mathbb{R}$	h_app: sequence of $\mathbb{R}$	-

13.4 Semantics

13.4.1 State Variables

None

13.4.2 Environment Variables

None

13.4.3 Assumptions

None

13.4.4 Access Routine Semantics

calculate_step2($h\_total, t2$):

- transition: None
- output: out := $\frac{h\_total}{t2}$, where h_total and t1 are read from Data Model Reading Module
- exception: exc := None

13.4.5 Local Functions

None

14 MIS of Single Water SAS Calculation Module

This module determine water sprayed and splashed by one truck using a (CFD)-based analytical model, taking into account of the four primary mechanisms of vehicle spray and splash: capillary adhesion, tread pickup, bow wave, and side wave.

14.1 Module

calculation_step3

14.2 Uses

Constant Module (Section 11), Melted Water Thickness Module (Section 13)

14.3 Syntax

14.3.1 Exported Constants

None

14.3.2 Exported Access Programs

Name	In	Out	Exceptions
calculate_step3	h_app: sequence of $\mathbb{R}$	SD_total: sequence of $\mathbb{R}$	-

14.4 Semantics

14.4.1 State Variables

None

14.4.2 Environment Variables

None

14.4.3 Assumptions

None

14.4.4 Access Routine Semantics

calculate_step3(*h_app*):

- transition: None

- output: out := SD_{CA} + SD_{TP} + SD_{BW} + SD_{SW} # the mass of water per unit air volume kicked up by each passing truck is the sum of the four mechanisms, calculated by the local functions below.
- exception: exc := None

14.4.5 Local Functions

$V_{speed}, b, K, h_{film}, \rho_{water}, V'$ are constants read from Constant Module.
mass_flow_rate(h_app):

- transition: None
- output: out :=

$$\begin{cases} MR_{CA} = V_{speed} \times b \times K \times h_{film} \times \rho_{water} & \text{for } CA \\ MR_{TP} = V_{speed} \times b \times (1-K) \times h_{app} \times \rho_{water} & \text{for } TP \\ MR_{BW} = MR_{SW} = 0.5 \times V_{speed} \times b \times & \\ (h_{app} - K \times h_{film} - (1-K) \times h_{app}) \times \rho_{water} & \text{for } BW \text{ and } SW \end{cases}$$

- exception: exc := None

spray_density($MR_{CA}, MR_{TP}, MR_{BW}, MR_{SW}$):

- transition: None
- output: out :=

$$\begin{cases} SD_{CA} = (-2.69 \times 10^{-5} \times V' + 2.43 \times 10^{-3}) \times MR_{CA} & \text{for } CA \\ SD_{TP} = (1.16 \times 10^{-5} \times V' - 5.25 \times 10^{-5}) \times MR_{TP} & \text{for } TP \\ SD_{BW} = (2.67 \times 10^{-5} \times V' - 4.71 \times 10^{-4}) \times MR_{BW} & \text{for } BW \\ SD_{SW} = (1.65 \times 10^{-5} \times V' - 3.99 \times 10^{-4}) \times MR_{SW} & \text{for } SW \end{cases}$$

- exception: exc := None

14.4.6 Local Functions

None

15 MIS of Single Chloride Ions SAS Calculation Module

This module determines the chloride ions sprayed and splashed by one truck.

15.1 Module

calculation_step4

15.2 Uses

Deicing Salts Calculation Module (Section 12), Single Water SAS Calculation Module (Section 14)

15.3 Syntax

15.3.1 Exported Constants

None

15.3.2 Exported Access Programs

Name	In	Out	Exceptions
calculate_step4	M_app: sequence of $\mathbb{R}$, h_app: sequence of $\mathbb{R}$, SD_total: sequence of $\mathbb{R}$	SD_totalCl: sequence of $\mathbb{R}$	-

15.4 Semantics

15.4.1 State Variables

None

15.4.2 Environment Variables

None

15.4.3 Assumptions

None

15.4.4 Access Routine Semantics

calculate_step4(M_app, h_app, SD_total**)**:

- transition: None
- output: out := $SD\_total * salt\_water\_ratio$(M_app, h_app) $* chloride\_ratio$, where chloride_ratio is a constant read from Constant Module.
- exception: exc := None

15.4.5 Local Functions

salt_water_ratio(M_app, h_app**)**:

- transition: None
- output: out := $\frac{M\_app}{h\_app * water\_density}$ where water_density is a constant read from Constant Module.
- exception: exc := None

16 MIS of All Chloride Ions SAS Calculation Module

This module determines chloride ions sprayed and splashed by all vehicles in one winter season

16.1 Module

calculation_step5

16.2 Uses

Constant Module (Section 11), Data Model Reading Module (Section 10), Single Water SAS Calculation Module (Section 14)

16.3 Syntax

16.3.1 Exported Constants

None

16.3.2 Exported Access Programs

Name	In	Out	Exceptions
calculate_step5	SD_totalCl: sequence of $\mathbb{R}$, t2: sequence of $\mathbb{R}$, AADT: sequence of $\mathbb{R}$, AADTT: sequence of $\mathbb{R}$	C_s_air: sequence of $\mathbb{R}$	-
updateAADT	AADT: sequence of $\mathbb{R}$	AADT: sequence of $\mathbb{R}$	-
updateAADTT	AADTT: sequence of $\mathbb{R}$	AADTT: sequence of $\mathbb{R}$	-

16.4 Semantics

16.4.1 State Variables

None

16.4.2 Environment Variables

None

16.4.3 Assumptions

The AADT and AADTT are assumed to have 2% increase rate every year

16.4.4 Access Routine Semantics

calculate_step5($M\_app, h\_app, SD\_total, t2, AADT, AADTT$**)**:

- transition: None
- output: out := $(\frac{SD\_totalCl}{ldv\_ratio} * (updateAADT(\text{AADT}) - updateAADTT(\text{AADTT})) + SD\_totalCl * AADTT) * t2$, where ldv_ratio is a constant read from Constant Module.
- exception: exc := None

updateAADT($AADT$**)**:

- transition: None
- output: out := AADT # calculate the AADT for future year, assuming a 2% annual increase rate
- exception: exc := None

updateAADTT($AADTT$**)**:

- transition: None
- output: out := AADTT # calculate the AADTT for future year, assuming a 2% annual increase rate
- exception: exc := None

16.4.5 Local Functions

None

17 MIS of Deicing Salts Deposition Calculation Module

This module determine the deposition of chloride ions on the surface of the bridge substructure

17.1 Module

calculation_step6

17.2 Uses

Constant Module (Section 11), All Chloride Ions SAS Calculation Module (Section 16)

17.3 Syntax

17.3.1 Exported Constants

None

17.3.2 Exported Access Programs

Name	In	Out	Exceptions
calculate_step6	C_s_air: sequence of $\mathbb{R}$	results: sequence of $\mathbb{R}$	-

17.4 Semantics

17.4.1 State Variables

None

17.4.2 Environment Variables

None

17.4.3 Assumptions

None

17.4.4 Access Routine Semantics

calculate_step6(C_s_air):

- transition: None

- output: out := $C\_s\_air * 0.015 * e^{-0.05*d} + C\_s\_air * 0.985 * e^{-0.5*d}$, where d is a constant read from Constant Module, 0.015 and 0.985 being the coefficient of the formula.
- exception: exc := None

17.4.5 Local Functions

None

18 MIS of Chloride Exposure Database Generation Module

This module performs the calculation process(calculation_load to calculation_step6) to generate the database, it is related to the R2, R3 in SRS.

18.1 Module

calculate

18.2 Uses

Data Model Reading Module (Section 10), Constant Module (Section 11), Deicing Salts Calculation Module (Section 12), Melted Water Thickness Module (Section 13), Single Water SAS Calculation Module (Section 14), Single Chloride Ions SAS Calculation Module (Section 15), All Chloride Ions SAS Calculation Module (Section 16), Deicing Salts Deposition Calculation Module (Section 17)

18.3 Syntax

18.3.1 Exported Constants

None

18.3.2 Exported Access Programs

Name	In	Out	Exceptions
calculate	AADT: sequence of $\mathbb{R}$, AADTT: sequence of $\mathbb{R}$, t1: sequence of $\mathbb{R}$, h_{total}: sequence of $\mathbb{R}$, t2: sequence of $\mathbb{R}$	result: sequence of $\mathbb{R}$	DataMissingError, DataInvalidError
savefile	long: sequence of $\mathbb{R}$, lat: sequence of $\mathbb{R}$, results: sequence of $\mathbb{R}$	file: String	-

18.4 Semantics

18.4.1 State Variables

None

18.4.2 Environment Variables

File: the result of calculation will be stored in an output csv file.

18.4.3 Assumptions

The map of Ontario is divided into multiple 25km * 25km grid (as mentioned in SRS) and the coordinates are the center of those grids. The locations inside each grid are consider to have same chloride exposure rate.

18.4.4 Access Routine Semantics

calculate($AADT, AADTT, t1, h_{total}, t2$):

- transition: use all the formulas from calculate_step1 to calculate_step6, conclude the final result
- output: out := result # Sequence of $\mathbb{R}$
- exception: exc:=

Expression	Exception
$\exists e \in [AADT, AADTT, h_{total}, t1, t2], e = \varnothing$	DataMissingError
$(\exists i \in [0..\lvert AADT \rvert - 1], AADTT[i] > AADT[i]) \vee (\neg(t1, t2 \in (0, 365)))$	DataInvalidError

savefile($long, lat, results$):

- transition: Save the longitude, latitude and the corresponding results for each grid to a csv file, which is the prediction of chloride exposure rate. The file has a row label as coordinate and a column label as year.
- output: out := file
- exception: exc := None

18.4.5 Local Functions

None