Case-Based Reasoning in Construction and Infrastructure Projects
- Short Report

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1. PROJECT OVERVIEW

Many processes in design, construction and maintenance of infrastructure are complex and highly influenced by a wide range of design, climate and usage parameters. For example, predicting metallic corrosion rates, and hence component life, is a complex process which includes reasoning about examples in which corrosion rates are known, knowledge of the material properties and the impact of the environment on those materials, and an interpretation of the site.

The ability to accurately predict the lifetime of building components is crucial to optimising building design, material selection and scheduling of required maintenance. ISO 15686 (Clause 9) has suggested the factor method as a means of estimating the service life of a particular component or assembly in a specific set of conditions. The factor method is based on a reference service life (RSL), which is defined as the expected service life of a component or assembly situated in a well-defined set of conditions. It incorporates a series of modifying factors that relate to the specific conditions of the case to give the predicted service life distribution of a component (PSDLC) according to the equation:

$$PSLDC = RSLC \cdot f_A \cdot f_B \cdot f_C \cdot f_D \cdot f_E \cdot f_F \cdot f_G$$

The factor indices relate to quality of the component, design, work execution, environments etc. The problem still remains, however, of defining the reference service life for a vast array of building components.

Two approaches have been used in the past to predict the corrosion process - statistical and process-based models. Statistical models have proven unable to cope with the complexity of the problem. Studies have demonstrated that statistical models of component life though useful are extremely limited in their application and cannot predict outside the data sets used to generate the models. Thus a statistical model of life of reinforced concrete in bridges in inland NSW is unlikely to be useful for predicting life for the same bridges on the coast and could not predict life of reinforced concrete in buildings etc.

Process-based models are much more flexible, for example the Construction Mapping System (CMS) developed by CSIRO can predict the life of galvanised steel within any building anywhere in the country. This method is based on the holistic model, within which processes controlling corrosion across a wide range of physical scales and based on different phenomena are modelled. A solution to component life prediction is generated by post-processing the corrosion rate obtained from combining different modules defining specific processes through first principles. Although the theoretical component life of a component can be calculated for any applicable area within Australia, the accuracy of this result reduces dramatically when input data crosses the boundary conditions of the model.

The problem is to combine the two approaches to corrosion prediction so that a variety of sources of data, from studies, from experience and from first principles using the holistic model, can be combined to form the basis of the lifetime prediction tool. In addition, once the predicted lifetime for a particular situation has been determined, then this should be available for future reference. Thus, the required system must be able to store, manipulate and compare numerous use-case scenarios. Case-based reasoning is seen as an ideal method for linking together the different data sources and reusing previous experiences in the current context to solve new problems.

Discussions with the project partners identified two areas of particular interest for formulation of initial applications to apply the concept of case-based reasoning to prediction of lifetime of metallic building components.

The project has delivered:

- Design and implementation of a case-based reasoning (CBR) engine for life prediction of metallic building components in general,
- An application of the CBR engine tailored to predicting durability of gutters in Queensland schools,
- A stand-alone program for modelling the degradation rate of gutters using the CSIRO holistic model,
- A stand-alone program for estimating salt deposition levels on bridge structures in Queensland to be used as the basis for a CBR program in the future, and
- A report on the Sunshine Coast site visit to school and bridge locations, which has identified several corrosion problems of interest to the industry partners.

The implementation of the CBR engine necessitated characterisation of the environment and building locations to enable development of case definitions. Similarity rules were formulated for a number of parameters so that different cases could be compared and the closest match selected.

The QDPW application incorporates several sources of data for access by the CBR engine. These include the Delphi survey (from Project 2002-010-B), maintenance information from the QDPW and the holistic model. The holistic model required modifications to tailor the outputs for use with gutters. The three main materials currently used in gutters are galvanised steel, Zincalume and Colorbond® so rules for the degradation of polymeric coatings had to be determined and included in the model for use with Colorbond®. In addition, experiments were carried out to determine an appropriate 'Time of Wetness' factor for different gutter states, given that they are a building component where dirt can accumulate and affect the run-off of water and drying rate. The modelling calculations result in a mass loss per year for metals so this had to be related to a predicted life span, with consideration also given to whether this is aesthetic life or service life. These modifications to the holistic model were incorporated into a stand-alone program which can be used to estimate degradation of gutters at any location in Australia.

The QDMR application is not as advanced as the gutter application. The project team has focussed on the definition of structural elements of five typical Queensland bridges to define representative cases which could be used in a future extension into CBR. A detailed CFD analysis of salt deposition on the five bridge structures has been carried out and elements with common deposition rates were identified. A stand-alone program has been developed that will estimate a salt deposition factor, for a selected bridge element at any location in Queensland

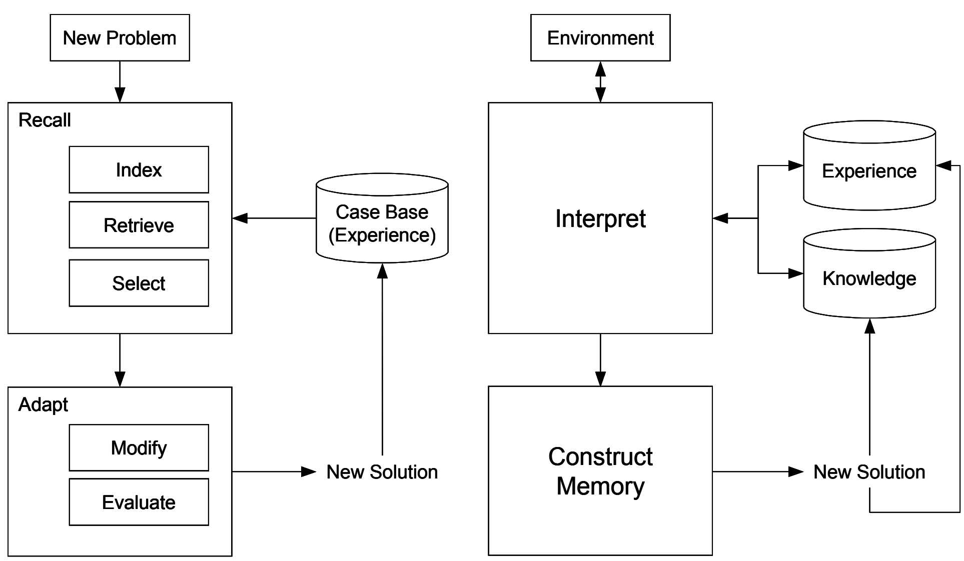
These software applications require further development to generate a commercially usable product. The design of the CBR engine is such as to allow the development of a comprehensive tool that can span a wide range of materials and a variety of environments, covering buildings, constructed facilities and infrastructure. The current tools have been developed as proof of concept with a very limited field of application. Some modification of the case-based reasoning program will also be necessary to fully implement an inference engine and optimise the selection of cases and construct the final case input values from the alternatives retrieved from the databases. At present, the CBR can interrogate the various databases and select cases considered to be relevant to a given situation. There is no process for selecting which of the retrieved information should be stored as a new case.

The development of these applications will provide economic benefits to the two industry partners. These are difficult to quantify but contain elements of design savings and maintenance savings for facility owners, managers and maintenance providers. The potential for the tools is significant given the amount of metal used in the areas of interest and the levels of corrosion found in the project site visit to the Sunshine Coast. It has been estimated that nearly $5 million was spent by Queensland Department of Public Works in 03/04 in replacing corroded metallic components of Queensland schools. Substantial cost savings can be made through the use of the software tool to select construction materials suited to the environment in which they will be used, and optimisation of maintenance schedules.

2. SITUATED CASE-BASED REASONING MODEL

Case –based reasoning (CBR) provides a model for design reasoning based on the use of a set of previous design experiences represented as design cases (Maher et al 1995). These cases are indexed and retrieved using information about a current design problem, and then through analogical reasoning, a selected case (or set of cases) is adapted until it satisfies the current design specifications and constraints. One aspect of design reasoning that is not addressed by traditional models for case-based reasoning is that designing is situated (Gero 1998). To accommodate the notion of 'situatedness' in designing, the basic idea of case-based reasoning is extended to create a model of situated case-based reasoning (situated CBR, Figure 2.1), based on a model of constructive memory that operates within a framework of situatedness.

Figure 2.1 A conventional case-based reasoning model (a) and a situation case-based reasoning model (b)



In the situated CBR model, instead of focusing on just the design problem and finding a solution to it, emphasis is also given to the environment within which the problem is framed. The model interprets the environment according to the current situation and the problem is framed accordingly. This interpretation is dependent on the current environment, the internal state of the situated CBR system and the interactions between the system and the environment.

The internal state of a situated CBR system is defined by its content. This content is made up of individual entities that are classified either as experience or knowledge. Interactions between the system and the environment define different interpretations of the environment according to different interpretations of the selected entities used for memory construction.

A distinctive characteristic of situated CBR is the way the knowledge and experience are understood and used. In CBR, retrieved cases provide a solution or a starting point for case adaptation. In Situated CBR, the memory of an experience and/or knowledge (entities) is constructed according to an interpretation of the environment and an interpretation of the selected entities relevant to the problem at hand. Rather than adapt a selected case to new design specifications, the selected entities are interpreted according to the interactions between the system and the environment. These interactions provide a specific view (interpretation) of the relationship between the design specifications and the environment. This view dictates another interpretation of the environment that can introduce new specifications. This “feedback” loop causes the interpretations of the environment and the selection of experiences and knowledge to occur recursively until a common interpretation is reached.

The recursive interpretations of the environment and the selected entities result in new memories as well as new indices to the selected experiences and knowledge to be created. Memories are constructed by:

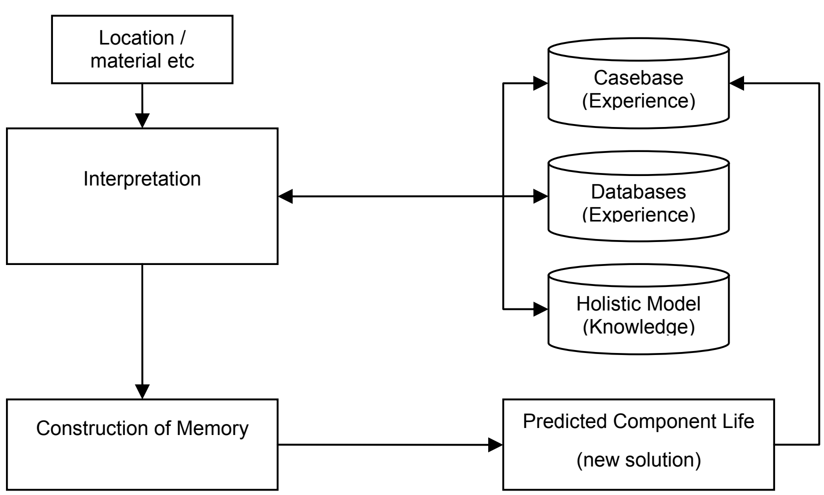
- instantiating the parameter values of the selected entities according to the current situation;
- mapping existing parameters in the selected entities to new ones through an analogical process; and
- restructuring the selected entities according to the current situation.

This is similar to creation of new functional or behavioural indices to an old design prototype within the domain of situated analogy (Gero and Kulinski, 2000).

The situated CBR model will be used to design a system that predicts the service life of building materials as shown in Figure 2.2. Predicting component life is a complex process which includes reasoning about examples in which service lifetimes are known, knowledge of the material properties and the impact of the environment on those materials, and an interpretation of the site in which the material is located.

The local conditions of the site in which the material is located are used to determine the environmental component of the situated CBR system. Parameters within this environment are used to select previous experiences and/or knowledge from the system for memory construction. A memory is constructed based on a combination and interpretation of previous experiences that can be used to predict the component life of a specific material on a specific site.

Figure 2.2 Model of situated CBR applied to the prediction of component service life



3. CBR APPLIED TO CORROSION PREDICTION OF BUILDING COMPONENTS

In order to apply the paradigm of case-based reasoning to corrosion prediction of building components, several elements needed to be provided:

- sources of corrosion data to be interrogated to find relevant knowledge (holistic model) and experience (databases),
- definition of materials, environments and component characteristics and associated 'similarity indices' to enable comparisons between specified instances and the contents of the databases and casebase to finding matching entries, and
- a CBR engine to link the different sources of data, perform case comparisons, and store knowledge in a continually updated casebase.

3.1 Databases

The sources of data available to the project and utilized in the software developed are:

- Delphi database. This is a database of predicted lifetimes for a range of metallic building components derived from expert opinion in a process known as a Delphi survey. It is the outcome of another CRC for Construction Innovation project (2002-010-B) completed in 2004. The database covers a representative subset of 30 building components in a range of materials, and environments and considers service life (with and without maintenance), aesthetic life and time to first maintenance. An example of the entries in the database is shown in Table 3.1.
- Maintenance Database. In conjunction with the Queensland Department of Housing, CSIRO (outside this project) has analysed over 10,000 records with regard to significant maintenance to generate the table of predicted lifetimes (example shown in Table 3.2).
- Holistic Model. Through many years of research, CSIRO has developed a holistic model for corrosion which is based on an understanding of the basic corrosion processes ranging in scale from atomic electrochemical reactions to the macro scale of continental environmental factors. This mathematical model has been used to generate a database of predicted lifetimes for the different materials in the Queensland school locations. (An example of the data for one school is shown in Table 3.3. The school location details have been omitted).

3.2 Definition of cases

For metallic building components, the important parameters for determining the rate of corrosion include the component type, and where on the building it is situated, the material type and the environmental conditions.

Materials in common use include:

- steel and steel alloys (bare and painted)
- zinc and zinc alloys (bare and painted)
- aluminium alloys.

Table 3.1 Example of entries in the Delphi database (Mode, Standard Deviation and Mean are given in years

Building type	Component	Measure	Environment	Material	Maintenance	Mode	SD	Mean	Criteria
Commercial	Gutters	Service Life	Marine	Galvanised Steel	No	5-10	5	9	2
Commercial	Gutters	Time to First maintenance	Marine	Galvanised Steel	Yes	<5	4	6	2
Commercial	Gutters	Aesthetic Life	Marine	Galvanised Steel	Yes	10-15	6	11	2
Commercial	Gutters	Service Life	Industrial	Galvanised Steel	Yes	10-15	9	15	2
Commercial	Gutters	Service Life	Industrial	Galvanised Steel	No	5-10	5	10	2
Commercial	Gutters	Time to First Maintenance	Industrial	Galvanised Steel	Yes	5-10	5	8	2
Commercial	Gutters	Aesthetic Life	Industrial	Galvanised Steel	Yes	5-10	6	10	2
Commercial	Gutters	Service Life	Benign	Galvanised Steel	Yes	30-50	16	32	2

Table 3.2 Example of entries in Maintenance database

Centre Code	CentreName	Long Deg	Lat Deg	<10 km	CaseLocation	Dist From Case	Case Long	Case Lat	Material	Service Life (years)	No of Cases
801	Aitkenvale State School	146.76	-19.29	1	VINCENT	1.0	146.77	-19.28	GAL/ZINC (UNPAINTED)	33.6	29
801	Aitkenvale State School	146.76	-19.29	1	VINCENT	1.0	146.77	-19.28	COLORBOND	38.0	1
801	Aitkenvale State School	146.76	-19.29	1	VINCENT	1.0	146.77	-19.28	GAL/ZINC (PAINTED)	38.8	164
190	Albany Creek State School	152.97	-27.34	1	ACACIA RIDGE	4.6	153.02	-27.35	GAL/ZINC (PAINTED)	42.6	8
190	Albany Creek State School	152.97	-27.34	1	ACACIA RIDGE	4.6	153.02	-27.35	GAL/ZINC (UNPAINTED)	43.0	1
190	Albany Creek State School	152.97	-27.34	1	ACACIA RIDGE	4.6	153.02	-27.35	ALUMINIUM	52.2	29
190	Albany Creek State School	152.97	-27.34	1	ACACIA RIDGE	4.6	153.02	-27.35	COLORBOND	45.0	1
1892	Albany Hills State School	152.97	-27.35	1	ACACIA RIDGE	4.4	153.02	-27.35	GAL/ZINC (PAINTED)	42.6	8

Table 3.3 Example of entries in Holistic model database (Mass Loss per annum is given in g

BuildingType	Position	Exposure	Material	BuildingFace	FacePos	Gutter Pos	Maintenance	MassLossPA
gutters	Building facade	Open	galvanized	Front face	edges	Sides-interior		13.28
gutters	Building facade	Open	galvanized	Front face	edges	Bottom-interior	Cleaned	21.92
gutters	Building facade	Open	galvanized	Front face	edges	Bottom-interior	Not cleaned	143.61
gutters	Building facade	sheltered	galvanized	Front face	edges	underside		11.50
gutters	Building facade	Open	zincalume	Front face	edges	Sides-interior		8.47
gutters	Building facade	Open	zincalume	Front face	edges	Bottom-interior	Cleaned	15.41
gutters	Building facade	Open	zincalume	Front face	edges	Bottom-interior	Not cleaned	76.70
gutters	Building facade	sheltered	zincalume	Front face	edges	underside		9.12
gutters	Building facade	Open	Colorbond	Front face	edges	Sides-interior		
gutters	Building facade	Open	Colorbond	Front face	edges	Bottom-interior	Cleaned	
gutters	Building facade	Open	Colorbond	Front face	edges	Bottom-interior	Not cleaned	
gutters	Building facade	sheltered	Colorbond	Front face	edges	underside		

The parameters identified to control corrosion degradation rates are summarised as:

- Time of wetness
- Chloride concentration
- Sulfur dioxide concentration (or deposition of other sulfur impurities)
- Ozone concentration
- Temperature
- pH of precipitation
- Volume of precipitation
- Deposition of dust
- Nitrogen oxide (NO_x) concentration

These parameters are all strongly dependent on geographic location, with climate and local industry level of paramount importance. Once the macroclimate has been identified then the rate of corrosion will also depend on placement within the building eg internal or external, if external then whether sheltered or exposed etc. A final parameter of importance is whether the building element is subject to regular maintenance. Maintenance includes cleaning and repainting but does not extend to replacement of the building component.

3.2.1 Characterisation of Environment

For the purpose of corrosion the environment needs to be characterized in terms of the pollutant, RH and type of rainfall. This is summarised in Table 3.4.

Table 3.4 Environment classifications

Pollutant	**RH**	**Rainfall**
Severe Marine	Very Humid	Frequent and Heavy
Marine	Humid	Frequent and Light
Severe Industrial	Standard	Standard and Heavy
Moderate Industrial	Standard	Standard and Light
Industrial	Dry	Infrequent and Heavy
Benign	Very Dry	Infrequent and Light

In addition, for the severe marine, marine, severe industrial and industrial classifications the neighbourhood must also be considered in terms of how the surrounding land use affects pollutant transport. Classifications include grassland, urban, forest and high rise.

3.2.2 Detailed Building Characterisation

Location in Building

Building structures have been considered with regard to the situations that will affect the amount of aerosol deposition of pollutants. Thus building locations have been divided into twelve types and these are listed in Table 3.5.

Table 3.5 Description of building locations for case definition

Case	Description
Open Rooftop	The top of any surface that bridges between the tops of two or more walls and has an average slope of 45 degrees or less. This includes flat, hip, gable, monoslope, multispan, sawtooth, arched mansard and conical roofs. It includes projections and indentations of 0.3 metres or less. The roof is to have a minimum dimension of at least two metres.
Open Wall	Any flat non-sheltered surface with a slope of less than 45 degrees off vertical including any projections or indentations that depart less than one metre from planarity. The wall is to have minimum dimension of at least one metre. Also includes bridge piers.
Sheltered Wall	Any area that is covered with a covering that stops all direct sunlight when the sun is less than 45 degrees from the zenith
Edges and External corners of walls or roofs	Comprises the area within one metre of any external corner. This excludes re-entrant corners, corners on isolated steelwork, and corners on some roofs (such as saw-tooth roofs). The angle of the external corner is to be between 0 and 135 degrees. It includes corners of bulk objects projecting from roofs.
Dirt Accumulation Zone	Any area in which water, dirt, leaves or dust can accumulate. This surface usually has an angle of less than 3 degrees to the horizontal but as corrosion develops it can grow to encompass much steeper angles
Roof cavity	Any object lining or found within the cavity between the ceiling and roof of a building.
Wall cavity	Any object lining or found within the cavity between the inner and outer walls of a building. Also includes cavities in multistorey buildings between the false ceiling and the floor above.
Moisture Accumulation Points in Wall Cavities	e.g bottom Plates
Underfloor cavity	Any object lining or found within the space under the ground floor of a building. Excludes any such space that is artificially heated or ventilated.
Semi-enclosed space	Seem most frequently as a lower floor in a multistorey car park. Defined as any object in a space with at least one large opening to the atmosphere. Excludes any such space that is artificially heated or ventilated.
Enclosed room	Includes rooms in domestic residences, commercial establishments, factories and warehouses, and elsewhere. Estimating the corrosion in an enclosed room requires further information on heating, artificial ventilation, and local sources of aerosols, gases and moisture.

Cleaning

Corrosion is also affected by how much of any pollutant deposition can be removed by the natural cleaning of rain, condensation and wind. Classifications with regard to cleaning levels are listed in Table 3.6.

Table 3.6 Definitions of cleaning

Case	Description
Open Rooftop	Any area exposed to sun and rain with a slope between 3 degrees and 45 degrees (but see (6) below
Open Wall	Any area that is not sheltered with a slope of less than 45 degrees off vertical.
Sheltered	Any area that is covered with a covering that stops all direct sunlight when the sun is less than 45 degrees from the zenith.
Crevice	Any gap small enough for capillary attraction to drag water upwards
Drop-off Zone	Any area from which water will drop. This typically occurs under the edges of overhangs
Dirt Accumulation zone	Any area in which water, dirt, leaves or dust can accumulate. This surface usually has an angle of less than 3 degrees to the horizontal but as corrosion develops it can grow to encompass much steeper angles.

Maintenance

If a metallic building element is subject to a regular maintenance schedule that will pick up and deal appropriately with the first signs of corrosion, then it is likely to last longer than one that is not maintained in the same situation. Thus maintenance, or lack of, is considered as important parameter for definition of a case. It is particularly an issue for building components, such as gutters, where dirt and debris can collect over time and affect drainage and the rate of drying after rainfall or condensation.

3.3 Defining Case Similarity

When the lifetime prediction tool is presented with a new case, it will search through the casebase library to find similar cases that have already been constructed. Whilst it is possible that a stored case may exist that matches all the case parameters exactly, it is more likely that some variation will occur. Thus it is necessary to have some method of defining how similar the new case is to each of those stored in the casebase and extracting the cases considered most 'similar'.

Similarity between cases must be based on similarity in the attributes that affect the corrosion rate of the building materials under consideration i.e.

- Geographic location
- Location in Building
- Maintenance, and
- Cleaning

Overall, a similarity number (S) will be defined, where:

$S = M_s \times C_s \times L_s \times G_s$

Where:

M_s is a measure of similarity in Maintenance, the Maintenance similarity index,

C_s is a measure of similarity in Cleaning, the Cleaning similarity index

L_s is a measure of similarity in Location in Building, the Location similarity index and

G_s is a measure of similarity in geographic location, the geographic similarity index.

If two parameters match exactly, the similarity index will equal 1. If two parameters are different but have similar effects on the likely corrosion rate, then the similarity index will be close to 1 (0.8-0.9). The lower the similarity index, then the greater the difference will be between the two situations in terms of likely corrosion rates. Since the individual similarity indices are multiplied together to provide the overall similarity index S, variations in individual indices result in a cumulative lowering of S. The cut-off point for S at which a case is not retrieved from the case base can be defined to broaden or narrow the cases chosen.

Values for the similarity indices have been defined in a series of tables. In this stage of the project development, not all cases have been considered, so only a subset (relevant to the gutter application) have been allocated values.

In defining the geographic location similarity index, further clarification was necessary. The most important aspect for geographic location is considered to be whether or not the specified case is in a marine environment or not (benign, salinity < 15 $mg/m^2.day$). If two cases do not match in this aspect then $G_s = 0$.

If two cases being compared are both non-marine then:

$G_s = 1$ if they are within 20 km of each other, and

$G_s = 0.9$ if they are within 50 km of each other.

For two marine cases or non-marine cases > 50 km apart then G_s is assigned values according to:

$$G_s = W_s * M_s$$

where W_s is the time of wetness similarity factor and M_s is the marine salinity factor. both of which have been defined by comparison of the TOW(%) and salinity values which can be found for locations from the Geographical Information System.

4. DESIGN AND IMPLEMENTATION OF SITUATED CBR FOR CORROSION PREDICTION

4.1 Specification and Design

The project has focused on the creation of the software architecture for component life prediction based on situated CBR. The architecture provides a structure for utilising existing knowledge and experiences to reason about the current situation (interpretation) and construct a solution to component life prediction (construction).

The software has been designed with consideration for the two applications specified by the project's industry partners, and not all the attributes for the cases discussed in the previous sections have been implemented in this stage of the project.

The user of the system supplies the following information (items in parenthesis indicate their possible values):

- Location of Site (coordinates pair on longitude and latitude in decimal degrees)
- Type of Component (roof / gutter)
- Material of Component (galvanised steel / zincalume / Colorbond®)
- Maintenance State (maintained / not maintained)
- Cleaning Condition (dirt can collect / dirt cannot collect)
- Cleaning State (cleaned / not cleaned)
- Location of Component within Building (list of locations in Table 3.5, Table 3.6)
- Condition of Geographic Location (marine application / non marine application)

Based on the input supplied, the situated CBR system computes a predicted component life value from its casebase and databases. The development of the system entails the creation of the following:

- interfaces to different databases;
- interface to a casebase to store previous problem solving episodes;
- a software framework to contain the above, and
- different entry points within the framework to allow the incorporation of different inference engines for interpretation and construction as defined in situated CBR.

The situated CBR system is expected to operate within the Windows XP environment utilizing Java version 1.4.

4.1.1 Software Architecture

Figure 4.1 illustrates the overall software architecture of the prototype system. All codes reside within a single machine and no distributed computations are considered in the design of the system. Software wrappers are used to insulate data storage technologies from the situated CBR system. A wrapper encapsulates the details of an underlying persistence technology through an interface. This interface provides a set of common access methods to the required data across different persistence technologies. Components of the situated CBR system that require data storage and retrieval functionalities are only required to conform to the method signatures of the relevant interface without being concerned about the technology used. When the technology is changed in subsequent development of the system, changes to the situated CBR system are isolated to the backend of the wrapper that interacts directly with the new technology. Codes within the situated CBR that utilize the wrapper are not affected.

Figure 4.1 Software architecture of the situated CBR system

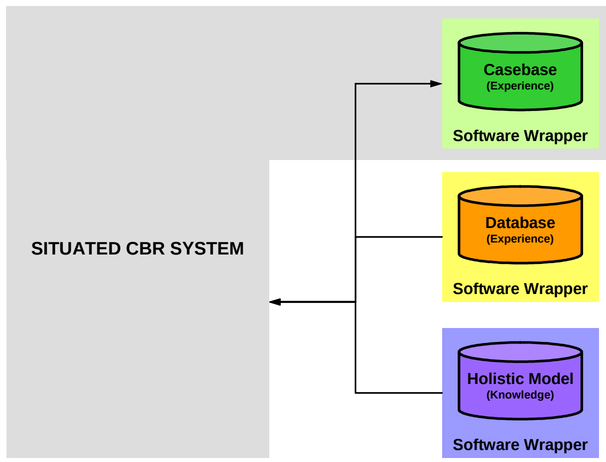


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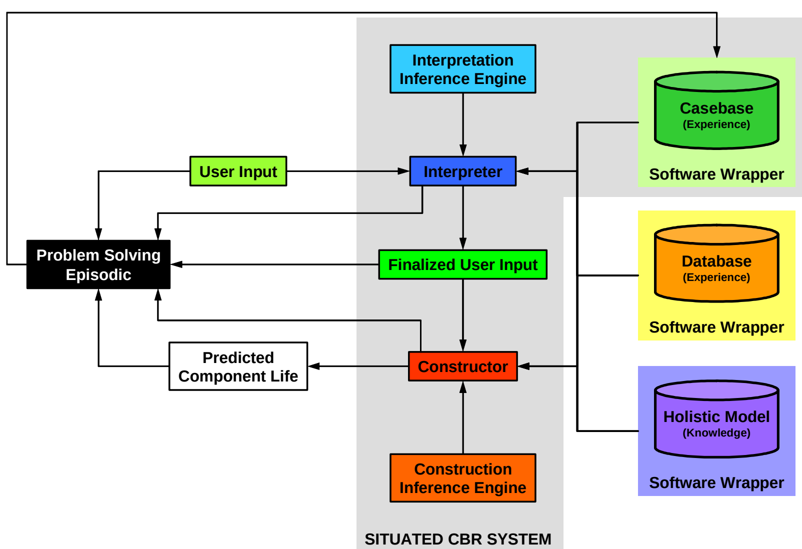
Figure 4.2 Key software components for interpretation and memory construction illustrates the key components that will implement the interpretation and construction of memory for the situated CBR system.

Figure 4.2 Key software components for interpretation and memory construction



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The end result of using the system is a new case. This case is made up of the following:

- initial user input;
- finalized user input;
- alternatives (subcases) used in construction consisting of: similar cases from the casebase, similar data from the Delphi and field databases, as well as similar computations from the holistic model;

- prediction component life;
- time stamp; and
- an inference module indicating how the prediction value is computed.

Information from interpretation is not stored.

4.1.2 Generation of Alternative Solutions

In terms of information from the casebase, associated cases of previous prediction episodes are retrieved so that previous problem solving experience can be utilized. A retrieved case is defined as similar to the current situation when its similarity index is computed to be >0.5. This value is set arbitrarily for the current development and can be fine-tuned later.

Experiences in terms of data from the databases that are retrieved are based on the use of retrieval key values as entered by the user eg. material, location and environment.

An inference engine is employed for the finalization process. The intelligence for this process is currently implemented by displaying the alternatives. Based on the finalized input data, alternatives for memory construction are generated from the casebase, databases and holistic model in the same way as in interpretation. Another inference engine is employed to combine these results and construct a complete solution for predicting component life.

The interpretation and construction inference engines have not been implemented in the current system but an entry point within the system's architecture has been provided. The intelligence for construction is currently implemented by displaying all the alternatives. Inference engines based on Artificial Intelligence (AI) technologies that model the required domain heuristics during interpretation and construction are accessed through the interpreter and constructor respectively. Currently, dummy function calls are used to emulate these accesses.

4.1.3 Secondary Issues

The following were taken as secondary issues during the development of the system:

- user interfaces
- extensive error handling; and
- performance and efficiency.

The structure of the software framework was seen as the main focus of the project, and simple user interfaces were developed later to facilitate the development of the applications. No provisions were made for handling errors, performance and efficiency issues for the same reason.

4.1.4 Software Modules

The situated CBR system is composed of the following:

- user input module;
- display module;
- interpretation module;
- construction module;
- inference module
- similarity computation module;
- data source module and
- wrappers for data source.

Figure 4.3 presents the overall picture of how these modules relate to each other as part of the whole system. The responsibility of each module is outlined in Table 4.1.

Figure 4.3 Relationships between different modules of the situated CBR system

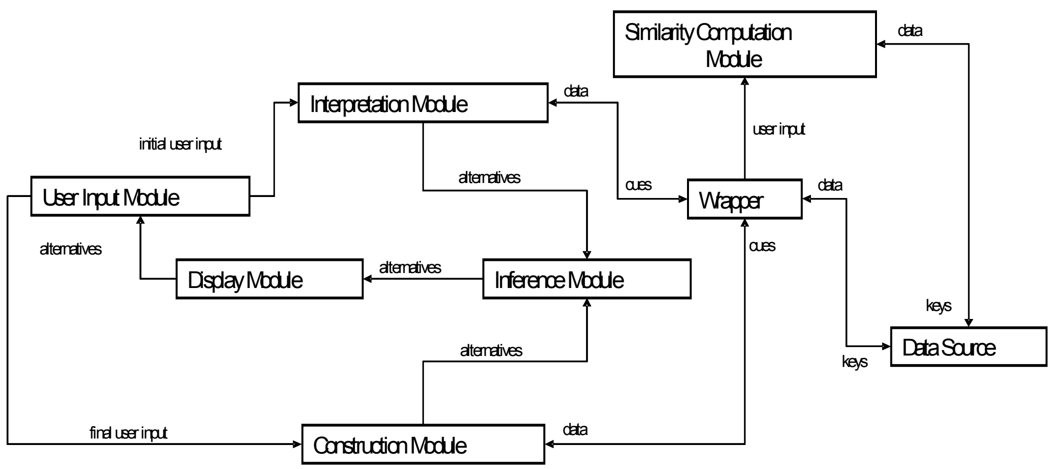

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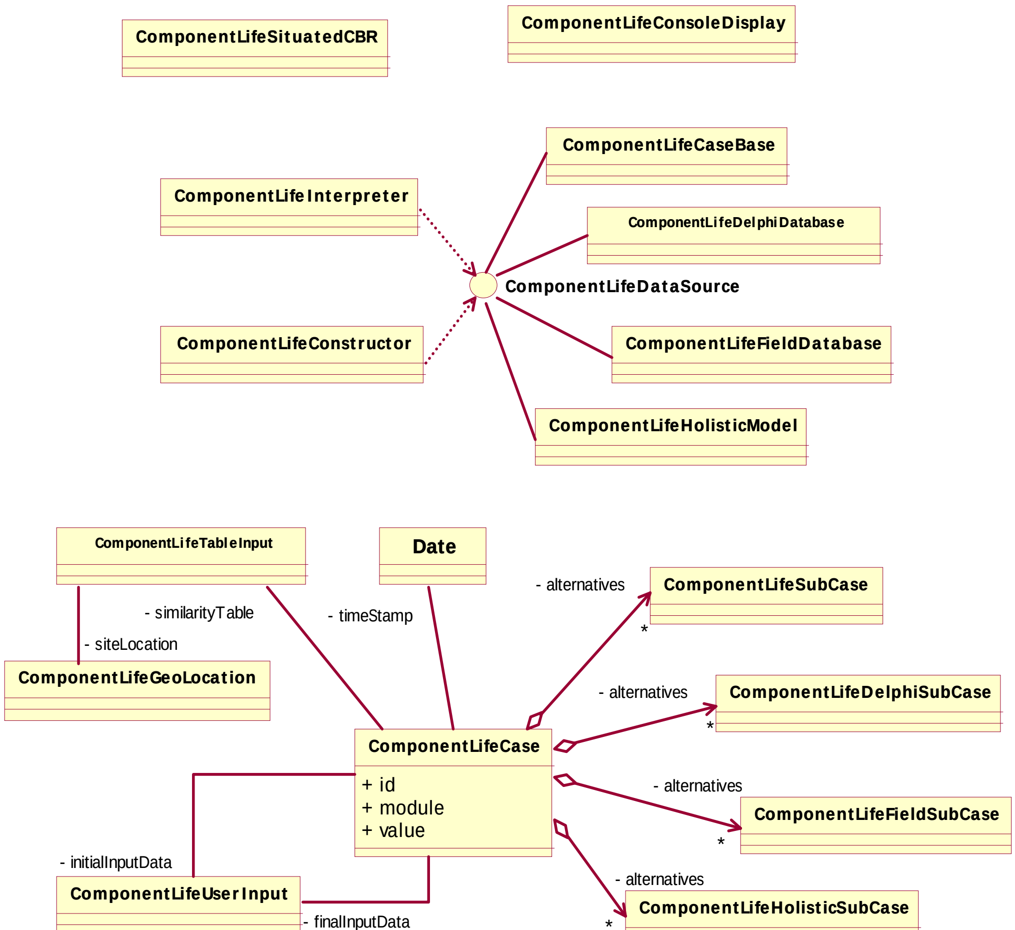
Table 4.1 Software modules in the situated CBR system

Module	**Responsibility**
User Input	To represent the set of user input parameters.
Display	To display the output of different processes.
Interpretation	To provide the required interpretative function for situated CBR.
Construction	To provide the required constructive function for situated CBR.
Inference	To represent domain heuristics for finalizing user input and constructing a solution from a series of alternatives. To provide an entry point for incorporating different AI engines for inferencing.
Similarity Computation	To calculate the similarity between the input parameters and previous problem solving episodes. To provide an interface to different ways to calculate similarity indices so that changes are isolated when different methods are used.
Data Source Module	To provide the required data for interpretation and construction of solutions.
Wrappers for Data Source	To provide an interface to various data sources so that changes are isolated when persistence technologies changes. To an entry point for incorporating different mechanisms that allow alternatives to be retrieved from the data sources based on variable keys.

4.2 Implementation

Figure 4.4 outlines the key classes of the situated CBR system.

Figure 4.4 Key Classes in implementation of CBR



The situated CBR framework developed in this project was thoroughly tested through a series of operation scenarios for the required behaviours as dictated by the specification of the system.

5. GUTTER APPLICATION FOR QUEENSLAND DEPARTMENT OF PUBLIC WORKS

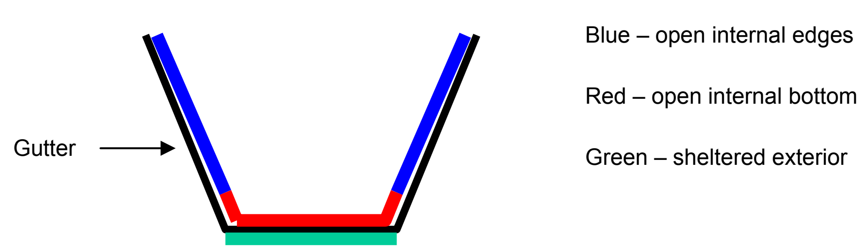
The implementation of the general CBR engine for corrosion prediction of building components has been further modified to provide the QDPW with an application that gives lifetime prediction for gutters in schools in Queensland.

Modifications included further specification of cases for gutters and adaptation of some of the modules in the general Holistic model to make it applicable for gutters and the three main gutter materials: galvanised steel, zincalume and Colorbond®.

5.1 Case Definition for Gutters

Gutters were broken up into different elements or cases as it was considered that the different elements would experience variations in local climate and as such were likely to degrade at different rates. These are shown in Figure 5.1.

Figure 5.1 Diagram of gutter cases



The bottom of the gutter is the area that will be most affected by an accumulation of dirt and debris, with the internal edges and sides less so. The exterior of the gutter is considered to be 'sheltered' and is not an area where dirt can accumulate. However as a sheltered location it will not be washed by rain and thus marine salt deposited by wind can accumulate.

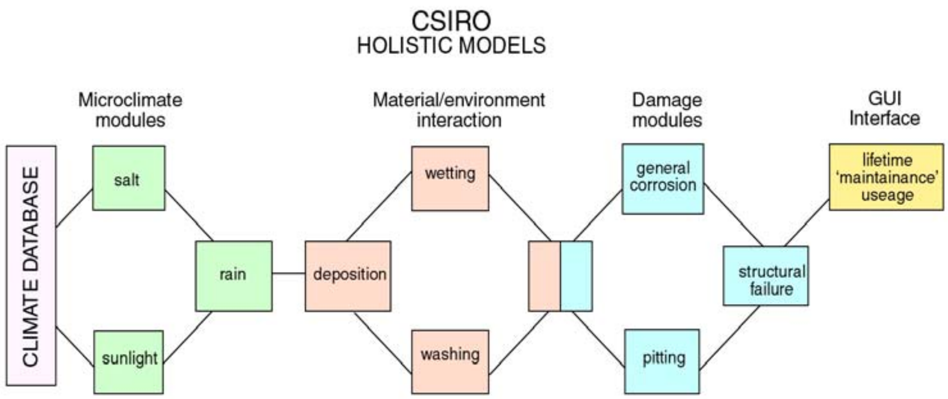
5.2 Holistic Model Modifications

The holistic model comprises a series of modules that consider the various effects of climate, microclimate, and material/environment interactions on the rate of corrosion damage (**Error! Reference source not found.**). Modifications to a number of the modules were required to make the model applicable for use with gutters.

5.2.1 Time of Wetness

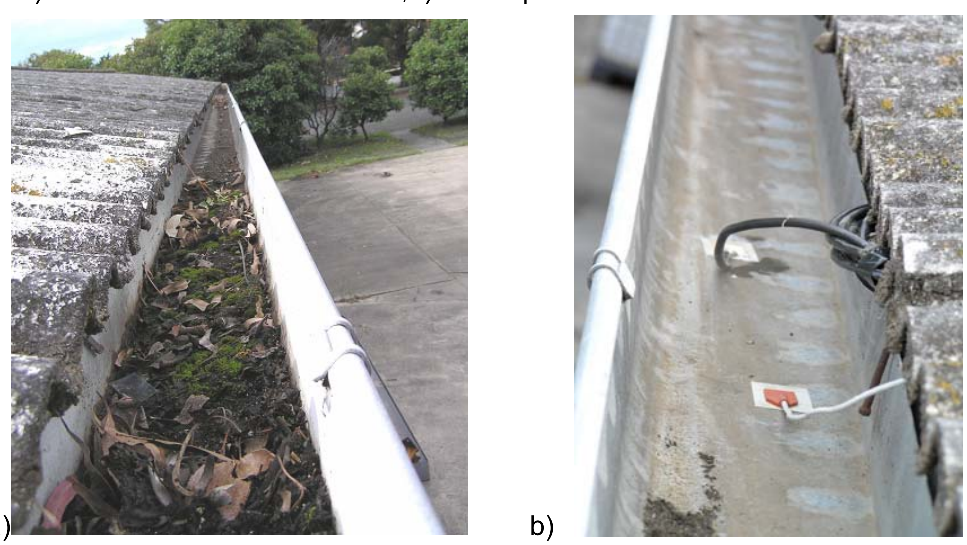
An important parameter in the holistic model is the Time of Wetness (TOW). Because gutters are a building component that is classified as a possible dirt accumulation zone, it was necessary to formulate new rules for TOW (following wetting events such as rainfall) to be incorporated into the model. Clean, freely flowing gutters will dry out more quickly than gutters that have an accumulation of leaves and dirt and may therefore have a different rate of degradation.

Figure 5.2 Schematic of the modules of the holistic model



TOW was measured experimentally by placing sensors (wetness and surface temperature) in a galvanised gutter on site at CMIT Highett, Melbourne. Sensors were placed in a clean section and one where there was significant build up of dirt and leaf litter to an approximate depth of 10mm. Figure 5.3a shows the two sections of gutter and Figure 5.3b the sensor placement in the clean section of the gutter. The CSIRO site at Highett also has an exposure station which is well characterised in terms of weather, corrosion and salt deposition.

Figure 5.3 a) Gutter used for TOW measurements, b) sensors placed in clean section

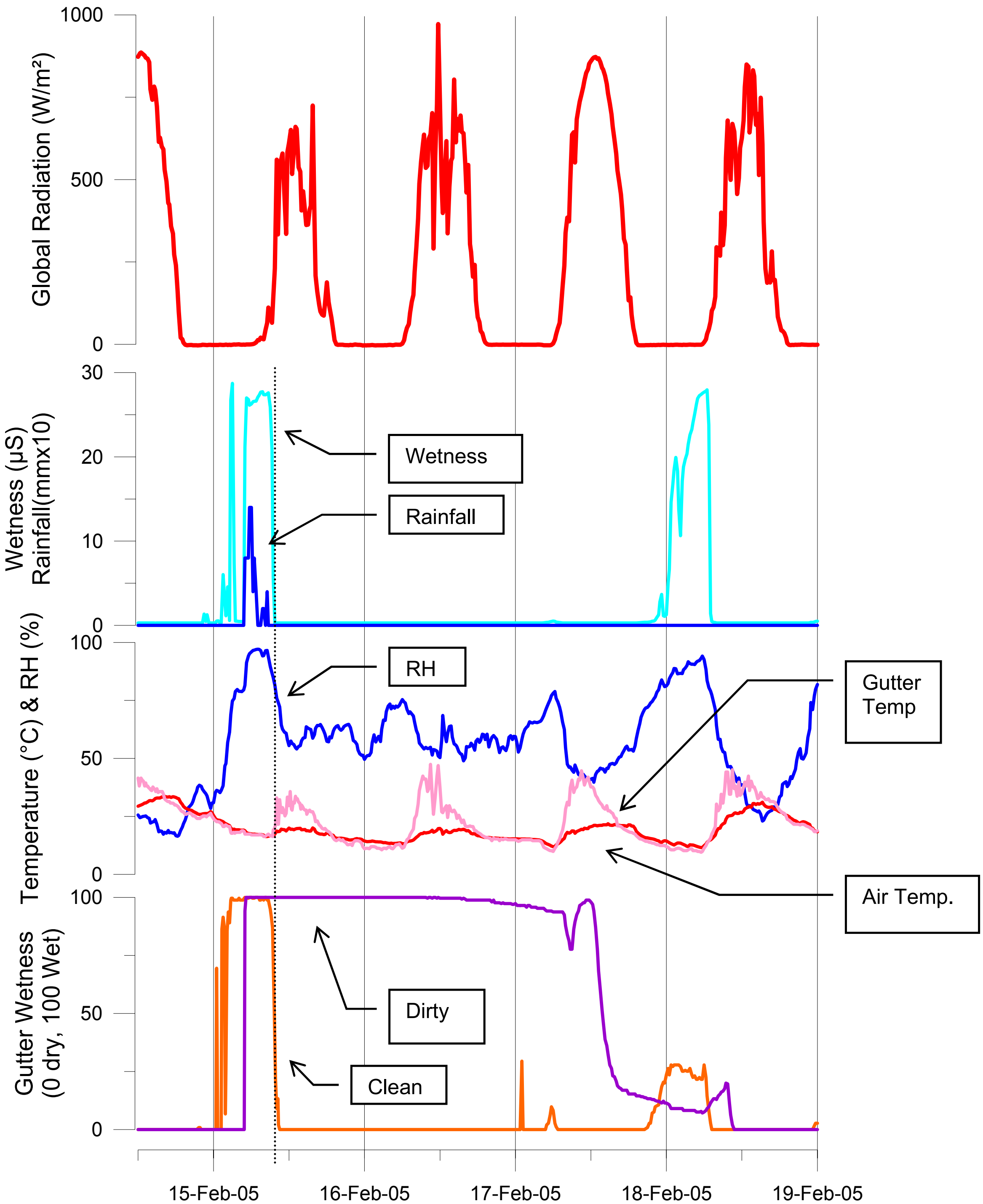


a) b)

Data was collected from the sensors at 15 minute intervals over a 43-day period in February-March 2005 and combined with data from the weather station. A section of the data collected is illustrated in Figure 5.4.

The graph shows that a wetness event, rain, occurred on the morning of the 15th of February and that both the clean and dirty sections of the gutter became wet. The sensor in the dirty section took longer to register the wetness as the moisture had to permeate the dirt and leaf litter in the gutter. For these experiments, the start of the drying period is timed from when the weather station wetness sensor starts to dry.

Figure 5.4 Graph of data from 15 - 19 February 2005



The drying period is considered ended when the gutter wetness sensor has returned to zero. The graph in Figure 5.4 shows the clean section of gutter took only 1.5 hours to dry whereas the dirty gutter took over 73 hours. The average values for all significant wetting events in the measurement period were 2.25 hours for the clean gutter and 52.33 hours for the dirty gutter.

Table 5.1 shows a summary of variables typically used for corrosion studies. TOW is the time of wetness expressed as a percentage of time, the ISO TOW is when the relative humidity is greater than 80% and temperature is greater than 0°C according to ISO 9223. The Gutter TOWs are based on the wetness sensors and the Air TOW is the wetness sensor on the weather station. Variation in these values would be expected at different times of the year.

Table 5.1 Summary data from TOW study

Variable	**Value**	**Units**
ISO TOW	22.8	% of time
Gutter TOW Clean	54.0	% of time
Gutter TOW Dirty	37.2	% of time
Air TOW	14.9	% of time
Average Air Temp	18.0	°C
Average Gutter Temp	20.8	°C
Average Air RH	65.9	%

It is interesting to note that the clean gutter has a longer TOW overall (54%) than the dirty section (37%). This is because the clean section is wet nearly every night due to condensation events while the dirt and leaf litter in the dirty section absorb a certain amount of water before the gutter or sensor get wet.

5.2.2 Application to the Holistic Model

The Time of Wetness is relevant to determining the state of the surface of the building component. Three states of a surface are defined

a) S1 - dry
b) S2 - wet from wetting of hygroscopic salts
c) S3 - wet from rain

The holistic model calculates state on a three hour interval. The standard model assumes that a surface is in state 3 whenever rain is occurring but once the rain has ceased, it is dry before the next 3 hour period .If the rain ceased in the middle of the last time period this implies drying takes no more than 1.5 hours. The studies of gutters indicate that this is a reasonable assumption for all cases, except the bottom of gutters filled with dirt and debris. For this case it is assumed that the gutter remains in State 3 for 48 hours after rain.

5.2.3 Colorbond® Degradation Model

Essentially there are six gutter types in Australia:

- Galvanised steel
- Painted galvanised steel
- Zincalume coated steel
- Painted zincalume coated steel
- Colorbond® with one-sided topcoat
- Colorbond® with two-sided topcoat

The degradation of galvanised steel and zincalume coated steel products could be predicted directly from the previously formulated holistic model. The application of paint to these two materials is not modelled because the application is carried out after gutter installation and quality control on such paint films is poor.

The holistic model was updated with the incorporation of a module dealing with the degradation of Colorbond® materials. Colorbond® is a product of Bluescope steel and has been proven to have exceptional performance in most locations across Australia. Although there are different grades of Colorbond®, the most common make-up for guttering is steel sheet (low carbon steel) with a coating of zincalume AZ 150 (150 g m^{-2}), which is overcoated on both sides with a 5 μm chromate-containing epoxy primer. The one-sided product has a 20 μm thick UV-resistant topcoat and a 5 μm grey backing coat covering the primer (Bluescope Steel, 2005). Colorbond® gutters are assembled so that the backing coat forms the interior of the gutter and the coloured topcoat forms the outer gutter.

Most paint films are thought to be best modelled with either a localised mechanism only or a combination of localised and general mechanisms (Sjöström, 1990). Colorbond®, which comprises of two organic layers, a thin epoxy primer containing inhibiting pigments and a poly vinylidene fluoride top coat, has been shown to fail in localised areas. Inspection of the defects located on unexposed Colorbond® suggested that they had a diameter in the range of 50 μm.

Figure 5.5 provides a visual representation of the sequence of steps assumed in formulating the model of Colorbond® degradation. The steps are:

a) A 50mm diameter defect in the organic coating is assumed,
b) Chromate is leached from the primer due to the presence of moisture and salts,
c) Upon depletion of chromate inhibitor zincalume is corroded
d) When the hole reaches the steel, surrounding zincalume is lost at an increased rate due to galvanic corrosion. Underlying steel corrosion is assumed to occur when the diameter of exposed steel > 1 cm and zincalume no longer provides sufficient galvanic protection for the underlying steel.

A summary of the inputs, parameters and mathematical details of the Colorbond® degradation model is presented in Table 5.2.

5.2.4 Conversion of Mass Loss to Life Estimate

The output from the holistic model is generally a mass loss per year for the metals and metallic coatings and the paint coatings provide a measure of the damage accumulation. In order to interface the holistic model with the CBR engine, the output needed to be converted into a component life, in years.

To convert the mass loss to a component life three additional pieces of information were required

1. Final Failure Criteria
2. Event "Tree" for failure
3. Conversion from mass loss per year to mass loss over an appreciable time.

Figure 5.5 Model for the degradation of Colorbond materials. (a) A 50 mm diameter defect in the organic coating is assumed, (b) chromate is leached from the primer due to the presence of moisture and salts, (c) upon depletion of chromate inhibitor zincalume is corroded with an aspect ratio of a/d = 50, (d) where d exceeds the thickness of zincalume, surrounding zincalume is lost at an increased rate due to galvanic corrosion. Steel corrosion is assumed to occur when g > 1 cm and zincalume no longer provides sufficient galvanic protection for the underlying steel.

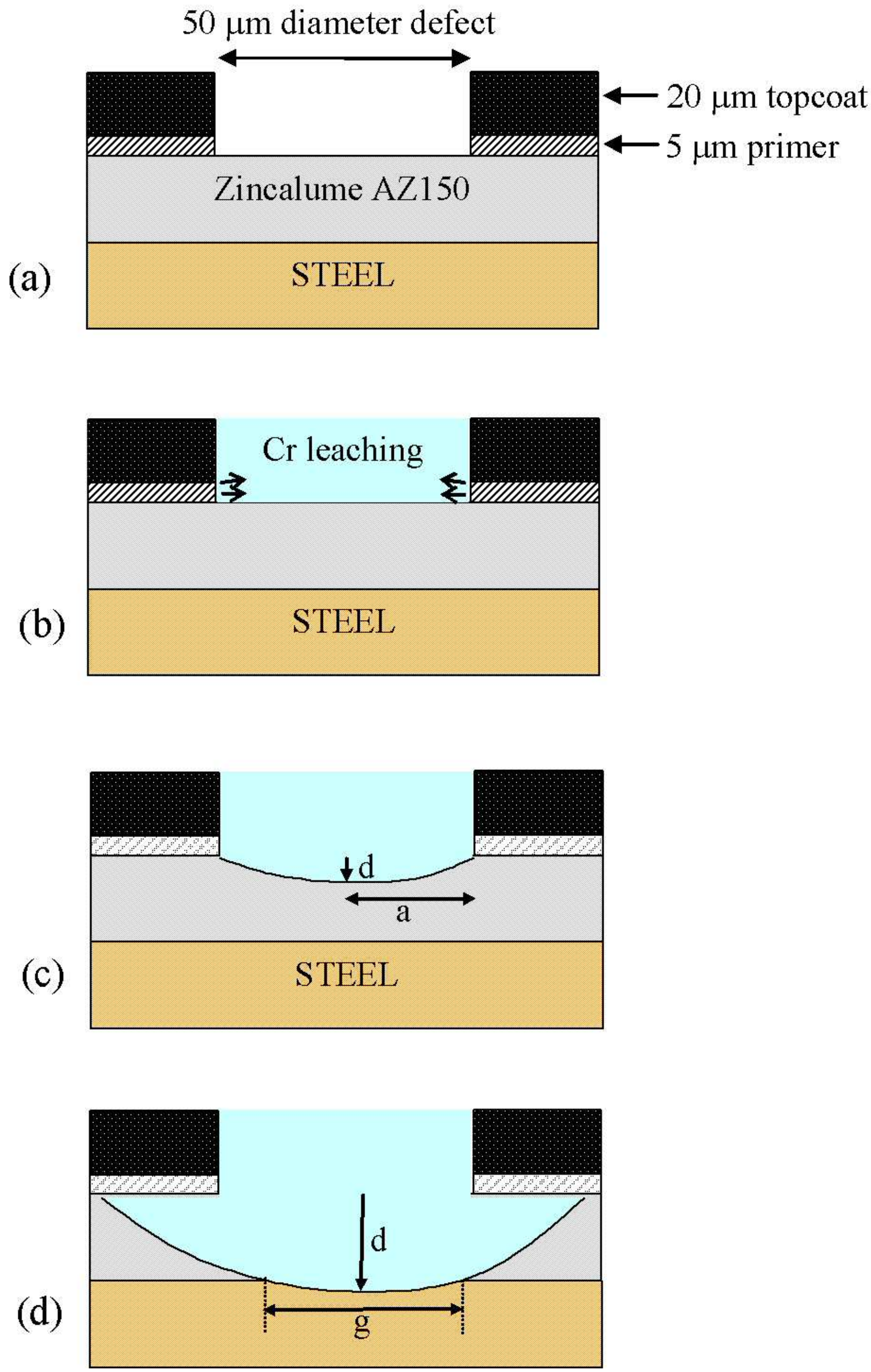


Table 5.2 Inputs, parameters and details of mathematics within the Colorbond® degradation model.

Parameter	Symbol	Units	Value	Description
Surface condition	S		0 = dry 1 = condensed moisture 2 = raining	Determines whether wet or dry. Derived from relative humidity and surface temperature data in holistic model.
Cumulative time-of-wetness	TOW_{cum}	hours	When S = 1 or 2, $=10^{\log(L_{cum})-0.5(\log\frac{TOW_{cum}}{TOW_{cum}+3})}$ For both topcoat and backing coat: L_{cum}=1.41E-13 mol when TOW_{cum}= 0 hrs.	Cumulative time-of-wetness, where S = 1 or 2 allows leaching of Cr from primer according to Fick's second Law.
Leached Cr	L_{cum}	mol	L_{cum} is the running accumulation of chromate that would be leached in the absence of chloride anions.	L_{cum} is dependent upon the area of primer exposed and not on the total chromate concentration or liquid volume.
Additional leaching	L_{add}	mol	Back: $=10^{\log(L_{cum})-0.5(\log\frac{TOW_{cum}}{TOW_{cum}+3})}$ Top: $=10^{\log(L_{cum})-0.5(\log\frac{TOW_{cum}}{TOW_{cum}+3})}$	The additional leaching of Cr through the backing coat or topcoat. Initial values, backcoat =1.128E-13, topcoat = 2.282E-14.
Salt modified leach rate	L_{Cl}	mol	= $((L_{cum}+L_{add})*1.2123*[Cl]^{0.1544})$	The loss of chromate in a single 3-hour period given that a certain concentration of chloride is present on the surface.
Latitude	LAT	Degrees		Input to describe the likely photooxidation rate (UV) exposure of paint films.
Sun/Salt leaching	L_{total}	mol	=(1+x*time)*(-0.0004*LAT^2+0.0003*LAT+1.2558)*L_{Cl} x = 0.8 for topcoat, 0.4 for backing sheet.	Leaching as a result of both sun and salt. x values are derived from Bauer (2000).
Cr remaining	Cr_{rem}	mol	Initial - L_{total} $Cr_{rem} = 1.084 \times 10^{-10} - L_{total}$ mol	Initial Cr present minus the cumulative sum of all leached chromate. Assuming the primer contains 20 % v/v strontium chromate, the total available pigment in a 25 μm zone surrounding the defect is of the order of 0.20 × 18.4 mmol cm^{-3} × 2.945 × 10^{-8} cm^3 = 1.084 × 10^{-10} mol. Cr has been shown to leach from no further into epoxy-based paints than about 25 μm from a defect.

Defect volume	V	L	= 3.92699E-11 for both topcoat and backing coat.	Initial volume (50 μm damage) + 25 μm area surrounding damage. 25 μm surrounding damage is the accessible area for Cr to leach from. Volume is generated from the 5 μm nominal thickness of primer.
Salt concentration	[Cl]	$mg/m^2.day$	Cumulative salt deposition derived from holistic model.	
Active chromate concentration	[Cr]	mol/L	$[Cr] = \frac{[L_{total}(t) - L_{total}(t-1)]}{V} \frac{Cr_{rem}}{1.084 \times 10^{-10}}$	The estimated amount of chromate in mol/L available to prevent corrosion. Calculated based upon leached amount and volume.
Parameter	**Symbol**	**Units**	**Value**	**Description**
Non-Cr zincalume mass loss	M_{ZA}	micron	Where d > 20 μm, M is multiplied by 1.42 due to increased galvanic corrosion resulting from steel exposure. =0.0000091+0.0000013[Cl]	Mass loss of zincalume calculated based upon holistic model at a given salt accumulation.
Chromate dependence	Cr_{dep}		(0.15+1.85*EXP(-Cr_{dep}/0.00002))/0.15	Dependence of corrosion rate on chromate concentration
Actual zincalume mass loss	d_{ZA}	micron	(Cr_{dep}-1)*M_{ZA}	Estimated real damage to zincalume in terms of depth.
Cumulative actual zincalume mass loss	d	micron	$\sum d_{za}$	Sum of corrosion damage
Steel corrosion	d_{STEEL}	micron	0.00336*LN[Cl]-0.00083	Where g > 50, d is predicted by holistic model for steel mass loss given a certain salt accumulation.
Cumulative metal mass loss	d_{total}	micron	$= \sum d_{za} + \sum d_{st}$	Total depth of penetration into substrate.

5.2.5 Final failure Criteria

There are three types of final failure criteria: structural safety, serviceability and aesthetics. The importance of each of these will depend on the building component and its use.

Definitions considered for roof sheeting and guttering are:

1) Structural safety – not relevant.

2) Serviceability – no through sheet corrosion.

3) Aesthetics:

   a) Light criteria – Red rust less than 50%.
   b) Tight Criteria – No Red rust.

5.2.6 Event Tree For failure

The event tree for failure would be different for different materials and criteria. These required events are set out in Table 5.3 and definitions of these events in

Table 5.4.

Table 5.3 Required Events for Failure

Material	Criteria	Event 1	Event 2	Event 3
Colorbond®	Serviceability	Failure of polymeric coating	Failure of Zincalume coating	Through Corrosion of Steel substrate
Colorbond®	Aesthetics-A	Failure of polymeric coating	Failure of Zincalume coating	50% Red Rust
	Aesthetics -B	Failure of polymeric coating	Failure of Zincalume coating	
Zincalume	Serviceability	Failure of Zincalume coating	Through Corrosion of Steel substrate	
	Aesthetics-A	Failure of Zincalume coating	50% Red Rust	
	Aesthetics -B	Failure of Zincalume coating		
Zincalume	Serviceability	Failure of Zinc coating	Through Corrosion of Steel substrate	
	Aesthetics-A	Failure of Zinc coating	50% Red Rust	
	Aesthetics -B	Failure of Zinc coating		

Table 5.4 Definition of Failure

Event	Definition	Explanation
Failure of polymeric coating	D= 1	D is damage index
Failure of Zincalume coating	ML= 0.75* Coating Mass	Coating mass is specified for all materials – assume Coating mass = 150 g/m2
Failure of Zinc coating	ML= 0.75* Coating Mass	Coating mass is specified for all materials – assume Coating mass = 275 g/m2
Through Corrosion of Steel substrate	TL= 1 * Component Thickness	Component Thickness is specified for all materials assume = 0.6 mm
50% Red Rust	TL=0.1 mm.	

5.2.7 Conversion of mass loss per year to life estimate

Using the definitions in the section above, formulae were derived to convert the mass loss per year into estimates of the time taken to reach each of the failure events.

5.2.8 Gutter Survey

A roof and gutter survey carried out by CSIRO MIT has been used to determine some parameter values in the modified holistic model for gutters. The age and condition of a number of gutters were assessed. The buildings surveyed were located in a 7-10 Km radius of CSIRO Highett. Highett is a suburb of Melbourne in Victoria. It is approximately 3 Km from Port Phillip Bay and has a salt deposition of approximately 8 mg/m².day and a corrosion rate for steel of approximately 10μm/year.

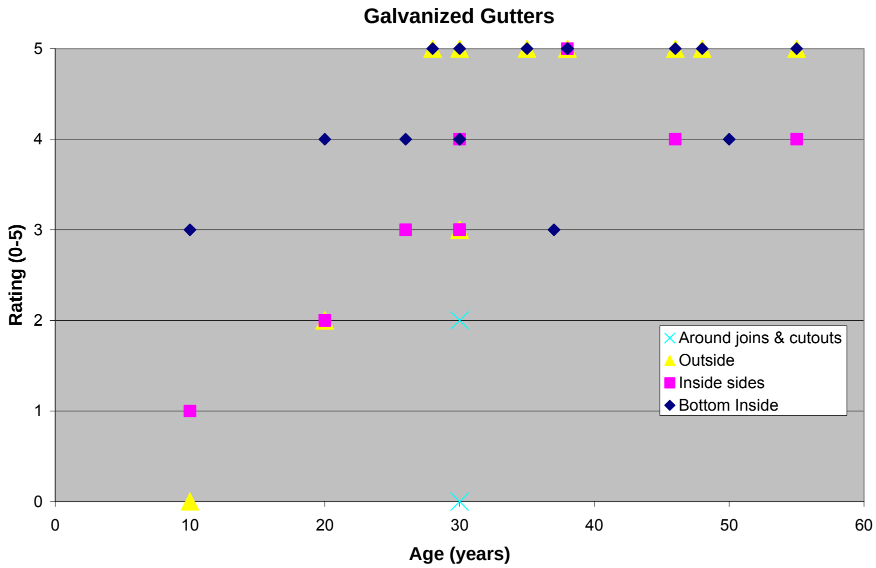
A damage rating scale was formulated to assess the condition of the gutters. The scale went from 0 (no damage) to 5 (perforation evident on gutter). The interpretation of the damage scale is explained in Table 5.5.

Table 5.5 Legend of damage ratings for Gutter survey

Damage Rating	Condition	Condition around joints
0	No Damage	No Damage
1	Some loss of paint gloss/coating (Top coat only on multi-coat systems), dulling of surface	Discolouration of paint at joins and near rivets, fasteners or brackets
2	Loss of paint (chips lost, peeling, undercoat may still be intact), White corrosion product less than 50%	Some corrosion of rivets, fasteners or brackets
3	Some red rust present, less than 50% of a particular area ie, bottom surface	White corrosion products on rivets, fasteners or brackets and cut edges
4	50- 100% red rust	Red rust and white corrosion products on rivets, fasteners or brackets and cut edges
5	Perforation	Loss of rivets, fasteners or brackets, perforation of material

Results were tabulated and graphed. An example of the results for galvanised gutters is shown in **Error! Reference source not found.**.

Figure 5.6 Graphical representation of the state of Galvanised gutters with age



From the gutter survey it was concluded that galvanised gutters in the survey area show some damage by 10 years, with significant damage, leading to the need for replacement, at around 20 years. The Zincalume® gutters showed some damage around 10 years and replacement was needed after 25 years. The Colorbond® gutters showed some damage after 5 years, but no significant damage causing the need for replacement in any of the gutters surveyed with the oldest being approximately 20-25 years.

5.2.9 Holistic Model Program for Gutters

The modifications made to the holistic model to adapt it for use with gutters have been incorporated into a stand-alone program, mainly for development purposes, but it can be used to model mass loss for gutters at any point in Australia.

The Holistic model as outlined previously Figure 5.2 contains a number of modules to:

a) predict the salinity at a location
b) predict the climate at a location
c) predict salinity retention on a component on a building
d) predict the state of a surface on a component on a building
e) predict the damage of the component on the building.

In adapting the holistic model for the gutter application:

a) and b) were unchanged from the prior holistic model,
c) modifications were made to constants in the model to reflect the different cases for gutters but the basic formulation remained the same,
d) modifications were made for the case of a gutter filled with dirt and debris (TOW),

e) modifications made for galvanised steel and zincalume and completely developed for Colorbond®.

Derivations for these modifications have been discussed in the previous sections.

5.2.10 Application of the Model

To test the model, the mass losses at two locations in southern Queensland were estimated. One was a Marine location and the other a benign location (Table 5.6). In

Table 5.7 a comparison of the estimate of the life of gutters based on the Delphi study, roof survey and holistic model is made. It is apparent that the lifespan estimates are similar when like cases are considered. However, before the modified holistic model is released commercially, it requires more verification and collection of data on maintenance and lifespans of gutters of the different materials.

Table 5.6 Estimated mass loss at two locations in Queensland

Longitude	**Latitude**	**Salinity**	**Exposure**				**Mass loss – g/m^2.**
153 441	28061	38	Open	bottom	zincalume	NC	19
			Open	bottom	zincalume	C	13.5
			sheltered		zincalume		7.3
			Open	edges	zincalume		8.9
153 441	28061	38	Open	bottom	galvanised	NC	33
			Open	bottom	galvanised	C	31
			sheltered	zincalume	galvanised		31
			Open	edges	galvanised		18
153 425	28049	6	Open	bottom	zincalume	NC	67
			Open	bottom	zincalume	C	16
			sheltered		zincalume		9
			Open	edges	zincalume		12
153 425	28049	6	Open	bottom	galvanised	NC	56
			Open	bottom	galvanised	C	18
			sheltered	zincalume	galvanised		11
			Open	edges	galvanised		18

Table 5.7 Comparison of Gutter Life by Model and other Methods

Location	Component Case	Method	Life
Marine	Unspecified position, galvanised	Delphi	10
Benign	Unspecified position galvanised	Delphi	32
Marine	Unspecified position Zincalume	Delphi	21
Benign	Unspecified position Zincalume	Delphi	42
Marine	Unspecified position galvanised	Survey	15
Benign	Unspecified position galvanised	Survey	55
Benign	Unspecified position zincalume	Survey	>40
Marine	Sheltered-galvanised	Holistic Model	15
Marine	Internal Edge-galvanised	Holistic Model	33
Marine	Internal –bottom –cleaned-galvanised	Holistic Model	15
Marine	Internal –bottom –not cleaned-galvanised	Holistic Model	14
Benign	Sheltered-galvanised	Holistic Model	33
Benign	Internal Edge-galvanised	Holistic Model	>60
Benign	Internal –bottom –cleaned-galvanised	Holistic Model	33
Benign	Internal –bottom –not cleaned-galvanised	Holistic Model	7
Marine	Sheltered-zincalume	Holistic Model	24
Marine	Internal Edge-zincalume	Holistic Model	37
Marine	Internal –bottom –cleaned-zincalume	Holistic Model	16
Marine	Internal –bottom –not cleaned-zincalume	Holistic Model	5
Benign	Sheltered-zincalume	Holistic Model	37
Benign	Internal Edge-zincalume	Holistic Model	50
Benign	Internal –bottom –cleaned-zincalume	Holistic Model	21
Benign	Internal –bottom –not cleaned-zincalume	Holistic Model	13

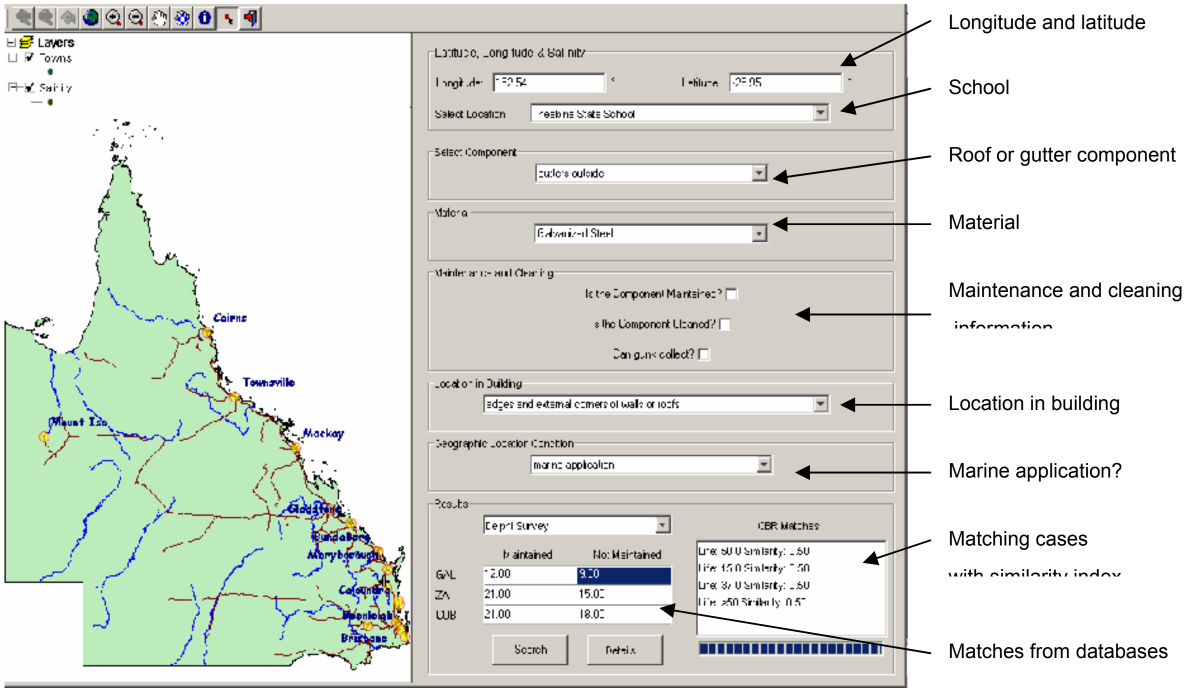
5.2.11 Database for CBR Program

The longitude and latitude coordinates for a subset of the Queensland schools were run through the Holistic Model program to generate a database to interface with the CBR engine.

5.3 CBR Program User Interface

A GUI has been created to allow users to interrogate the CBR program developed for the gutters in Queensland Schools' application (Figure 5.7). A subset of schools in the Southern coastal regions has been used in the program and can be accessed through a drop down menu. A red cross will indicate the position of the selected school on the map of Queensland. If a school is not chosen, the map of Queensland can be used to select points within the state which will define the longitude and latitude.

Figure 5.7 GUI developed for the Queensland schools' gutter application



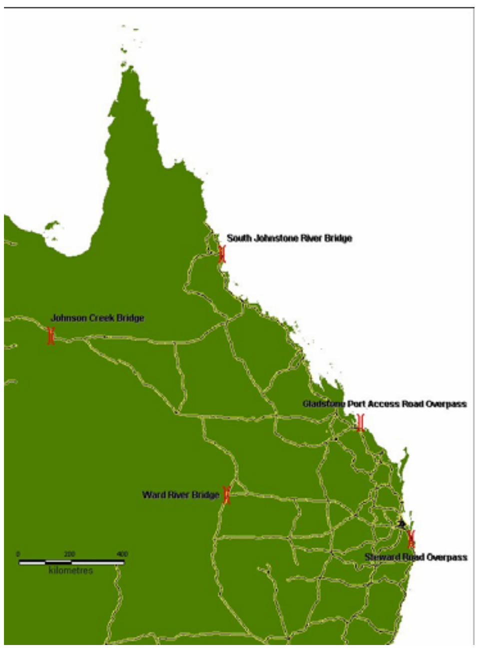
Dropdown menus have been incorporate to allow selection of gutter components and materials etc. Check boxes define whether the component under consideration is Maintained, or Cleaned etc. The search button at the bottom initiates the CBR engine and matching cases are retrieved and shown in the bottom right window, with the corresponding similarity index. Database matches are also shown in the table to the left, all three gutter material types are listed. A button at the bottom of the window can be used to get further details of the matching cases listed.

6. BRIDGE APPLICATION FOR QUEENSLAND DEPARTMENT OF MAIN ROADS

Maintenance of bridge structures is a major issue for the Queensland Department of Main Roads. An initial approach has been made to the future development of a CBR program for lifetime prediction of metallic bridge components. This involved the analysis of five representative bridge structures to determine common elements to be used as "cases" - those defined for buildings are not applicable.

The five bridges analysed included the Gladstone Port Access Road Overpass, Stewart Road Overpass, South Johnstone River Bridge, Johnson Creek Bridge and the Ward River Bridge. The locations of these bridges are shown in Figure 6.1.

Figure 6.1 Locations of the five bridges analysed



6.1 Analysis Methodology

The salt deposition on the five representative bridge structures was computed using computational fluid dynamics (CFD) and compared against the deposition on a salt candle at the same location.

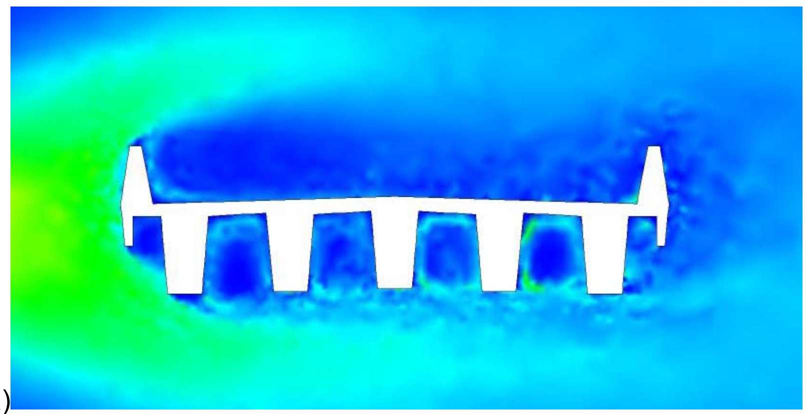
Illustrative results for the Gladstone Port Access Road Overpass are shown. The Gladstone Port Access Road Overpass in Gladstone City is located at latitude 23°51' and longitude 151°30'. It is on the Gladstone Port Access Road between Glenlyon Road and the Port Precinct and passes over the top of Auckland Street and the railway lines. There is ocean to the North, North East and East of this bridge.

The bridge comprises twelve spans ranging in length from 28.4 metres to 37 metres. The superstructure consists of a reinforced concrete deck on rectangular prestressed concrete deck units for span 12 and on five T-ROFF trough-shaped prestressed concrete girders for spans 1 to 11. For these 11 spans the total width of the superstructure is 10.44 metres and the height is 2.81 metres, giving a height to width ratio of 1:3.7.

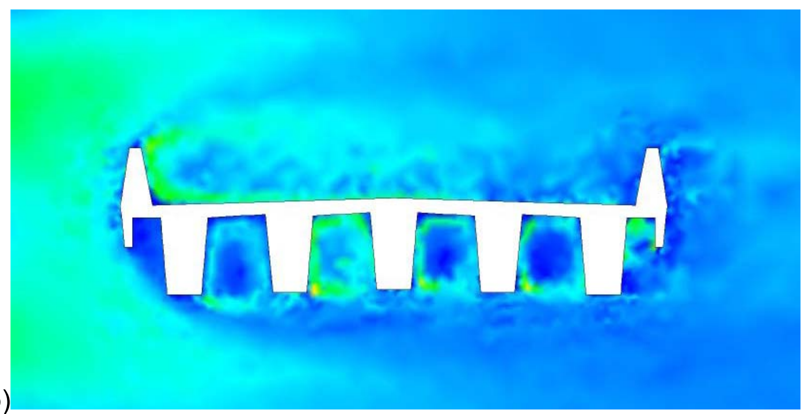
The salt deposition on a salt candle, extracted from the CSIRO GIS database at the location of Gladstone for a marine environment at the latitude and longitude given, is 13.3 mg.m^2/day. This does not take into account the bridge height.

The deposition on the superstructure was checked using three different aerosol release strategies. In one, aerosols were released directly upwind of the bridge, in the second they were released in bands above and below the bridge, in the third they were released over a broad area. Results for the Gladstone overpass are shown in Figure 6.2. The aerosol was diffused upstream due to turbulence.

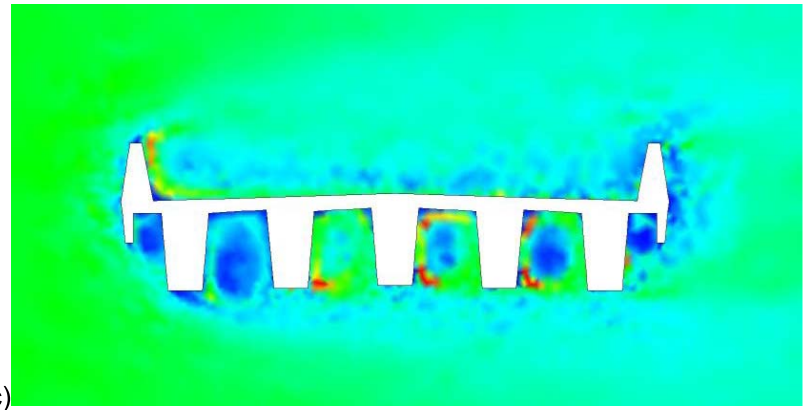
Figure 6.2 Volume fraction of salt around the superstructure of the Gladstone Port Access Road Overpass;
a) particles released within 1.4 metres of the mid-height,
b) particles were released between 1.4 and 2.8 metres of mid-height,
c) all salt aerosol particles. Flow is from left to right. Red is high concentration and blue is low concentration



a)



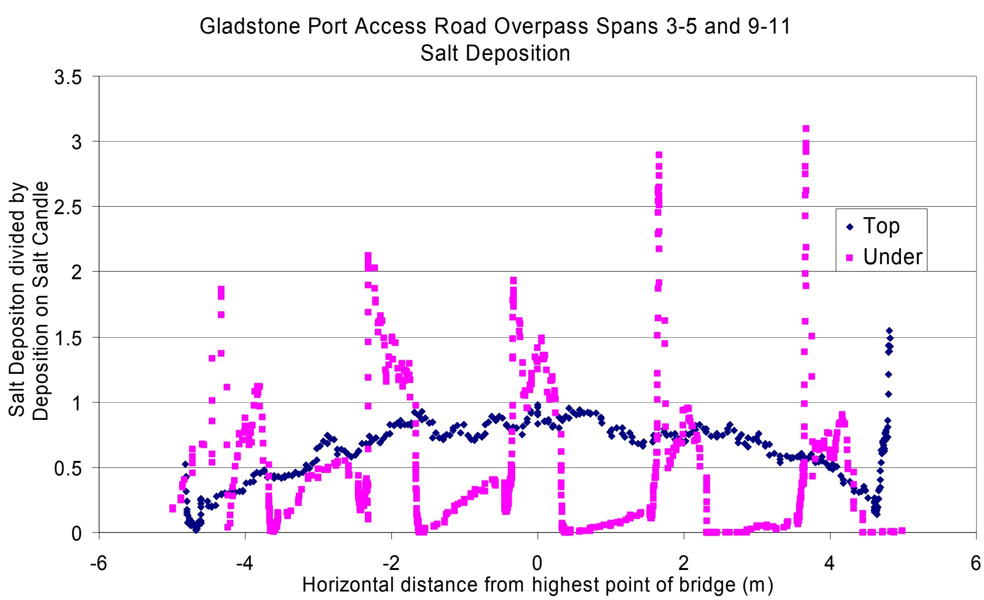
b)

c) 

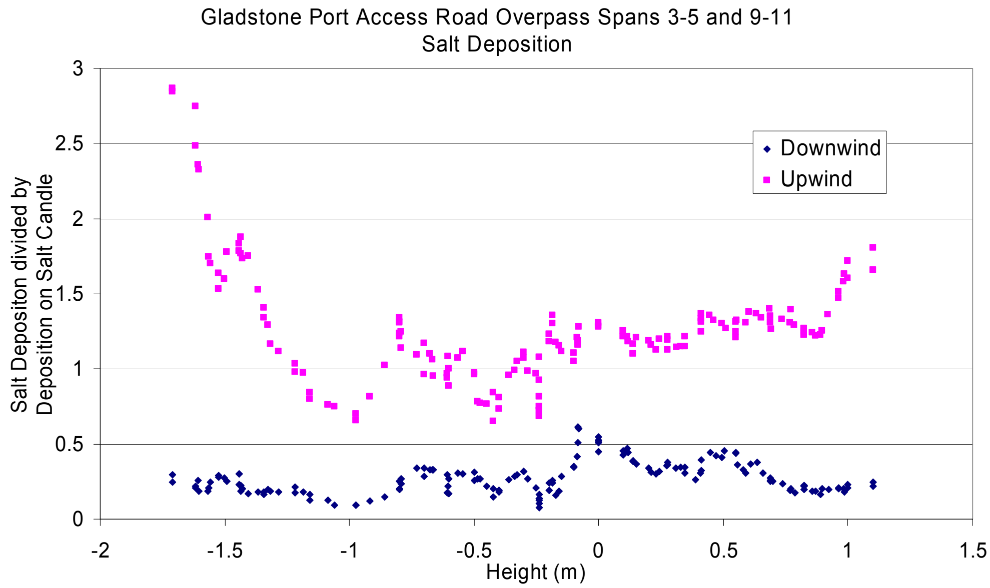
Salt becomes trapped in the recirculation regions between the bridge girders, but although the concentration of the salt in the air between the girders is high, not much of it is deposited on the girders and the underside of the deck.

The salt deposition on the bridge structure is summarized in Figure 6.3. The deposition is largest on upwind faces, intermediate on horizontal faces and least on downwind faces and in protected parts of the under bridge deck. The highest deposition rates are found on the bottom edges of the two downwind girders and on the upwind face of the upwind face of the upwind parapet.

Figure 6.3 Salt deposition on the Gladstone Port Access Road overpass measured relative to the salt candle deposition



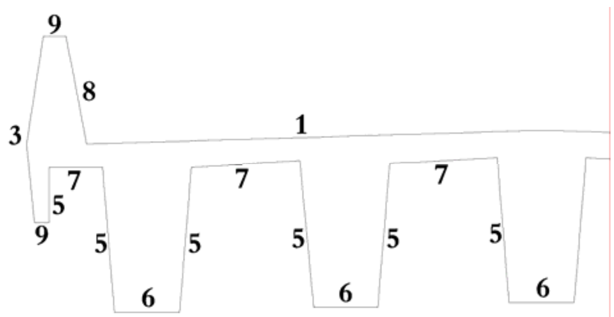
a)



b)

Figure 6.4 shows the locations of the zones used in analysing the deposition on the superstructure of the Gladstone Port Access Road Overpass. This is referred to in the subsequent graphs of salt deposition and in Table 6.1.

Figure 6.4 The locations of the zones for the superstructure of the Gladstone Port Access Road Overpass



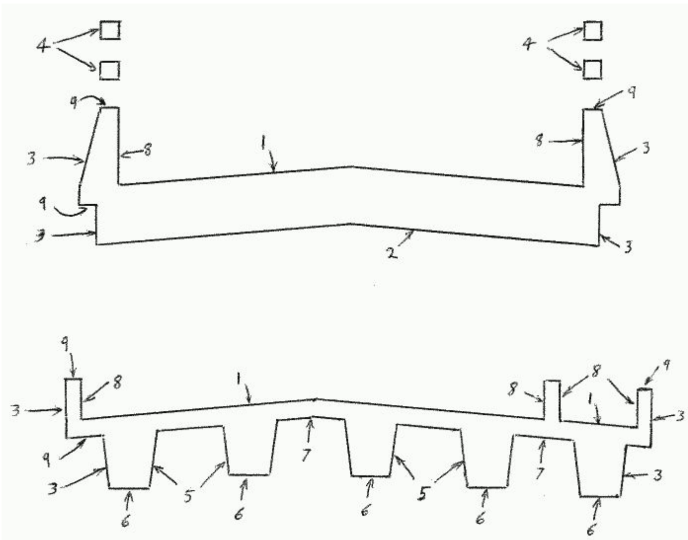
6.2 Defining Common Elements

The deposition of salt on any structure depends on two independent processes. The first is the transport of salt aerosol to the vicinity of the structure and the second is the effect of the shape of the structure on the deposition rate. The first of these can be measured by a salt candle. The salt deposition measured by a salt candle at any location can be reliably extracted from the GIS model of metallic corrosion.

For each bridge, a computation similar to that shown for the Gladstone Port Access Road overpass was carried out as well as a separate computation of deposition on a salt candle at the same location. The ratio of the deposition on the bridge to that on the salt candle quantifies the effect of the shape of the structure on the deposition rate.

For the comparison of different bridge superstructures, results were averaged over a set of physical locations (zones) on each bridge. These zones are shown for two typical bridge cross sections in Figure 6.5

Figure 6.5 The layout of zones on two typical bridge cross sections.



1. Road surface and median strip
2. Bridge undersurface
3. Side face
4. Handrails
5. Side of support beams
6. Undersurface of support beams
7. Protected undersurface
8. Lane divider and inside the parapet
9. On top of the parapet and under the side overhang

If the support beams are closer than 100 mm apart then "2" applies instead of "5, 6 and 7".

The deposition rates in these zones can depend on the detailed bridge design. Some zones will have similar deposition rates. Table 6.1 gives a summary of the computed results. For approximate Zone locations see Figure 6.1.

Table 6.1 A summary of computed results; salt depositions on the 9 zones for the 5 bridges in DSC. u′/U is the upstream turbulence intensity and H:W is the height to width ratio of the superstructure.

		Gladstone	Stewart	Sth Johnstone	Johnson	Ward
	u' / U	0.29	0.18	0.12	0.41	0.3
	H:W	1:3.7	1:13.3	1:5.7	1:7.3	1:4.1
Zone	1	0.65	0.19	0.79	0.36	1.13
	2		0.27	0.97	0.58	0.89
	3 seawards	1.30	1.47	1.46	1.66	1.22
	3 landwards	0.27	0.11	0.69	0.08	0.72
	3 average	0.79	0.79	1.08	0.87	0.97
	4			2.53	1.59	
	5	0.38				0.37
	6	1.03				1.06
	7	0.18				0.87
	8	0.44	0.41	0.55	0.95	0.66
	9	0.50	0.69	0.80	0.80	0.78

The salt deposition is influenced by the height to width ratio (H:W) of the superstructure. There is a critical H:W ratio, similar to that of the bridge over the Ward River, that maximises the salt deposition on the downwind side of the superstructure (Zone 3 landwards). The H:W ratio for the Johnson Creek Bridge is intermediate between that of the Stewart Road Overpass and the South Johnstone River Bridge and all use deck units; that explains why the deposition on Zone 2 for the Johnson Creek Bridge is intermediate between the other two.

The upstream turbulence intensity (u' / U) influences salt deposition in conjunction with the bridge roughness, the mean aerosol size and the relative humidity. For a smooth surface (eg. glass) with small aerosols (< 3 μm in diameter) the salt deposition rate can be so small as to be negligible. The same can be true when the relative humidity is low (< 33%). In these computations the surface is assumed to be rough enough and the relative humidity high enough for salt deposition to occur. In this case the deposition rate depends critically on u' / U, particularly when the aerosols are small. However, the effect of u' / U affects both the bridge and salt candle so the DSC value is relatively unchanged.

The salt deposition is also influenced by the structural details. For instance, the girders are further apart at Ward River than at Gladstone and this largely explains the difference in deposition between the girders (Zone 7). The high parapets on the Stewart Road Overpass help to explain the low deposition rate on the road surface there (Zone 1).

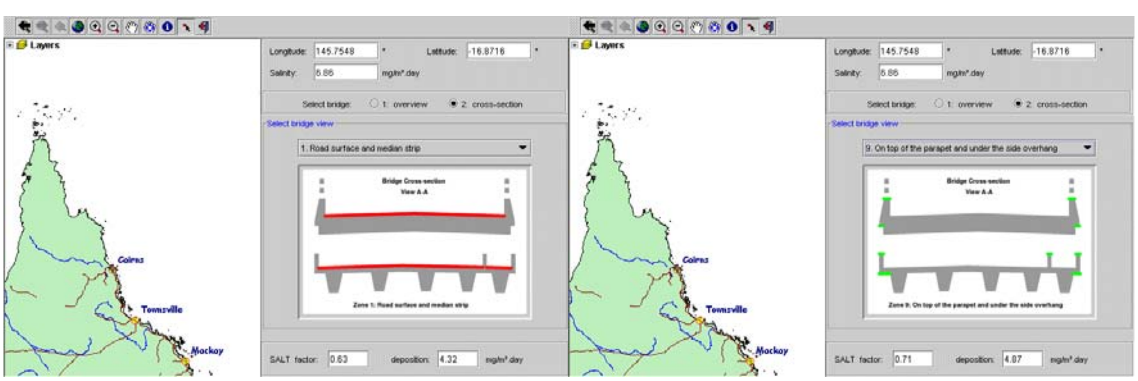
6.3 Program and User Interface

The information derived from the analysis of the five bridges and summarized in Figure 6.5 and Table 6.1 was amalgamated to give a generic bridge structure with nine different zones. Salt factors were derived for each zone to modify the salt deposition levels based on the data in Table 6.1. A software program has been implemented to facilitate the calculation of theoretical salt deposition values for the bridge cases at any point in Queensland. The salt values provided by the program have not been verified against actual deposition on the bridges. This should be included in any further development of the work.

The user interface of the program incorporates the GIS for Queensland, including a zoom facility, and clicking on a point on the map will get the salt deposition for that longitude and latitude location. One of the nine bridge zones can then be selected and the expected salt deposition on that zone will be calculated from the salt deposition figure and the salt factor for the zone.

Figure 6.6 which shows two examples of the selection of zones (Zone 1 – the road surface, in red, and Zone 9 – the parapet top surface and under the overhang, in green). The salt factor and calculated salt deposition are given in the boxes at the bottom of window beneath the zone diagram.

Figure 6.6 Two examples of the GUI screen showing different bridge zones being selected.



7. SITE VISIT

During the project, two CMIT team members undertook a site visit organized by the industry partners to look at corrosion concerns relevant to the software tools being developed. Four schools, a bridge and developments on a foreshore region were visited in the Sunshine Coast area, chosen for its coastal location and known corrosion problems.

All of the schools inspected had significant corrosion problems with most of the issues relating to sheltered corrosion. The main structures affected were covered walkways and shelters – areas where salt can be deposited but not washed away by rainfall. Other corrosion problems identified were due to inappropriate design, specifications or building practice eg. corrosion of roof fasteners. (Figure 7.1)

The bridge was in a severe marine environment with high salt content in the concrete and noticeable corrosion of the galvanized handrails and barriers.

Infrastructure on the foreshore area near Noosa also exhibited numerous instances of incorrect specification of materials for the severity of the environment eg. painted steel supports for shade umbrellas, stainless steel handrails and plaques where electropolishing would have avoided the formation of corrosion. (Figure 7.2)

Figure 7.1 Examples of corrosion found in inspection of schools a) deterioration at joins of gutters, b) roof fasteners showing corrosion

Figure 7.2 a) Bridge railing showing white corrosion product b) plaque showing “tea staining” from corrosion.

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