Stretto di Messina

Concessionaria per la progettazione, realizzazione e gestione del collegamento stabile tra la Sicilia
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EurolinK

PONTE SULLO STRETTO DI MESSINA

PROGETTO DEFINITIVO

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INDICE

Abbreviations

BMS:	Bridge Management System
CSP:	Computer Simulation and Prediction
EDMS:	Electronical Document Management System
ICMS:	Information & Coordination Management System
MACS:	Management and Control System
MMS:	Management, Maintenance and Simulations
SCADA:	Supervisory Control and Data Acquisition
WSMS:	Work Site Management System
TMS	Traffic Management System
SHMS	Structural Health Monitoring System

Other abbreviations:

OCC:	Operation Control Centre
I&M:	Inspection and Maintenance
O&M:	Operation and Maintenance
RBI:	Reliability Based Inspection
RCM:	Reliability Centered Maintenance
RFI	Rete Ferroviaria Italiana
UML	Unified Modeling Language

1 Executive Summary

The Messina bridge is a highly innovative bridge design for the world's longest span (3300m) to link Sicily with mainland Italy.The Messina Strait Bridge will span the Messina Strait between Calabria on the Italian mainland and the island of Sicily and will provide the first fixed link between Italy and Sicily. The suspension bridge crossing comprises a 3,300 m main span, which will be longest in the world when constructed.

This report describes the Computing of Simulations and Prediction(CSP) system, which is a sub system under Management and Control System(MACS). It is envision that CSP will be able to predict the future state of the bridge as a total structure and the individual parts which is being monitored by the Structural Health Monitoring System (SHMS) system. Furthermore it will be possible to make correlation between events recorded by all subsystems and relevant parameters chosen by the system operator. All predictions required by the specification GCG.F.06.01 have been described and furthermore the use of virtual channels for new prediction can easily be added to the system if it is seen beneficial for operating of the bridge.

The Bridge is to be equipped with a Management and Control System (MACS), which enables the Bridge Operator to carry out the operation and maintenance of the Bridge structure and installation in a safe-and structured manner.

The Management and Control System will be a collection of controlling software applications with analysis and management modules and interface to the following system packages:

- Monitoring (SCADA – described by the E&M design basis)
  - Traffic Management System (TMS)
  - E&M Control and Monitoring (EMC)
  - Structural Health Monitoring System (SHMS)
  - Communication (CS)
  - Railway monitoring (RTMS).
- Management, Maintenance & Simulations (MMS)

- Computing of Simulations and Predictions (CSP, Detailed in this report).
- Worksite Management System (WSMS).
- Bridge Maintenance Planning (BMS).
- Information and Coordination Management (ICMS).
- Electronic Document System Management (EDMS).

Figure 1.1 shows the overall system architecture for MACS where CSP, which is described in this report, is highlighted.

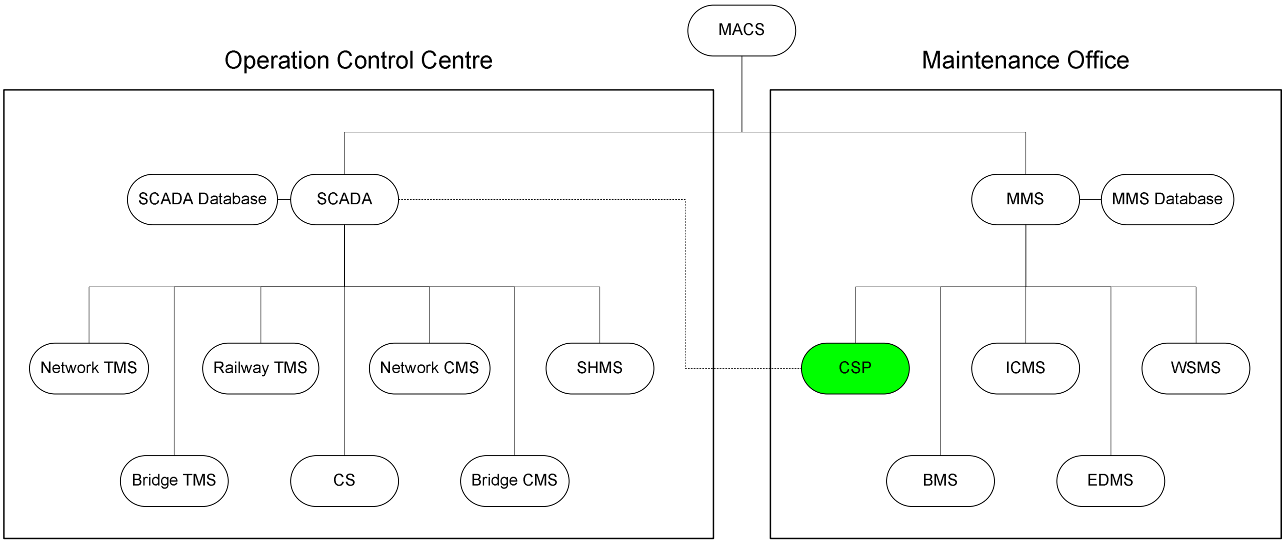


Figure 1.1 Over all system architecture.

A more detail description of MACS can be found in, Management and Control, doc. no. CG1000-P-2S-D-P-IT-M4-C3-00-00-00-01-B.

This document is a design definition plan for the CSP. It cannot be used as a tender document. It is expected that, during the Progetto Executivo, this document will be further developed into a system Specification. This design plan presents as outlined in the following

1.1 Computing of Simulations and Predictions (CSP)

The Bridge is to be equipped with a system for Computing of Simulations and Predictions (CSP), which is to be a part of MMS. The CSP system is closely tied to the MMS system which is described in the document named Management and Control, doc. no. CG1000-P-2S-D-P-IT-M4-

C3-00-00-00-01-B.

The module for Computing of Simulation and Prediction will comprise of the following applications

1 Event Manager

2 Bridge Rating

3 Traffic Simulation

4 Structural Simulation

5 Climate and Weather Simulation

The simulation software will obtain data from the sub-modules for simulation if relevant otherwise all data used in CSP will be obtained through the two databases in SCADA and MMS. Simulation results will be possible to report in the EDMS module and the conclusions of simulated investigations to be passed on to the SCADA operator, BMS and other relevant system and persons.

1.2 Event Manager

ICMS collects all the events occurring in MACS including events from external sources which will have an effect on the bridge. The CSP system will have the function of collecting and making a list of events, from the ICMS. After reading the event list from the ICMS, the CSP's event manager will sort the events into groups such as sensors, location, and priority, if applicable respectively. The MMS will then be able to access the different sorted/grouped event lists or the unsorted event list containing all events recorded by the ICMS.

1.3 Bridge Rating

The CSP will interface with the BMS and retrieves the current rating for the bridge component in question. The CSP will calculate a rating based on SHMS data and visual inspection /observations, which will then be assimilated with the BMS current rating in order to obtain a new total rating. A report based on the calculation and the assimilation of ratings will be generated for the use of BMS.

The grading system used by the CSP will be set up in cooperation with the BMS in order to find the correct scaling for the calculated fatigue/utilization/loading etc. in relation to the 6 point grading scheme used by the BMS.

1.4 Traffic Load Simulations

The SHMS will provide the CSP with traffic flow data which will enable the calculation and simulation of expected traffic.

Furthermore, the CSP will be able to forecast traffic situations by taking predicted weather conditions into account, such as wind speed, visibility, temperature etc.

The CSP will be able to provide prognosis for the short term (10 min), medium terms (1-2 hours) and long terms (days) dynamic traffic load. These CSP predictions will be used to calculate utilization of service limit capacity and plot the current and predicted state of the bridge in relation to load. The current and predicted traffic load will be shown in the same plot for easily identification of trends in the current traffic in comparison to historical data

1.5 Structural Simulation

The Structural Simulation module is in principal the module which calculates the loads and predictions in CSP. The data used for calculating loads and predictions are provided by the SHMS and the BMS. The calculated loads and predictions such as fatigue or stress will be used for interpretation and comparison to design limits. Based on these comparisons to loads and predictions the Structural Health Evaluation will be made. If any prediction exceeds a given design limit, an alarm will be sent to the SCADA operator which then will make a judgment on the importants and the validity of the prediction. Depending on the decision of the SACDA operator whether or not to proceed with the alarm an event will be manually log in the ICMS system.

1.5.1 FE-Simulation

The structural simulation will be used whenever BMS or other relevant systems identify a structural problem which needs clarification in relation to the effect on the bridge. The system can also be used to simulate and predict bridge performance for a giving dynamic load situation and load capacity evaluation when special heavy vehicles applies for passing the bridge.

The structural simulation software shall, through the data from SHMS, be able to simulate any possible given load situation and compare it with the measured bridge. The FE-model used for structural simulation should be an existing model updated to as build documentation. This model should then be verified through a comparison of the simulated results from the FE-model and the data logged by the SHMS.

1.6 Climate and Weather Simulations

The climate and weather simulations will be based on local metrological station and prognosis from a well established weather institute.

The weather forecast will give high accuracy data for wind speed, wind direction, temperature, precipitation and estimation of visibility. The data will be available for all system in MACS with access to the MMS database.

The CSP system shall feed the SHMS, with future predictions from wind and traffic which shall be added to the SHMS displays.

High definition real time data from the SHMS will be used in conjunction with statistical data in simulating and predicting bridge loads under different wind conditions.

1.7 General for the CSP

CSP will interact with databases situated in SCADA(CG1000-P-2S-D-P-IT-M4-C3-00-00-00-06-B_Design_Spec_Mech_Elec_ANX and MMS (see doc. no. CG1000-P-2S-D-P-IT-M4-C3-00-00-00-01-B). These databases will have a common architecture to ensure communication between systems. Furthermore the CSP will be able to communicate with each of the other systems directly if needed. The CSP software will be build upon standard software with the necessary extensions to achieve the required extra functionalities if possible, otherwise specialized software will be developed to handle the needed functionality under the CSP.

2 Introduction

This section gives at small introduction to the bridge and the individual system which is relevant for the CSP system.

2.1 General

The Messina Strait Bridge will span the Messina Strait between Calabria on the Italian mainland and the island of Sicily and will provide the first fixed link between Italy and Sicily. The suspension bridge crossing comprises a 3,300 m main span, which will be longest in the world when constructed.

The bridge carries four marked vehicle lanes, two emergency lanes and two rail lines. The bridge superstructure comprises three separate orthotropic deck steel box girders, one for each of the Sicily and Italy bound roadways and one for the railway. The three box girders are connected by transverse steel box cross girders spaced at 30 m. The superstructure is supported by pairs of hanger cables connected to each cross beam end. The hangers are connected to pairs of main cables on each side of the bridge (four main cables). The main cables are anchored at each bridge end in massive reinforced concrete anchor blocks. The main cables are supported by two steel main towers, each with a height of 399 m above mean sea level. The main towers are founded on reinforced and post-tensioned concrete footings, which are supported on underlying rock formations.

This document is a design definition plan for the CSP. It cannot be used as a tender document. It is expected that, during the Progetto Executivo, this document will be further developed into a system specification. This design plan presents as outlined in the following

2.2 MACS

The Bridge is to be equipped with a Management and Control System (MACS), which enables the Bridge Operator to carry out the operation of the Bridge and maintenance of the Bridge structure and installations in a safe and structured manner.

The Management and Control System will be the controlling software platform and consist of a collection of sub applications with analysis and management modules and interface to the following system packages:

- Monitoring (SCADA – described by the E&M design basis)
  - Traffic Management System (TMS)
  - E&M Control and Monitoring (EMC)
  - Structural Health Monitoring System (SHMS)
  - Communication (COM)
  - Railway monitoring (RTMS).
- Management, Maintenance & Simulations(MMS)
  - Computing of Simulations and Predictions (CSP, Detailed in this report).
  - Worksite Management System (WSMS).
  - Bridge Maintenance Planning (BMS).
  - Information and Coordination Management (ICMS).
  - Electronic Document System Management (EDMS).

Figure 2.1 shows the overall system architecture for MACS where CSP, which is described in this report, is highlighted.

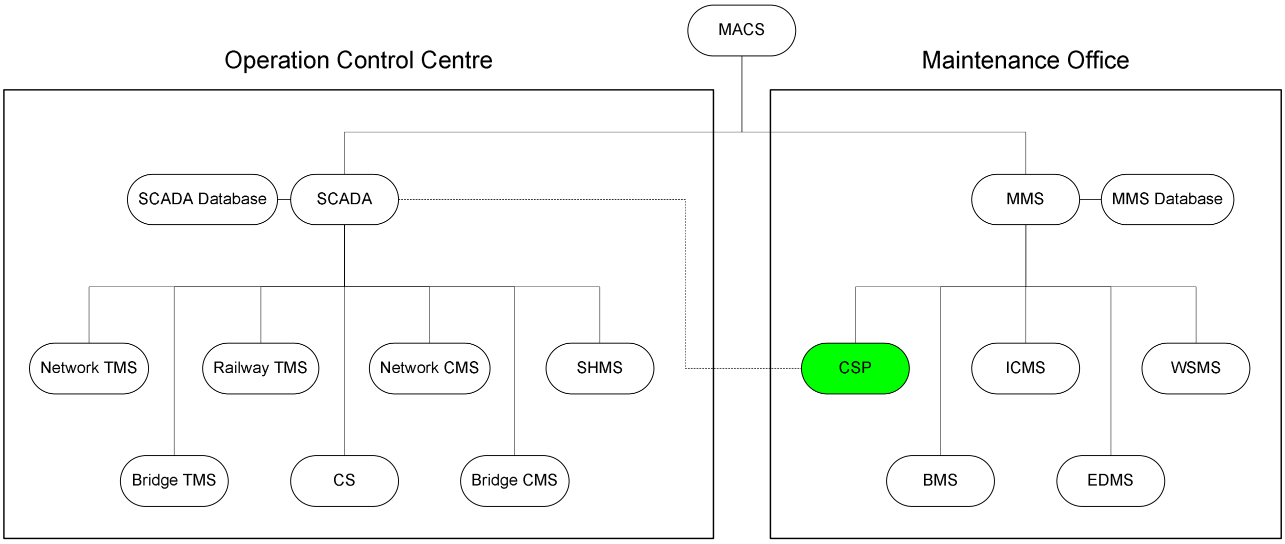


Figure 2.1 Over all system architecture.

The CSP, which is detailed in this report, will interact with sub system under both SCADA and MMS as well as with external data provides as shown in the flow chart below.

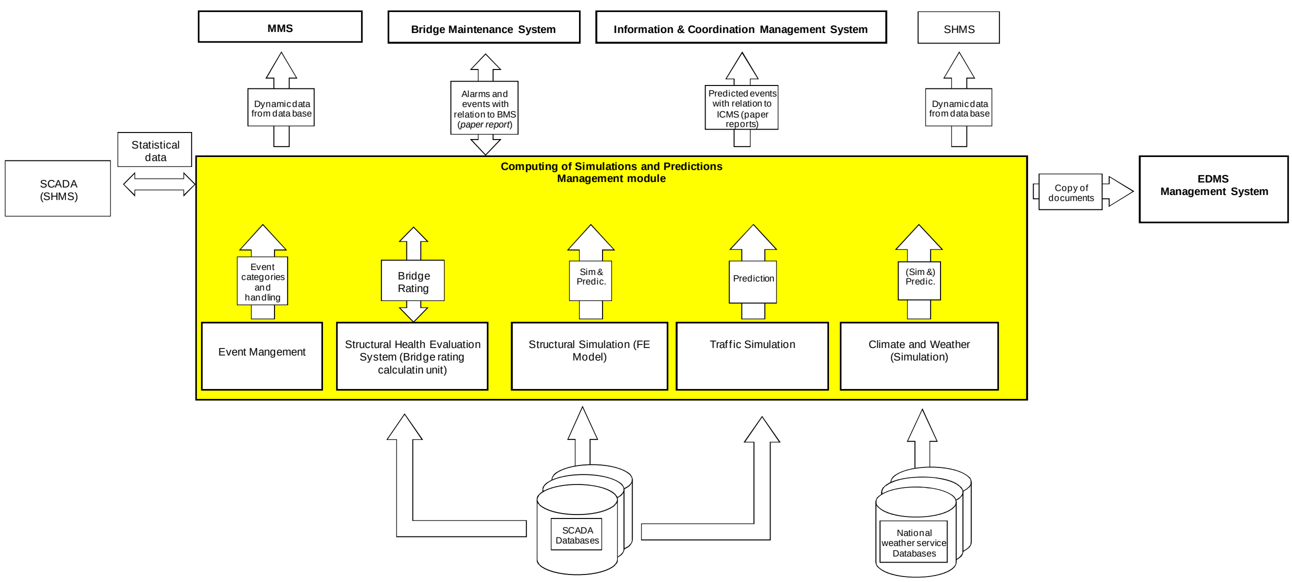


Figure 2.2 CSP and systems communication

Some of the functionality will be automatic whereas other will require manual input from a user. An example could be a load simulation in the FE-module, where the user needs to update the FE-model with the latest findings from BMS and SHMS. This will have to be performed manually.

The CSP software will be build upon standard software with the necessary extensions to achieve the required extra functionalities if possible otherwise specialized software will be developed to handle the function under the CSP. The CSP will enable the operator to make predictions on load, displacements, fatigue and will provide the MMS with plot data.

Whereas it is possible to interface to CSP through MMS, not all function for data analysis is available trough this interface, which basically covers the need for plotting/listing of data from relevant sub-programs. Results of daily analyses of data performed in CSP will have the possibility of being made available to MMS.

A summary of the individual function shown in Figure 2.2 is listed Section 0, below.

3 CSP

3.1 General

The Bridge is to be equipped with a system for Computing of Simulations and Predictions (CSP), which is to be a part of the Management and Control System (MACS).

The module for Computing of Simulation and Prediction will comprise of the following applications

- Event Manager.
- Bridge Rating.
- Traffic Simulations.
- Structural Simulations.
- Climate and Weather Simulations.

The simulation software will be allowed to pull SCADA data for calibration and control purposes. Also simulation results will be possible to report in the EDMS module and the conclusions of simulation investigations to be passed on to the ICMS.

The UML user case shown in Figure 3.1 gives at overview of the different interconnection and data flows, where Table 1 lists the actors, which is relevant for the CSP system.

Table 1 Description of Actors used in the following UML diagrams

Actor	Description
EDMS	- Provides reports with information used in a manual simulation
ICMS	- Provides event data to the CSP through the MMS database
MMS	- All user in MACS
BMS	- Provides data through the MMS database
MMS database	- Provides a platform for exchange of data
SCADA database	- Provides a platform for exchange of data
SCADA:SHMS	- Provides data used in prediction calculations
Weather service	- Weather data provided to/by an externally weather service
SCADA operator	- Staff (3 shifts, 24 hours): • Team Leader 1, 2, 3, 4 and 5. - Responsibilities: • Control and command of operation & emergency of the bridge • Coordination of all parties with actions interfering with bridge • Logging of the operation and emergencies
User	- Staff • Engineer - Responsibilities: • making structural calculation • Calibration of FE-model • Structural simulations

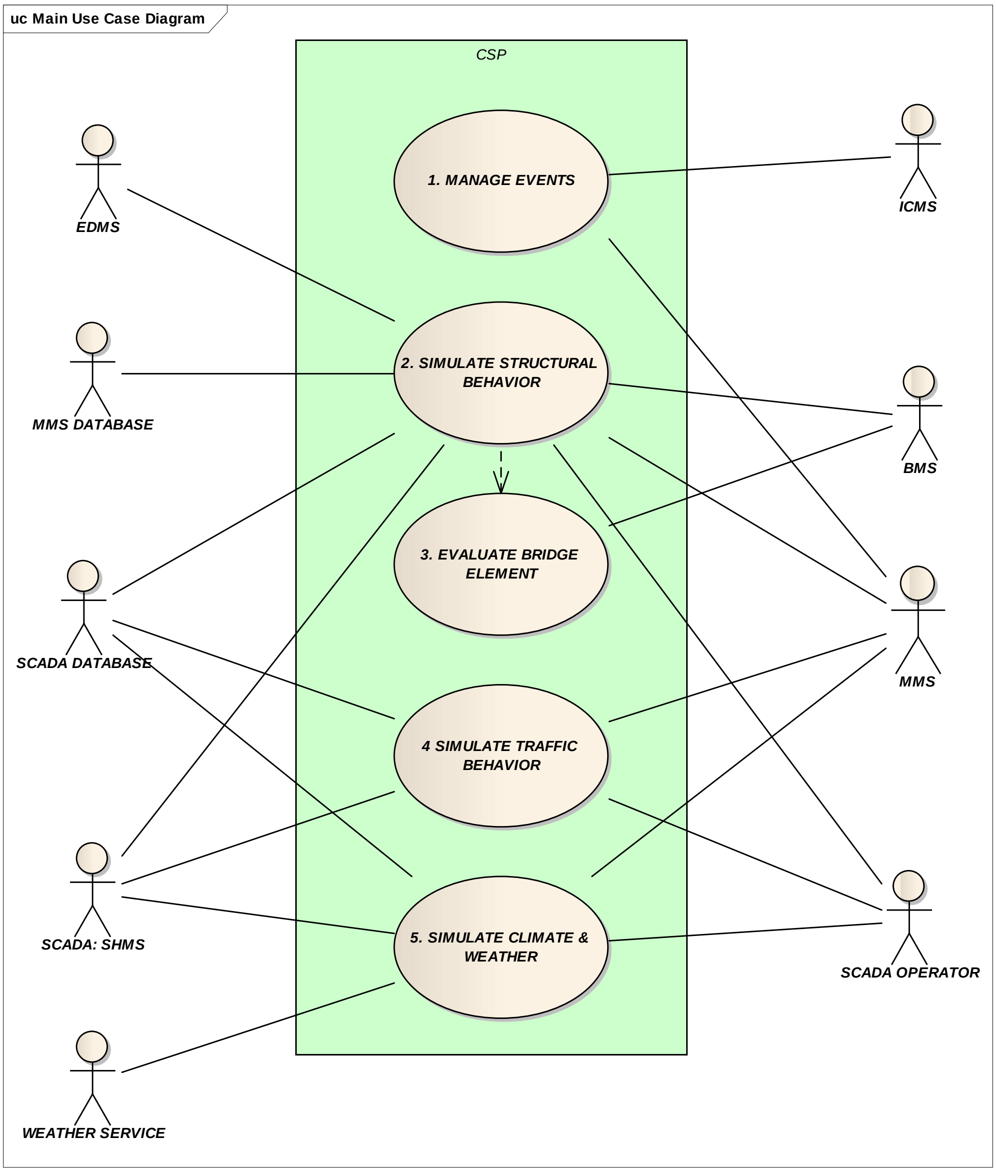


Figure 3.1 Overall CSP System

Table 2 contains a short description of the individual main use cases within the CSP system, the right column list the use cases and the left column list the shot description.

Table 2 Main use cases within the CSP

Use case	Description
1. Manage Events:	Handles events with relation to plots and calculation in CSP.
2. Simulate Structural Behavior:	Uses SHMS data for prediction and simulating how the bridge might react in the future in relation to the present conditions.
3. Evaluate Bridge Element:	Uses SHMS data, BMS data and prediction data to evaluate individual bridge elements and grades them according to the BMS grading scale.
4. Simulate Traffic Behavior:	Uses current and historical traffic data to predict traffic patterns over short, medium and long term.
5. Simulate Climate & Weather:	Predicts how the climate and weather looks like in the future. This is done by providing a well establishes weather institute with local weather data from SHMS for predictions of the climate and weather in a local weather model.

In the following the individual Use Cases are described in more detail.

Figure 3.2 shows the sub Use Case defining the inner function of the "1. Manage Events", which are descripted in Table 3 shown below.

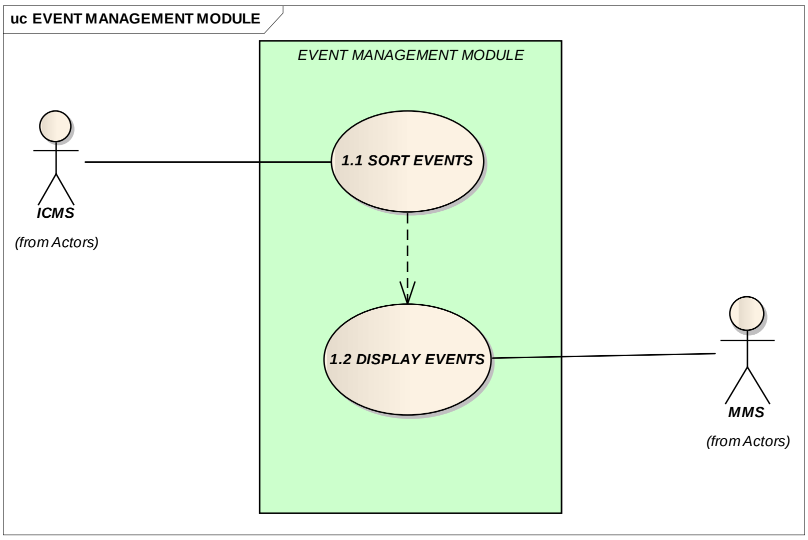


Figure 3.2 Use Case for the Event manger

Table 3 Short description of the main use cases within the use case "1. Manage Events"

Use case	Description
1.1 Event sorter:	Events are attached to a list which can be sorted in relation to Name, Group and Time. If an internal event happens in CSP then it will be pushed to the ICMS.
1.2 Display events:	Display data locally and handles requests from MMS.

Figure 3.3 shows the Use Case defining the inner function of the "2. Simulate Structural Behavior", which are descripted in Table 4 shown below.

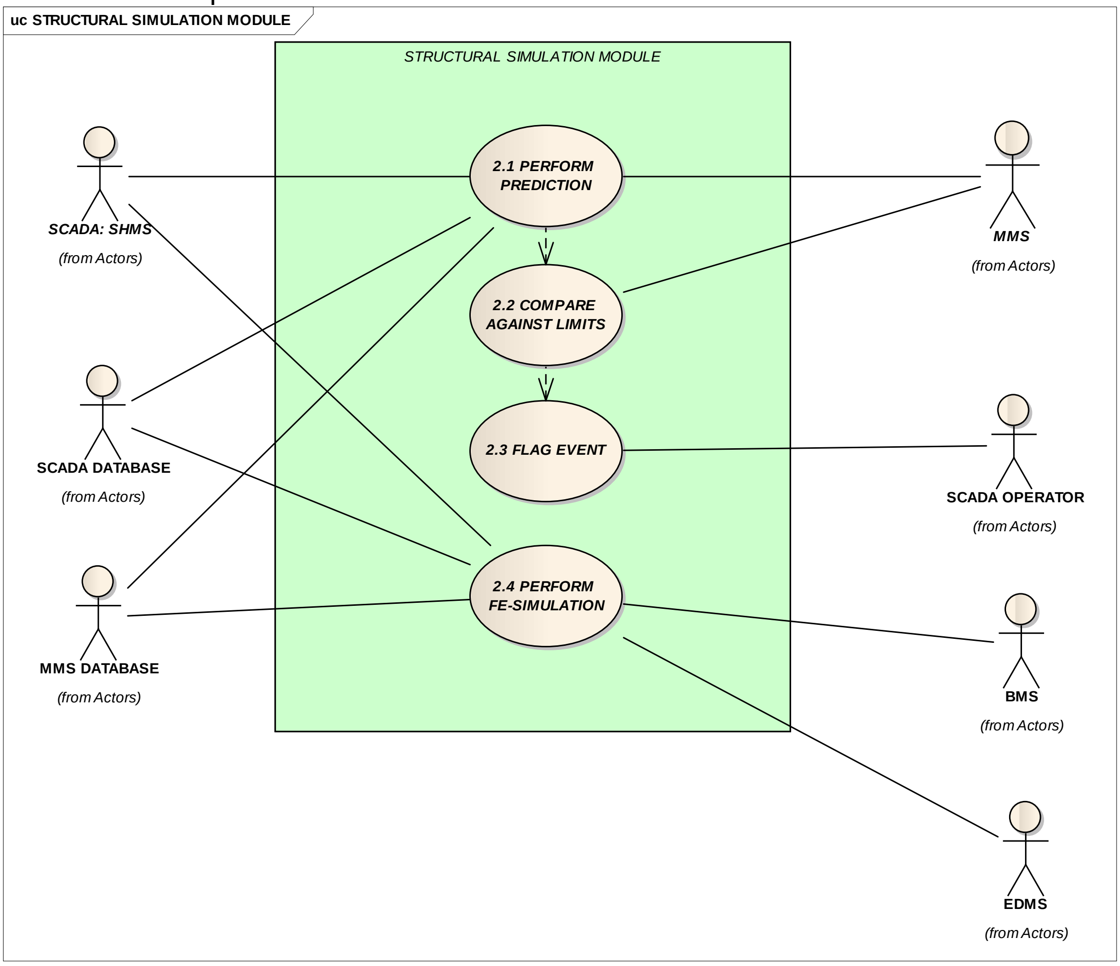


Figure 3.3 Use Case for the Structural Simulations.

Table 4 Short description of the main use cases within the use case "2. Simulate structural behavior"

Use case	Description
2.1 Perform prediction:	Handles all prediction made by the CSP, in relation to structural behavior. The predictions are made by using data from the SHMS.
2.2 Compare against limits:	Makes comparison between predicted values and preset limits.
2.3 Flag event:	If predicted values is greater then a given limits, then an alarm is push and the predicted event is sent to the SCADA operator for evaluation of the predicted event.
2.4 Perform FE-simulation:	Handles all FE-Simulation made by the CSP. Data from SHMS, BMS and prediction will be used in making the FE-Simulation.

Figure 3.4 shows the sub-Use Case defining the inner function of the "2.1 Perform prediction", which are descripted in Table 5 shown below.

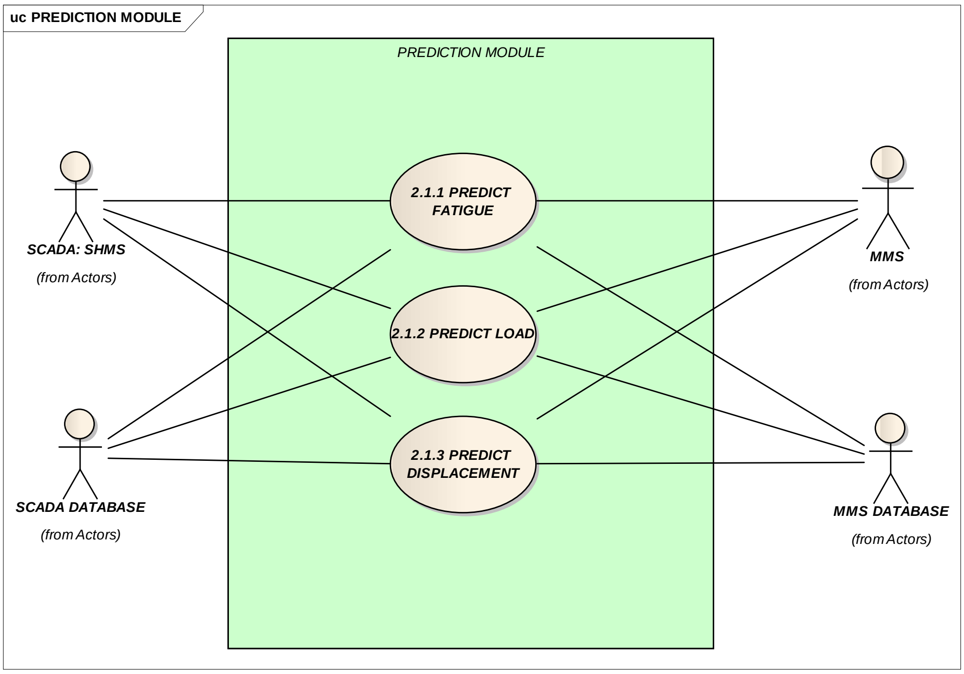


Figure 3.4 Sub-Use Case "2.1 Perform prediction" from the "2 Structural Simulations".

Table 5 Short description of the main use cases within the use case "2.1 Perform prediction "

Use case	Description
2.1.1 Predict fatigue:	Fatigue will be calculated of bridge components where structural stress is monitored by the SHMS.
2.1.2 Predict load:	Loads with respect to wind, traffic and temperature will be calculated.
2.1.3 predict displacement:	Displacements with respect to wind, traffic and temperature will be calculated.

Figure 3.5 shows the sub Use Case defining the inner function of the "2.4. Perform FE-simulation", which are descripted in Table 6 shown below.

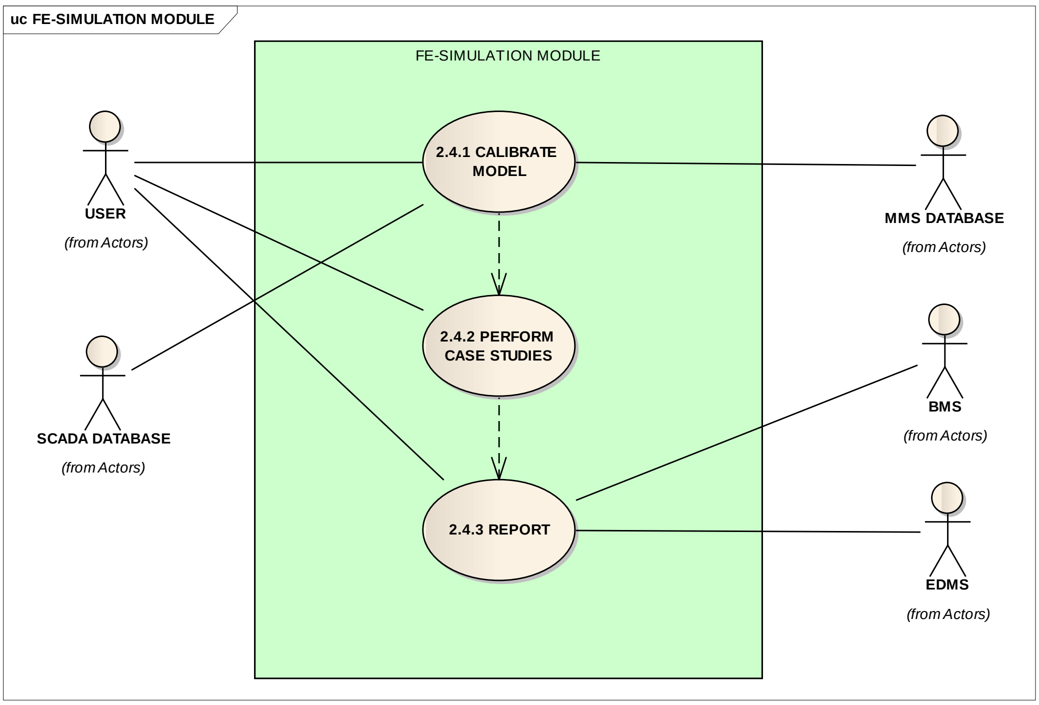


Figure 3.5 Use Case for the FE-Simulation.

Table 6 Short description of the main use cases within the use case " Perform FE-simulation"

Use case	Description
2.4.1 Calibrate model:	The FE-model will be calibrated against the as build documentation and measured data from the SHMS.
2.4.2 Perform case studies:	The calibrated FE-model will be used to calculate special load cases such as heavy transport, load scenarios from predicted storms or seismic events.
2.4.3 Report:	Reports written based on the calculated results.

Figure 3.6 shows the inner function of the Use Case defining "4 Simulate Traffic Behavior", which are descripted in Table 7 shown below.

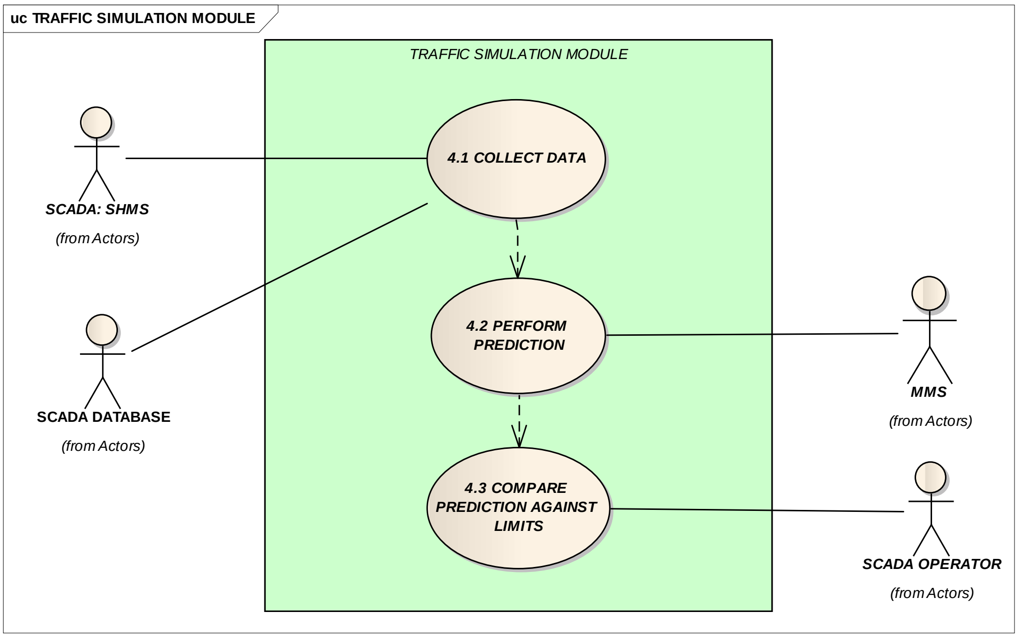


Figure 3.6 Use Case for the Traffic Simulations.

Table 7 Short description of the main use cases within the use case " 4. Simulate Traffic Behavior"

Use case	Description
4.1 Collect data:	Collect data will ask the SHMS and the SCADA database for relevant data.
4.2 Perform prediction:	Prediction of the obtained data will be performed.
4.3 Compare prediction against limits:	Comparison to given design limits will be performed. If a given limit is exceed the SCADA operator will be ask to evaluate the predicted event before sending it to ICMS.

Figure 3.7 shows the Use Case defining the inner function of the 4.2. from "4 Traffic Simulations", which are descripted in Table 8 shown below.

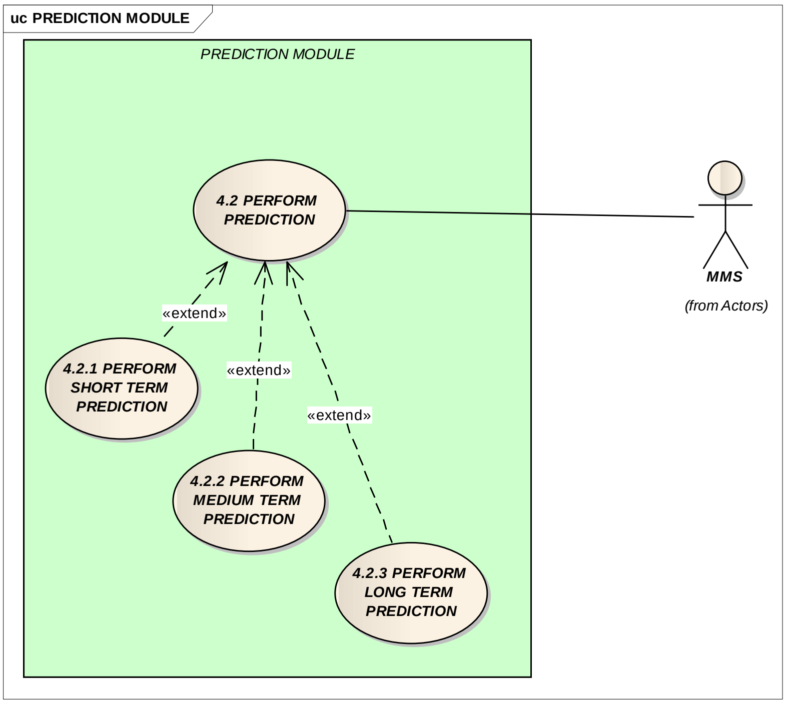


Figure 3.7 Use Case for the 4.2 Perform prediction under 4. Traffic Simulations.

Table 8 Short description of the main use cases within the use case "4.2 Perform prediction"

Use case	Description
4.2.1 Perform short term prediction:	Performs a short term prediction based on traffic, using standard software.
4.2.2 Perform medium term prediction:	Performs a medium term prediction based on traffic flow and statistical data and using standard software..
4.2.3 Perform long term prediction:	Performs a long term prediction based statistical data.

Either of the above described predictions can be made or all of the same time.

Figure 3.8 shows the Use Case defining the function of "5 Simulate Climate & Weather", which are descripted in Table 9 shown below.

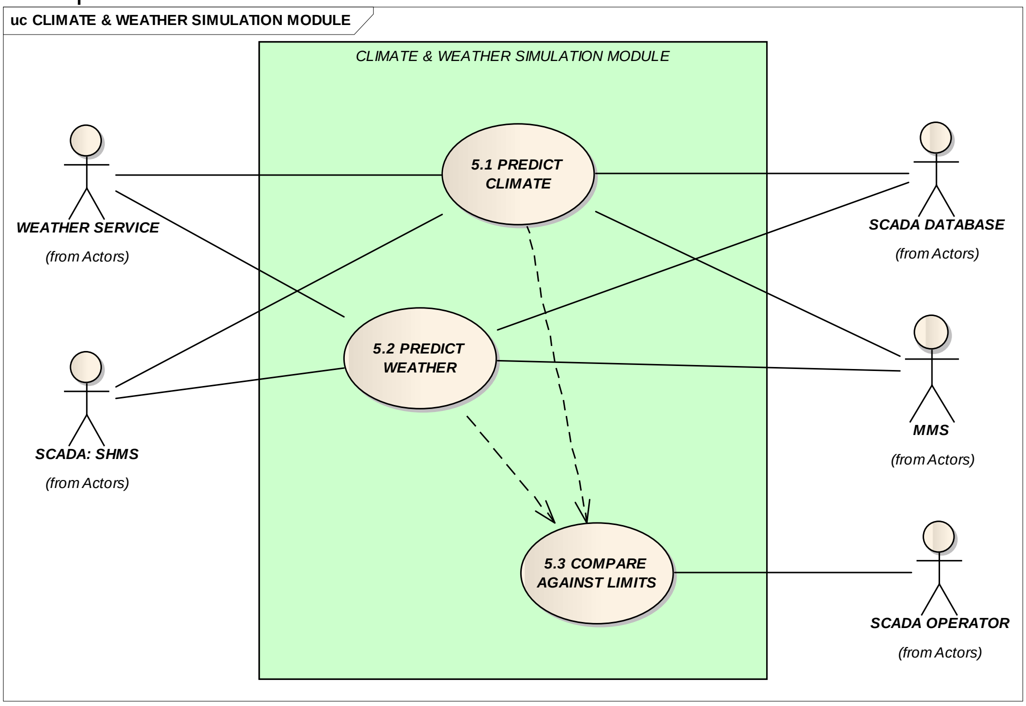


Figure 3.8 Use Case "5. Simulate Climate & Weather".

Table 9 Short description of the main use cases within the use case "5. Simulate Climate & Weather "

Use case	**Description**
5.1 Predict climate:	The Climate predictions will be performed in collaboration with a well established weather institute. The prediction will be used internally in CSP and made available to the MMS and SCADA database for plotting and reporting of predicted events.
5.2 Predict weather:	The weather predictions will be performed in collaboration with a well established weather institute. The prediction will be used internally in CSP and made available to the MMS and SCADA database for plotting and reporting of predicted events.
5.3 Compare against limits:	Comparison to given design limits will be performed. If a given limit is exceed the SCADA operator will be ask to evaluate the predicted event before sending it to ICMS.

4 Summary of CSP component

4.1 Event Manager

The CSP system will have the function of collecting and making a list of events, from the ICMS, which collect all the events occurring in MACS, including events from sources external to the bridge, which will have an effect on the bridge. All events and the appropriate action to perform if an event occurs will be described in the Preliminary Operation and Emergency Manual, O & E Manual
(CG1000-P-MI-D-P-M7-00-00-00-00-00-01-A) and the ICMS will handle the notification of the appropriate system and people.

Monitoring the event list from the ICMS, the CSP's event manager will sort the events into groups, sensors, location, and priority, if applicable and respectively. The MMS will then be able to access the different sorted event lists or the unsorted event list containing all event recorded by the ICMS.

The handling of events and alarms will be a part of the O&E-manual and effectuated through the ICMS system.

Examples of alarms is shown below

The event pre processing will in specific be handled by the following systems.

- Serviceability alarm
  - Real time Load alarm, located at SHMS and pushed to TMS and externals as ANAS and RFI
  - Predicted Load alarm, located at CSP and pushed to SCADA operator
  - Real time Weather alarm, located at SHMS
  - Predicted Weather alarm, located at CSP and push to SCADA operator
  - Accident Alarm, located at TMS.
- Structural Warning Alarm, located at SHMS.
- Bridge Rating Alarm, located at CSP and pushed to BMS for verification.

The data exchange between the systems will be through the common service layer described in document Management and Control, Annex - CG1000-P-2S-D-P-IT-M4-C3-00-00-00-01-B

4.2 Alarms within the CSP

If any automatic prediction exceeds a given design limit an alarm will be sent to the SCADA operator which then will make a judgment on the importants and the validity of the prediction. Depending on the decision of the SACDA operator whether or not to proceed with the alarm an event will be manually logged in the ICMS system. Meaning that the SCADA operator manually needs to accept or disregard the alarm and make a note in the alarm log describing the reason behind the decision. Depending on the choice of the SCADA operator the event will be logged as an real event (the SCADA operator chose to believe the prediction) or the event will be logged as a false alarm(the SCADA operator do not believe the prediction).

Delaying or disabling of alarms will be possible, but only allowable by user with administration rights. This option is available in the case a prediction keeps generating an alarm.

In respect to delaying and alarm then it will be possible to specify a time in which the alarm is suppressed or a number of alarms which are suppressed.

In both cases of delaying and disabling an alarm it will be necessary to write a note on why the alarm is delayed or disabled or tick of a option from a list of predefined options (to be decided on). Furthermore a personal password and biometric identification will be required, which will ensure that the responsible persons id will be logged in case of circumstances relating to the delay or disabling of a alarm leads to future investigations.

4.3 Bridge Rating

The CSP will interface with the BMS and retrieves the current grade for the bridge component in question. The CSP will calculate a grade based on SHMS data, which will then be assimilated with this BMS current grade in order to obtain a new total grading. A report based on the calculation and the assimilation of grades will be generated for the use in BMS.

The grading system used by the CSP will be set up in cooperation with the BMS in order to find the correct scaling for the calculated fatigue/utilization/loading etc. in relation to the 6 point grading scheme used by the BMS.

4.4 Traffic Load Simulations

The SHMS will provide the CSP with traffic flow data which will be used for calculation and simulation of expected traffic.

Furthermore, the CSP will be able to forecast traffic situations taking into account weather conditions prognosis delivered to the CSP, such as wind speed, visibility, temperature etc, all based on statistical data collected from the SHMS traffic data. A standard software package as SimTraffic 7, Aimsun 6 or similar will be used in calculating the short to medium term flow, density and vehicle composition of the traffic and the potentially of traffic jams and there location. This software can also be used in planning of maintenance or defined hypothetical situations on the bridge as it is possible to simulate closing traffic lanes and see how this effects the traffic flow and demand.

The CSP will be able to provide prognosis for the short term (10 min), medium terms (1-2 hours) and long terms (days) dynamic traffic load. These CSP predictions will be used to calculate limit capacity and plot the current and predicted state of the bridge in relation to load. The current and predicted traffic load will be shown in the same plot for easily identification of trends in the current traffic in comparison to historical data

Based on the actual level of traffic reported from the SHMS, the CSP shall calculate the predicted traffic and limit capacity of the bridge and push data to TMS/SCADA operator which can regulate vehicular traffic on the Bridge and eventually intervene and regulate incoming fluxes, in order to guarantee safety, traffic fluidity and, in case, to prevent or limit queues' formation on the Bridge.

4.5 Structural Simulation

The Structural Simulation module is in principal the module which calculates the loads and predictions in CSP. Section 5.4, 6 and 7.1 shows the loads and prediction mad by the CSP. The data used for calculating loads and predictions are provided by the SHMS and the BMS. The calculated loads and predictions such as fatigue or stress(section 7.1 and 6.5.3)will be used for interpretation and comparison to design limits. Based on these comparisons to loads and predictions, the Structural Health Evaluation will be made, see section 7.1. Some of the evaluation will be automatic whereas others will be manual. An example on an automatic evaluation could be an evaluation of traffic load. Here an automated alarm/warning will be flagged to the SCADA operator if the prediction of the traffic load shows that the within the near future the traffic load will exceed 100%. An example of a manual evaluation could be a combination of a number of stress alarms, which would trigger a manual inspection by the BMS, which will make a manual evaluation based on measurements and observations.

A stand alone Structural Health Evaluation System (SHES) will not be apparently present in CSP but rather be subdivided into the Structural Simulation and Traffic Simulation modules.

CSP should have a function for displaying retrospective historical data from SHMS as an hour, day, month and year period. The SHMS and the CSP will have a facility for looking at high resolution event data, see section 5 and 6.

4.5.1 FE-Simulation

Structural simulation through FE-simulations will be used whenever BMS or other relevant systems identify a structural problem which needs clarification in relation to the effect on the bridge. The system can also be used to simulate and predict bridge performance for any possible given static or dynamic load situation, which can be used for predicting peak load scenarios with heavy traffic and heavy freight trains passing the bridge at the same time.

The structural simulation software shall through data from SCADA be able to simulate any possible given load situation and compare it with the measured bridge values for calibration of the model.

The FE-simulation are not intended to run in real time but intended to be used as a tool which will be used on special problems defined by the BMS or other case scenarios.

The FE-simulation will also be used for predicting the effect of seismic events as the bridge ages. This should be done by using information from the BMS and the SHMS and a calibration of the FE-model which reflect the current state of the bridge. The CSP will use a well established FE-software package, such as ADINA, Bentley RM 2000, SAP 2000 or similar products available at the time of implementation, to ensure that all need function are available.

4.5.1.1 FE-model

The FE-model used for structural simulation should be an existing model updated to as build if possible; otherwise a model should be constructed with the chosen FE-software. This model should then be verified through a comparison of the simulated results from the FE-model and the data logged by the SHMS. The bridge model shall be carried out by a commercial available software package, such as ADINA, Bentley RM 2000, SAP 2000 or similar.

Regular (time interval to be decided based on experience) verifications checks of the FE-model should be made in order to have reliable result.

4.6 Climate and Weather Simulations

The climate and weather simulations will be based on local metrological station and prognosis from a well established weather institute.

The weather forecast will give high accuracy data for wind speed, wind direction, temperature, precipitation and estimation of visibility. The data will be available for all system in MACS with access to the MMS database.

The data provide from the chosen weather institute will give a weather prognosis on an easy readable picture for MACS operators.

The SHMS shall display the real time data. This will include the basic wind pressure with time, total traffic load with time, wind pressure against total traffic load, wind speed with direction, and buffer force with buffer displacement. These later plots will show live data with data from a preceding period of time (that is to be agreed). CSP system shall feed the SHMS (in a manner that is equivalent to the SHMS set-up e.g. as if data), with future predictions from wind and traffic which shall be added to the display. The intervals for updating this data need to be agreed. The SHMS will need to include a buffer database for the high definition data files.

This high definition real time data from the SHMS can be used in conjunction with statistical data in simulation and predicting bridge loads under different wind conditions. The data should likewise be used for different cases of comparison (to be defined).

5 Analysis and review of data

The following section describes the option available for the user to review and analyse data from the SHMS and other relevant sub-system under MACS. The first section lists the data analyzing and manipulations tools whereas the second section describes the plots available to display the data which are under review.

In general all available data channels will be possible to plot in one of the forms presented in the plot section below, in order to review the data in nearly any format the user like.

5.1 Data analyzing and tools available in CSP

The following list of analyzing tools forms the basis of the tools available for the user of CSP. Using a established software package like National Instruments(NI) LabVIEW with appropriated add-ons will ensure that necessary tools will be available to CSP.

5.1.1 Required data analysis in CSP

The flowing list of data analysis are the minimum required for the CSP system

- Envelops of
    - Seismic load vs. relevant service limits.
    - Wind load vs. relevant service limits.
    - Traffic load vs. relevant service limits.
    - A combination of the above Seismic, Wind and Traffic loads vs. relevant service limits
    - Wind vs. Traffic
    - Wind vs. Displacements
    - Traffic vs. Displacements
    - Seismic vs. Displacements
    - A combination of the above Seismic, Wind and Traffic loads vs. Displacements
- Frequency analysis of bridge
    - deck vibration, Heave vs. torsion
    - tower vibration vs. deck vibration
    - cables vibration vs. deck vibration

  - cables vibration vs. tower vibration
- Fatigue analysis of steel deck
- Fatigue analysis of expansion joint
- Correlation between
  - cables vibration vs. wind speed and direction
  - deck vibration vs. wind speed and direction
  - tower vibration vs. wind speed and direction
  - cables displacements vs. Wind speed and direction
  - deck displacements vs. Wind speed and direction
  - tower displacements vs. Wind speed and direction
  - cables displacements vs. Traffic density, load and flow
  - deck displacements vs. Traffic density, load and flow
  - tower displacements vs. Traffic density, load and flow
  - Fatigue steel deck vs. Temperature
  - Fatigue steel deck vs. Traffic density, load and flow
  - Fatigue steel deck vs. Wind speed direction and gust speed
  - Fatigue steel deck vs. Seismic activity

5.1.2 Tools available in CSP for data analysis

The following list the tools available to the CSP operator in order to perform data analysis

- Digital filters:
  - Lowpass.
  - Highpass.

  - Bandpass.
  - Bandstop.
  - Smoothing.
- Curve fitting tool:
  - Linear.
  - Quadratic.
  - Spline.
  - Polynomial.
  - General least squares linear.
- Frequency analysis tools:
  - Magnitude (RMS): Measures the spectrum and displays the results in terms of root-mean-square (RMS).
  - Magnitude (peak): Measures the spectrum and displays the results in terms of peak amplitude.
  - Power spectrum: Measures the spectrum and displays the results in terms of power. All phase information is lost in the computation.
  - Power spectral density: Measures the spectrum and displays the results in terms of power spectral density (PSD).
  - Octave analyses.
  - Time frequency plots.
- Statistics:
  - Mean.
  - Median.
  - Mode: Finds the value that occurs most often in the values in Signals.

- Sum of values.
- Root mean square (RMS).
- Standard deviation.
- Variance.
- Kurtosis.
- Skewness.

• Correlation Analysis:

- Correlation.
- Cross correlation.
- Auto correlation.

• Data manipulation:

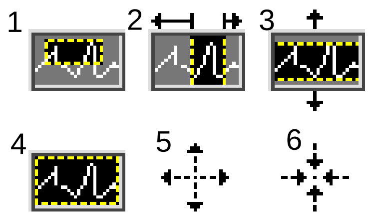
- Performing mathematical operation on data channels or subset of data.
- Creation of virtual channel.
    - A virtual channel could be set up to hold the data produced from any of the above mention mathematical operation, such as a Power spectrum of hanger vibration or statistical values for comparison of deck displacement against wind velocity and direction.
- Align: Aligns the signals to have the same start time.
- Resample: Re-samples the signals to have the same sampling interval.
- Selection of data subset.
- Copy of data subset
- Deletion of data subset.
- Substitution of data subset.

5.2 Available plots for data under review

The following section describes the plots which will be available to the CSP user while reviewing data from the SHMS and other relevant sub-systems. Using a established software package like NI LabVIEW with appropriated add-ons will ensure the necessary tools will be available to CSP.

5.2.1 General setup of plots:

- The plot will be auto scaled but it should be possible to control the axis with slides as shown below. Max and min value of the sliders will update automatically with respect to the plots axis.
- Legends of the plots should also be displayed but have the options of switching them on and off.
- It should be possible to trace a point on a graph showing the x and y value. The option of copying theses x and y values should also be possible.
- It should be possible to define a seconded axis on the right of the plot for comparing two vectors such as displacement and temperature.
- The axis should have the option of linear scale, log scale, inverting, dB scale and rotating ±90°.
- It should be possible to select a graph and copy its values to the clipboard for further analyses.
- It will be possible to plot a trendline for a selected graph. The options of trendlines will consist of:
    - linear
    - polynomial
    - exponential
    - logarithmic
    - power
    - moving average line.
- The following zoom option will be available.



1: Box **2**: Horizontal
3: Vertical **4**: All
5: zoom out by mouse click
6: zoom in by mouse click

- For XY-plots clicking the legend it will make it possible to chose the how to display data. The option available is shown in Figure 5.1

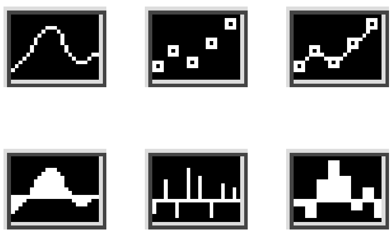


Figure 5.1 Plot options

Figure 5.2 shows a general setup for a XY-plot of four different data channels.

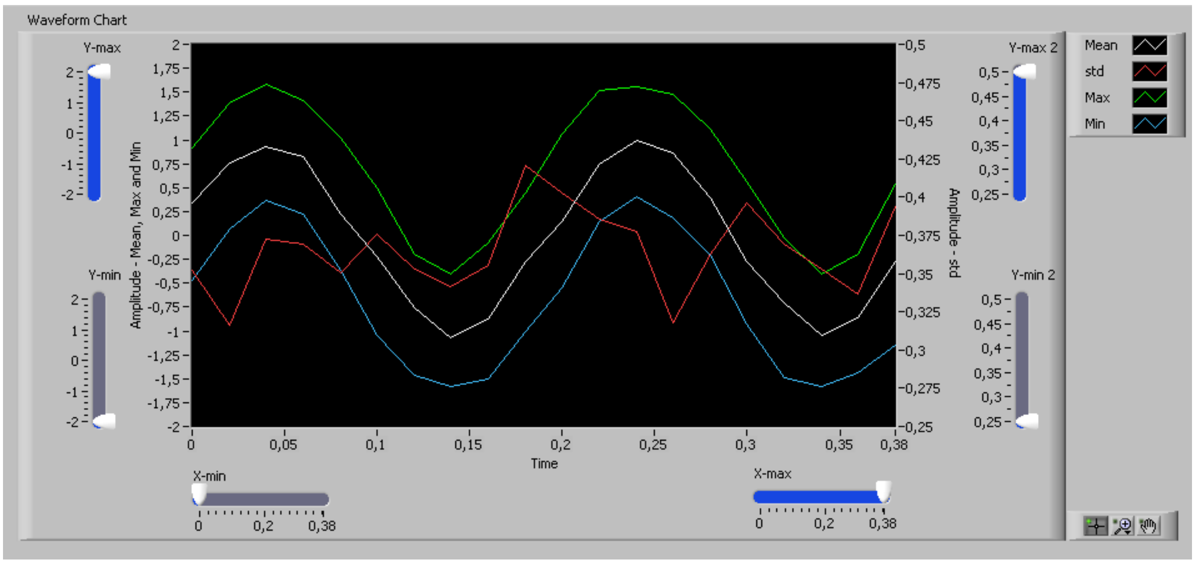


Figure 5.2 General setup for XY-plots.

5.2.2 Non-standard XY-plot

The following section displays the non-standard XY-plots which shall be available in the MMS and CSP.

An example of current and historical data would be that the wind direction is plotted real time but also with a tail of a set number of hours for spotting trends in the wind. The figure below shows an example of such a plot. The updating speed should be dynamic so the operator can choose an updating speed such as; real time, 10min, 1h or an arbitrary time defined by the operator. This should be done in order to clean up the plot if the trail of data has been set for many hours of data. Limits of wind speed should also be plotted so the operator can see if the in the wind speed are approaching these limits, Figure 5.3.

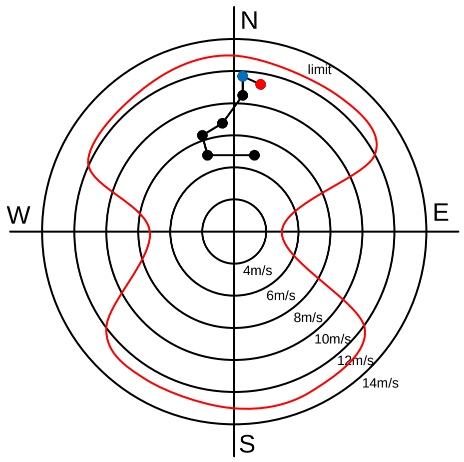


Figure 5.3 Wind rose showing a trail of wind speeds and direction, current situation (blue dot) and predicted situation (red dot). The red line is the limit wind speed.

For the Events a plot of their location and the number of events in one location is available, Figure 5.4. This plot is for example thought as a help for locating areas with high Deterioration. The scaling of the number of events is dynamic relative to the sensors which are chosen, meaning that the size of the circle at the sensor location is scaled according to the maximum and minimum number of events for all the chosen sensor. Different colors of the circle can be used for sensors overlapping each other or for displaying of alarms and warning in the same plot.

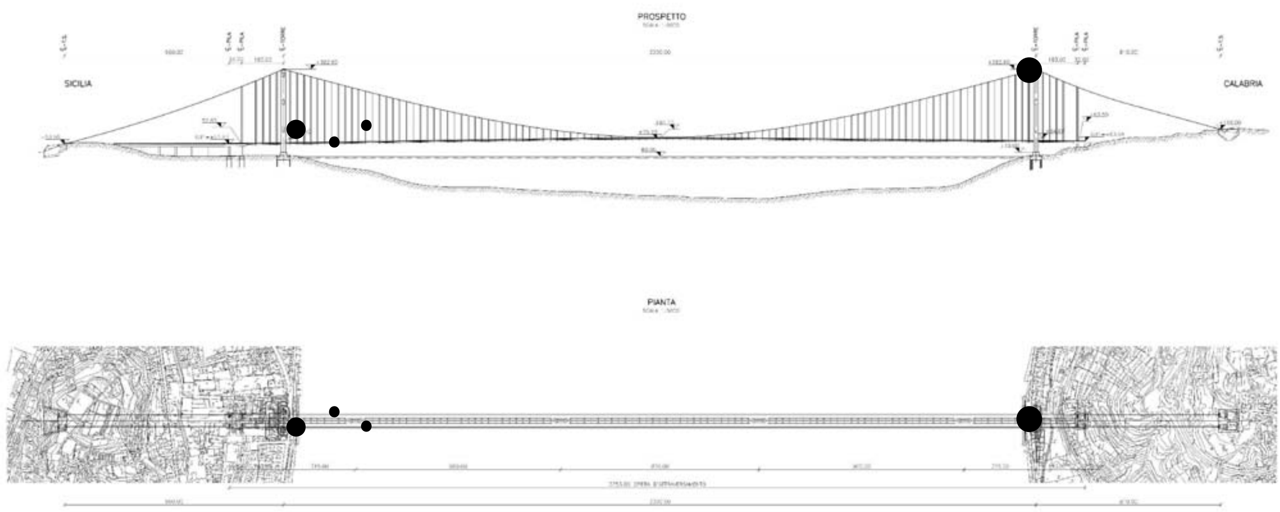


Figure 5.4 Accumulated events and location plot.

5.3 Review requirements

All plots specified and described in the SHMS specification, CG1000-P-2S-D-P-IT-M3-SM-00-00-00-01_B_Design Report-SHMS_ANX, section 10 and Appendix 1 shall be available for the CSP through web services as outline in MACS, CG1000-P-2S-D-P-IT-M4-C3-00-00-00-01_B_MACS_ANX.doc

5.4 Special review requirements

The following sections outlines special extra review requirements.

5.4.1 Correlation Analysis

Making a correlation of data will make it possible to setup prediction based on historical data. Figure 5.5 below shows and example where the longitudinal displacement of the bridge deck at an expansion joint is plotted against the deck temperature of the bridge. Based on such a plot, it is possible to predict a linear correlation between the longitudinal displacement and the deck temperature. By setting up a virtual channel which contain this linear correlation it would be possible to have this channel updated with new data as it is available and by that keep getting a better estimate on the longitudinal displacement as a function of temperature, which could be displayed in the MMS as well.

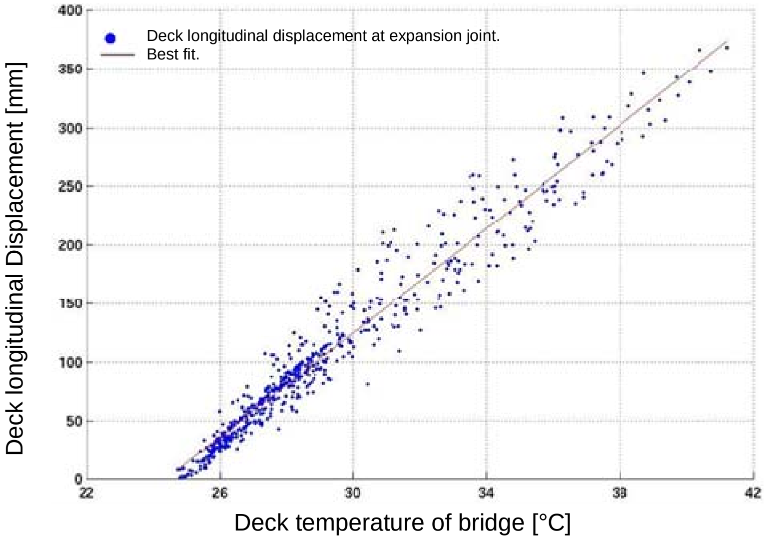


Figure 5.5 Example Plot of Effective Bridge Temperature vs. Deck Thermal Movement (Longitudinal)

Also required is a correlation analysis as shown in Figure 5.6 where the vertical displacement of the bridge deck is plotted in relation to the difference in temperature in the cable and the deck.

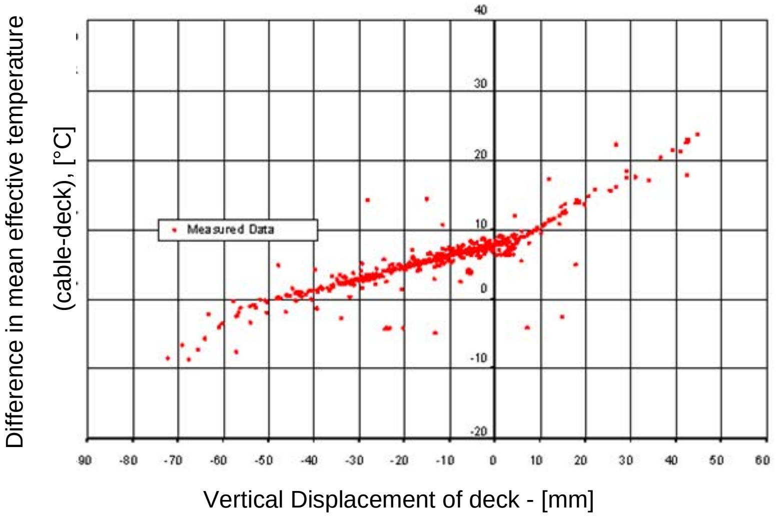


Figure 5.6 Bridge Deck Level with Effective Temperature

A part from displacements the correlation analysis shall also be use to se the strain on the towers as an effect of the wind, as Figure 5.7 illustrates.

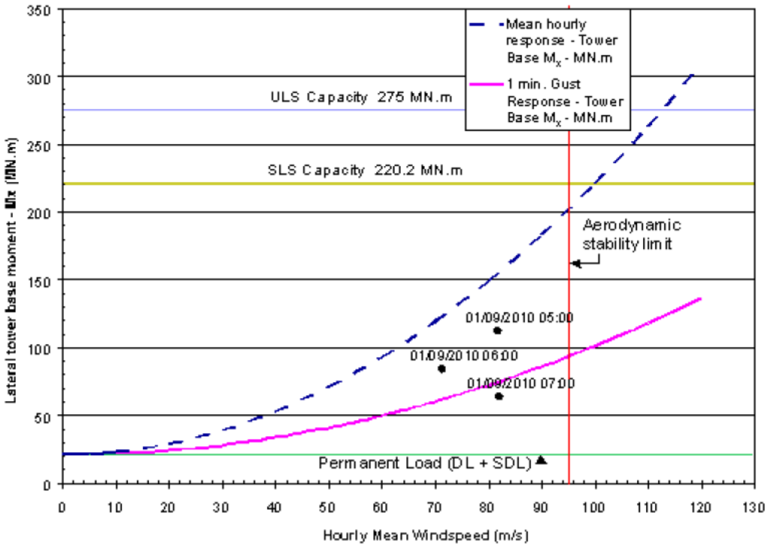


Figure 5.7 Plot of Correlation of Wind Loads and Tower Base Moment

In general using virtual channels to create new derived data channels makes it possible to setup what ever correlation plot which is possible in relation to the data logged by the SHMS and other derived channels from the CSP. It is required to be able to generate such plots for

- Seismic loads.
- Wind loads
- Traffic loads
- Combination of the above mention loads

Cross Correlation of the wind field along the bridge deck in order to simulate the wind force in a FE-calculation.

5.4.2 Frequency Analysis

Using the available frequency tools it shall be possible to produce combined plots as shown in Figure 5.8. It shall also be possible to produced Individual plots.

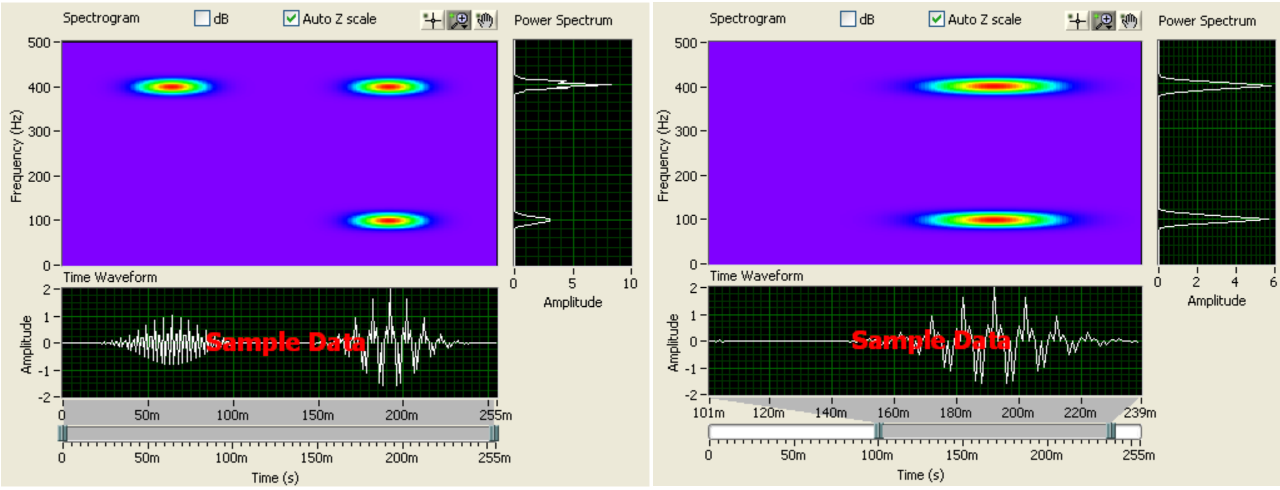


Figure 5.8 Example Plots a frequency analysis of sample data. (Left) investigation of the total time series, (Right) investigation of selected part of the time series

5.4.3 Fatigue Analysis

Fatigue of the different bridge components shall be display in a different ways, from remaining life-time to a S-N curve, see Figure 5.9, which is a plot of the magnitude of a cyclic stress (*S*) against the logarithmic scale of cycles to failure (*N*).

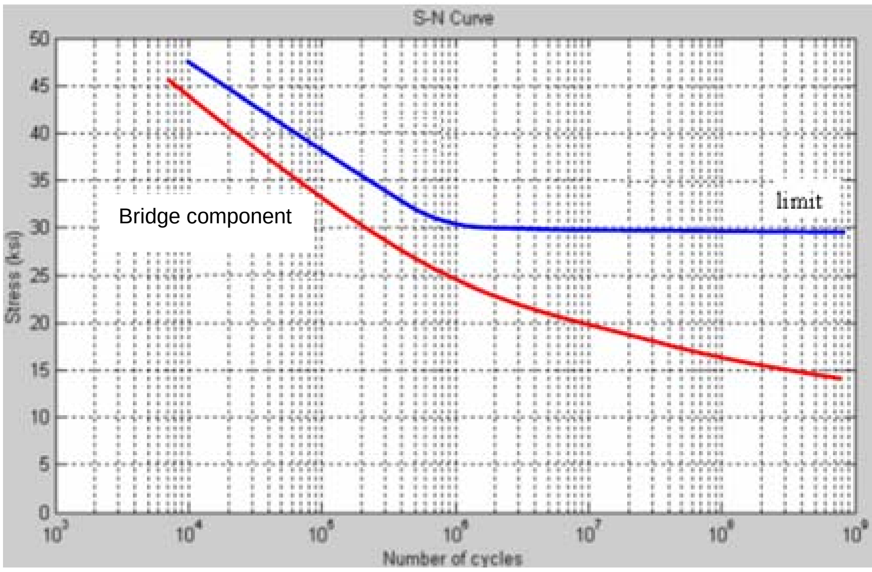


Figure 5.9 Example plot of a S-N curve for a bridge component

Using the same approach as for fatigue the maintenance utilization of the expansion joint can be calculated by making a rain flow count on the movement of the expiation joint and then adding up the rain flow bins to a total sum of movement.

6 Load Predictions

The following section describes the load predictions available in CSP. Load predictions shall be prepared to assist with traffic management on the approach network to the bridge as well as on the bridge. Predictions required for effective operation include:

- wind speed (mean and gust) and direction (gust) (weather data)
- rainfall (weather data)
- ice formation on road surface (weather data)
- vehicle traffic (traffic data)
- train passage (traffic data)

The influence of load predictions shall be assessed by comparison against loads established at serviceability limits:

- for the bridge e.g. navigation channel clearance, gradient requirements for trains, permissible load.
- for the safety of high-sided vehicles e.g. vehicle overturn, safe driving conditions.
- for the safety of low vehicles e.g. vehicle overturn, safe driving conditions.
- for the safety of trains e.g. train overturn.

Traffic flow predictions shall be available for the appropriate control of traffic flow across the network and bridge.

Load predictions shall be provided for the following timescales:

- short term : 10 minutes
- medium term : 2 hours

- long term : 1 day.

6.1 Data input for Load Predictions

Predictions shall be established around data received from other components of SCADA as well as from third parties:

- Weather data shall be recorded on the bridge by the SHMS including wind speed (mean and gust) and direction (gust), air temperature, air pressure, and precipitation.
- Traffic data on the approach network to the bridge and on the bridge shall be recorded by the Network TMS and the Bridge TMS, and processed by the SHMS. Traffic data recorded by the Network TMS and Bridge TMS includes vehicle and train weight, length, speed and time of passage at various detection points. Traffic data processed by the SHMS includes the total traffic (vehicle and rail) load on the bridge, the density of vehicle traffic on the bridge, the total vehicle traffic load approaching the bridge, the total rail traffic load approaching the bridge, and the vehicle traffic flow at licence-plate monitoring locations.
- Advance train movement data shall be supplied by RFI, including train total weight, total length, speed, and time of passage.

6.2 Weather predictions

The weather predictions are envisaged to be produced by a well established weather institute.

Local weather data, collected by the SHMS, Bridge TMS and Network TMS, can be supplied to the chosen weather service/institute to refine predictions for the local area. Local weather data includes:

- plan gust wind speed
- plan gust wind direction
- plan mean wind speed
- air temperature
- air pressure

- rainfall
- cloud cover

A local model of the area should be developed which can deliver predictions of:

- peak 10 minute mean wind speed in prediction interval
- peak 3 second gust wind speed and direction in prediction interval
- minimum and maximum air temperature in prediction interval
- maximum rainfall in prediction interval
- ice formation on road surfaces in prediction interval
- minimum visibility in prediction interval
- cloud cover (percentage coverage)

The prediction interval is to be agreed with the chosen weather service/institute. For short term and medium term predictions an interval of 1 minute is desirable, however an interval no greater than 10 minutes should be accepted. For long term predictions an hourly interval is acceptable. The predictions should be updated at regular intervals, say every 1 hour. Update intervals are to be agreed with the well established weather institute.

Data shall be provided in columns, with leading columns presenting the timestamp.

The CSP shall display data graphically. All prediction data shall be presented against time. Data extracted from the SHMS shall also be shown on the graphs. The operator shall be able to choose which deck anemometer is used to provide the data that is displayed. Serviceability limits shall be displayed on the graphs.

Gust wind speed and direction, and mean wind speed and gust wind direction, shall also be presented on rosettes. For clarity of presentation, a data point shall be presented for every 1-minute. Maximum wind speed in the 1-minute interval shall be presented. Average wind direction in the 1-minute interval shall be presented. The duration of data shown on the rosette shall be user-definable, initially set at 10 minutes of extracted data and 10 minutes of prediction data. Serviceability limits shall be displayed on the rosettes.

Figure 6.1 presents a representation of these images.

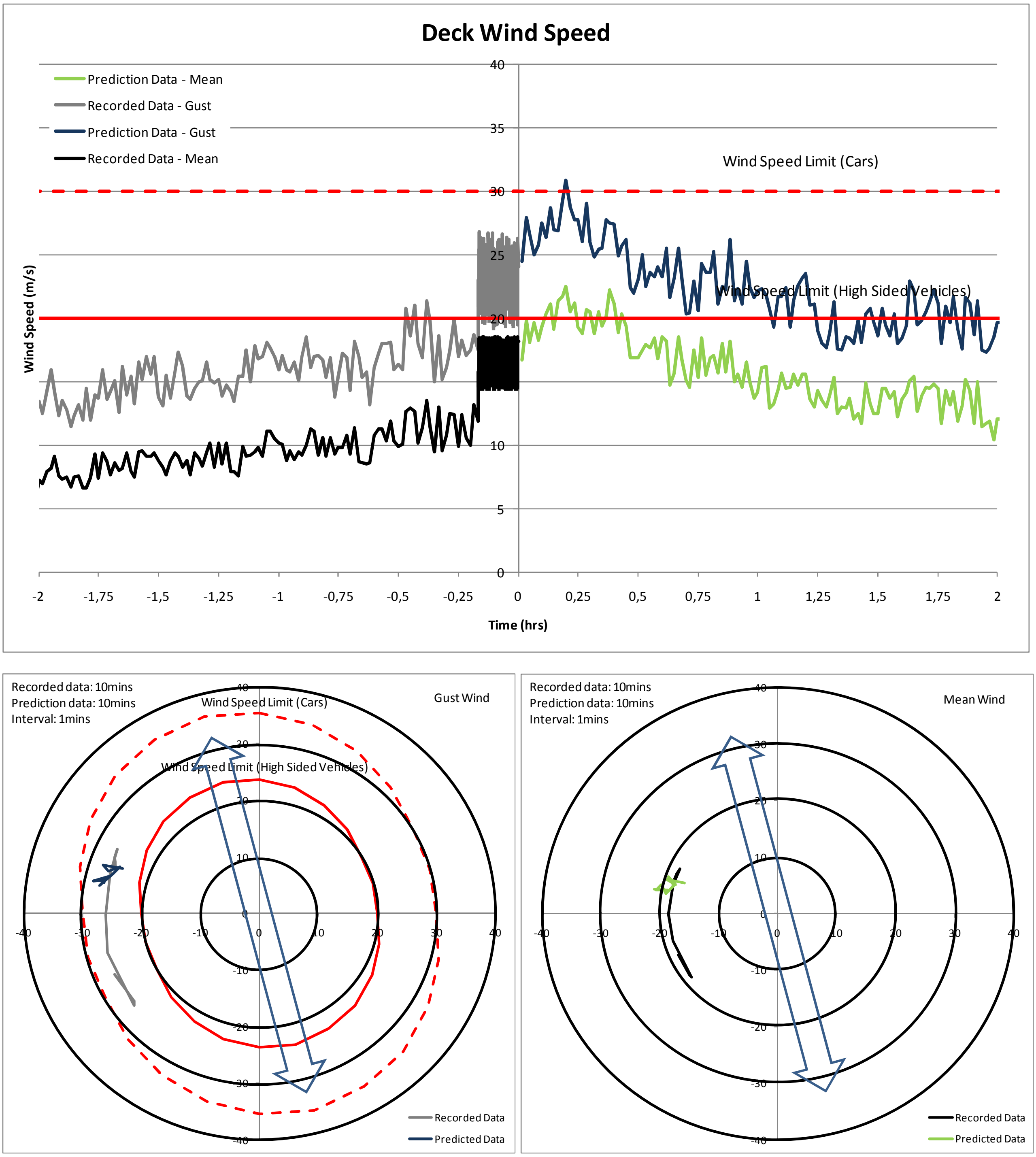


Figure 6.1 Example plot of wind data

6.3 Traffic predictions

The traffic predictions shall be produced by the CSP based on traffic data recorded by the Network TMS and Bridge TMS, and processed by the SHMS, and based on advance notice of rail traffic provided by RFI. A standard software package as SimTraffic 7, Aimsun 6 or similar(to be agree on be before implementation) will be used in calculating the short to medium term flow, density and vehicle composition of the traffic and the potentially of traffic jams and there location. This software can also be used in planning of maintenance on the bridge as it is possible to simulate closing traffic lanes and see how this results on the traffic flow and transportation time.

Data provided by the SHMS includes:

- total traffic (vehicle and rail) load on the bridge
- density of vehicle traffic on the bridge
- total vehicle traffic load approaching the bridge
- total rail traffic load approaching the bridge (as measured by the Network TMS)
- vehicle traffic flow at licence-plate monitoring locations.

Data associated with advance notice of rail traffic by RFI should include:

- train total weight
- train total length
- train speed
- time of passage

The following predictions shall be produced:

- total vehicle traffic load on the bridge
- total rail traffic load on the bridge
- total traffic (vehicle and rail) load on the bridge
- density of vehicle traffic on the bridge(congestion levels)

- vehicle traffic flow on the bridge vehicular composition (calculated from dynamic short term data from SHMS)
- congestion levels (calculated from dynamic short term data from SHMS)
- flow mean speeds (calculated from dynamic short term data from SHMS and mean speed based on statistical data)
- localization, duration and extension of possible queues (calculated from dynamic short term data from SHMS)
- vehicular load for each section of the Bridge
- vehicle traffic flow on the network

Vehicle traffic data shall be recorded on the approach network to the bridge. Vehicle traffic will be travelling at motorway speeds, in excess of 90km/h. Real-time vehicle data can only be traced across the network and the bridge for minutes, and therefore remain valid for short duration. However vehicle traffic patterns are, for all intents and purposes, well conditioned and follow 24-hour trends. The trends will be dependent upon primary influencing parameters e.g. day of the week, working day or holiday, commercial influences etc. Trends may vary over years, however they will be repetitive over months. Trends will therefore be established from data accumulated from numerous days with identical primary influencing parameters, and will be averaged and smoothed. An example of a trend is given in Figure 6.3, where Figure 6.2 shows a flowchart used for producing Figure 6.3.

Figure 6.2 and Figure 6.3 shows the procedure for calculating and plotting the predicted and actual traffic flow in % of the bridge limit based statistical data. This will be the same procedure used for calculating:

- traffic density
- vehicular composition
- congestion levels
- flow mean speeds
- vehicular load for each section of the Bridge

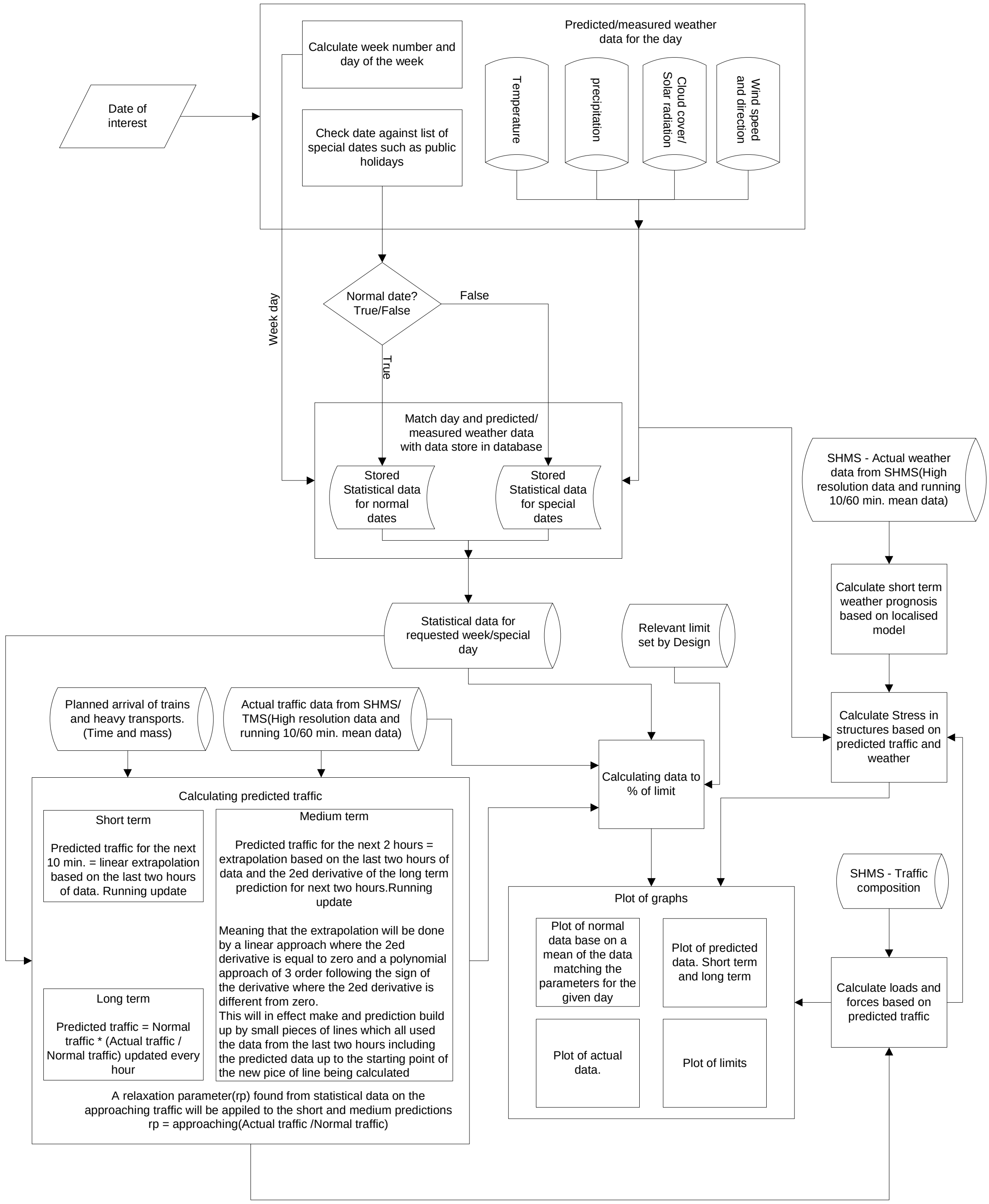


Figure 6.2 Flow chart for prediction and producing figures and plot

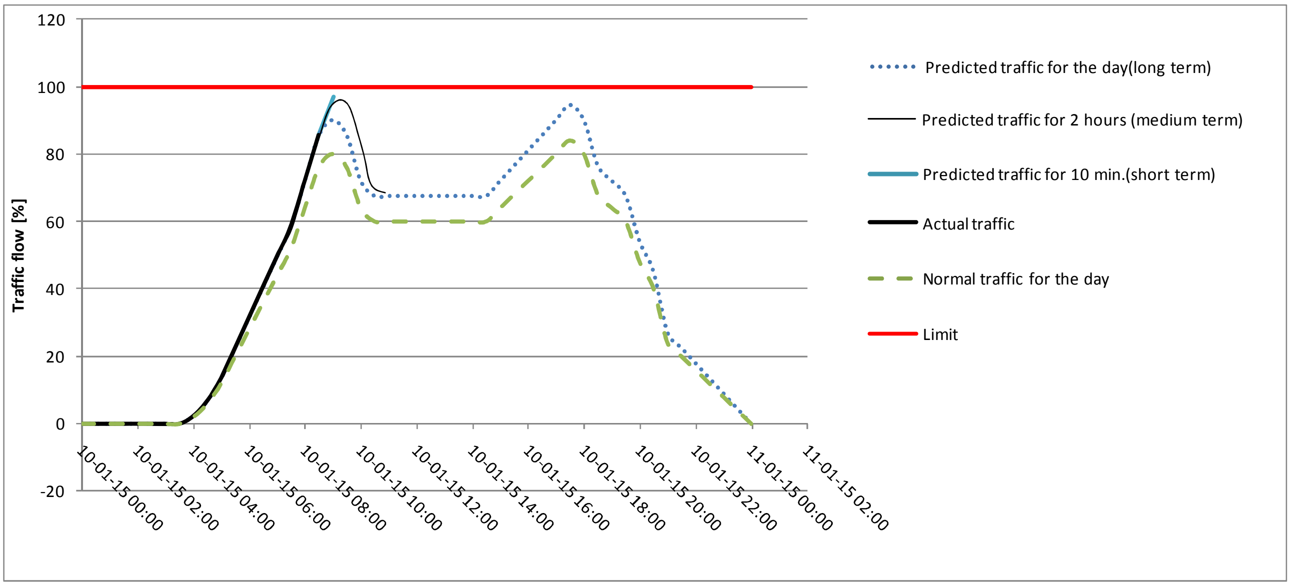


Figure 6.3 Example plot of traffic prediction for one day

Vehicle traffic predictions will be developed around statistical review of previously recorded traffic patterns data to establish reliable vehicle traffic flow trends, which can then be fine-tuned according to existing vehicle traffic flow conditions.

Regularly and automatically produced predictions will be based on typical trends in isolation of extraordinary events e.g. accidents, applied control measures, Predictions relating to extraordinary events shall be initiated by the operator with manual input at the CSP, by using the relevant software package, such as the above mentioned Traffic simulation or structural simulation software.

Short term predictions of vehicle traffic flow across the network and the bridge will be established from vehicle traffic flow measured at the vehicle traffic monitoring locations, extrapolated according to speed of flow and by the use of the Traffic simulation software mentioned above .

Medium term predictions of vehicle traffic flow across the network and the bridge will be established around statistical vehicle traffic trends, fine-tuned according to measured vehicle traffic data and by the use of the Traffic simulation software mentioned above .

Long term predictions of vehicle traffic flow across the network and the bridge will be established around statistical vehicle traffic trends.

Train data will be provided by RFI in advance of the arrival of trains. Train data will also be recorded as the train approaches the bridge, acting as an improvement to figures provided by RFI. Train traffic will be well regulated, and therefore the timing of trains will be predictable. Train traffic will need to be reviewed within the context of total load on the bridge. Train traffic total load can therefore be added as a manual input to the predictions over a duration covering the time that the train is expected to be on the bridge, including provision for error.

The detailed processes for establishing traffic predictions shall be established at the detailed design phase of the project when final positioning of licence-plate monitoring locations is known and processes for receiving information from RFI have been agreed.

The prediction interval for short term and medium term predictions shall be 1 minute. For long term predictions a 10 minute interval shall be adopted.

Data shall be provided in columns, with leading columns presenting the timestamp.

The CSP shall display data graphically. All prediction data shall be presented against time. Short, medium and long term predictions shall be displayed on the same graph. Data extracted from the SHMS shall also be shown on the graphs. Serviceability limits shall be displayed on the graphs. For the purpose of general prediction review for the passage of trains, a serviceability limit for vehicle traffic, that is limited by a notional allowance for trains on the bridge, shall also be displayed.

Total vehicle traffic load on the bridge and total traffic (vehicle and rail) load on the bridge will be plotted against density of vehicle traffic on the bridge. The duration of data shown shall be user-definable, initially set at 10 minutes of extracted data and 10 minutes of prediction data. Serviceability limits shall be displayed on the graph. For the purpose of general prediction review for the passage of trains, a serviceability limit for vehicle traffic, which is limited by a notional allowance for trains on the bridge, shall also be displayed. Two theoretical lines shall be provided indicating the expected correlation of 1) cars only, and 2) heavy goods vehicles only. These theoretical lines are also expected to assist with general prediction review.

Figure 6.4 presents a representation of these images.

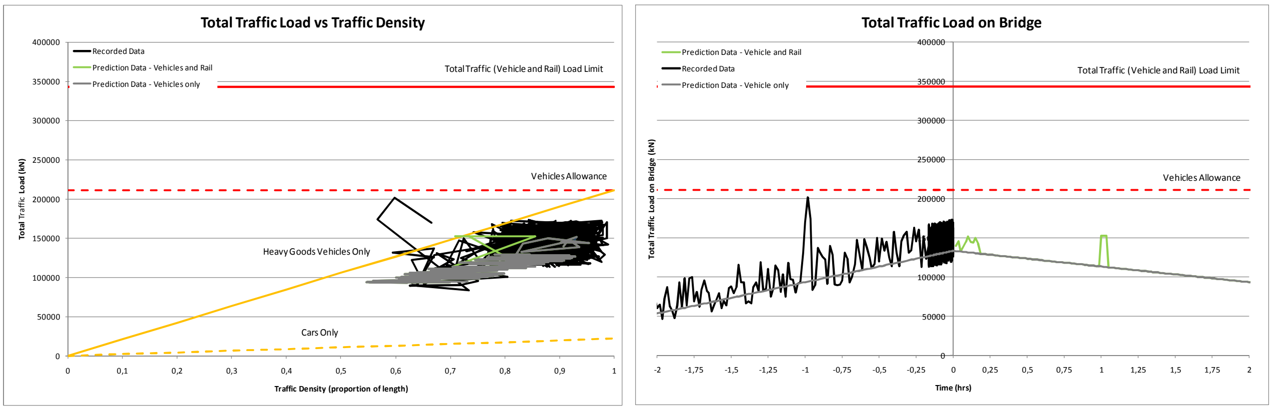
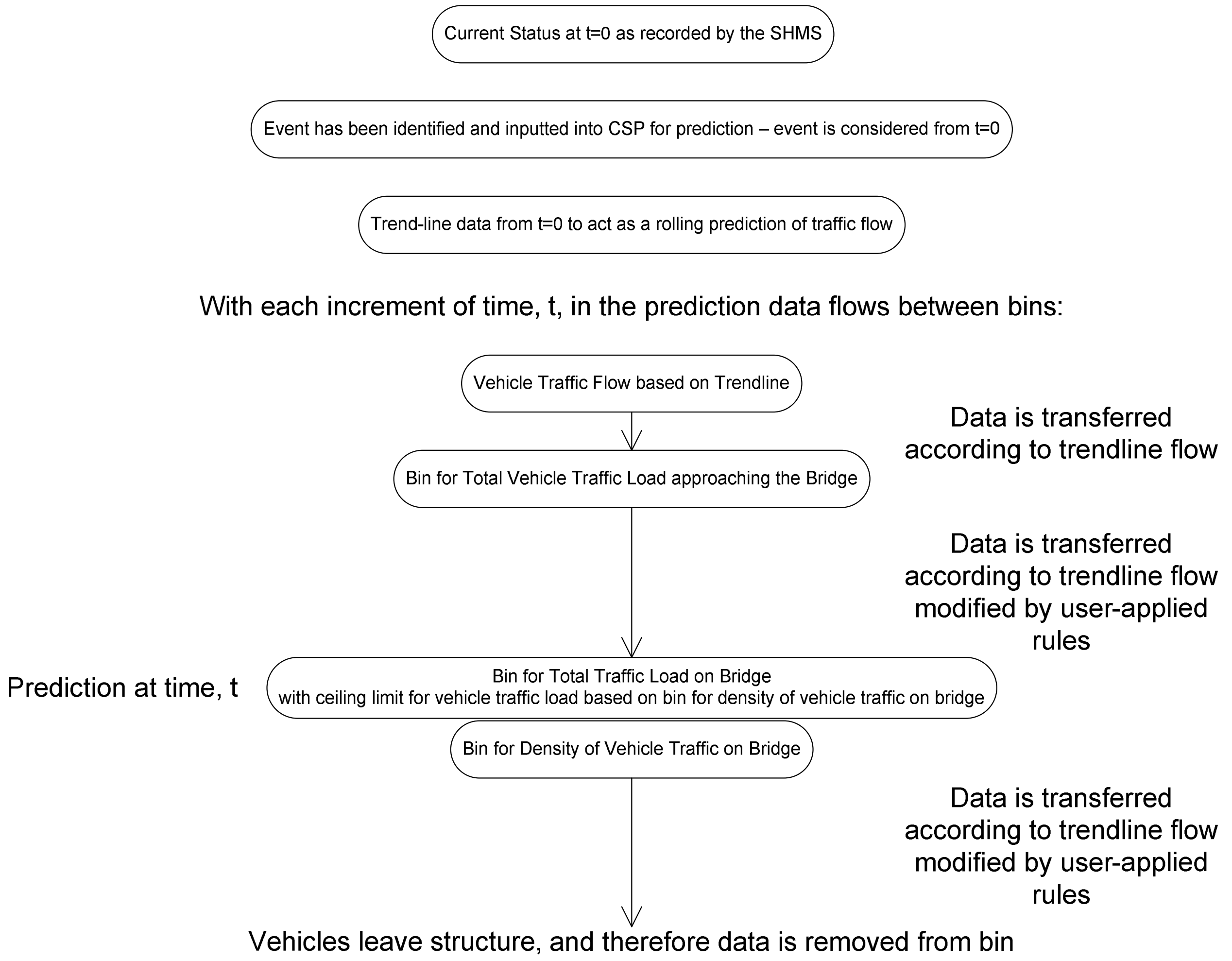


Figure 6.4 Illustrative plots of bridge load against traffic density and time.

Predictions may also be required to review the impact of an event e.g. an accident which closes one lane, or a traffic control procedure e.g. reducing the speed limit. Data contained within the vehicle traffic flow trends can be used as a representation of expected traffic and can thus be applied as a time-varying input data-stream that is manipulated through the prediction according to rules established for different scenarios, defined in the E&O manual. A database containing a list of "cause and effect" can be established to allow the predictions to be improved based on real data. An example of such a procedure could be as follows:



The detailed processes for establishing traffic predictions shall be established at the detailed design phase of the project when final positioning of licence-plate monitoring locations is known.

6.4 Structural Temperature Predictions

The structural temperature predictions shall be produced by CSP, using weather predictions produced by the chosen weather institute and measured data from the SHMS.

The following predictions shall be produced:

- global structural steel temperature
- difference in temperature between the main-cable and the global structural temperature

Structural temperature develops as a result of air temperature conditions and available solar radiation e.g. heat is absorbed from the sun. Air temperature predictions will be made available by the national weather centre. Solar radiation is more difficult to quantify. Solar radiation is dependent on the general weather conditions e.g. cloud cover (clear or cloudy), the time of the day e.g. the intensity of solar radiation is greatest in the middle of the day, and the time of the year e.g. the intensity of solar radiation is greatest in the summer. The temperature that develops as a result of solar radiation shall also depend on the pattern of shade throughout the day. The solar radiation, in isolation of shade, will be well conditioned and follow 24-hour trends that are dependent upon the date. Predictions of solar radiation will therefore be established from basic trendlines in isolation of shade, and shall be modified according to predictions of cloud cover produced by the national weather centre. A combination of review of statistical data showing the influence of air temperature and solar radiation will thus allow global structural temperature and difference in temperature between the main-cable and the global structural temperature to be predicted. The same method shall be adopted for short term, medium term and long term predictions. These prediction will be performed using the procedure shown in Figure 6.2.

The prediction interval for short term and medium term predictions shall be 1 minutes. For long term predictions a 10 minute interval shall be adopted. The predictions shall be updated automatically every 30 minutes.

Data shall be provided in columns, with leading columns presenting the timestamp.

The CSP shall display data graphically. All prediction data shall be presented against time. Short, medium and long term predictions shall be displayed on the same graph. Data extracted from the SHMS shall also be shown on the graphs

6.5 Other related displays

6.5.1 Wind load versus total traffic (vehicle and rail) load

Wind speed data shall be converted to wind pressure, which is a direct representation of wind load. Transverse wind pressure data shall be plotted against total traffic (vehicle and rail) load on the bridge. For clarity of presentation, a data point shall be presented for every 1-minute. Maximum values in the 1-minute interval shall be presented. Both prediction data and extracted data shall be shown. The duration of data shown shall be user-definable, initially set at 10 minutes of extracted data and 10 minutes of prediction data. Limits shall be displayed.

6.5.2 Displacement and moments

Influence lines shall be established for the below listed cases, which will be used in conjunction with the predicted loads listed in section 6:

- Moment of the tower base in the along bridge direction and transverse bridge direction due to wind velocity and wind direction.
- Moment of the tower base in the along bridge direction and transverse bridge direction due to traffic
- transverse deck displacement a function of wind velocity and wind direction
- vertical deck displacement due to traffic (vehicle and rail) load
- vertical deck displacement due to change in the global structural temperature
- vertical deck displacement due to change in difference in temperature between the main-cable and the global structural temperature

Displacement data shall be established from the recorded and predicted data, as applied to the influence lines. The data shall be plotted against time. Serviceability limits shall be added to the graphs.

Figure 6.5 presents a example of this type of graph.

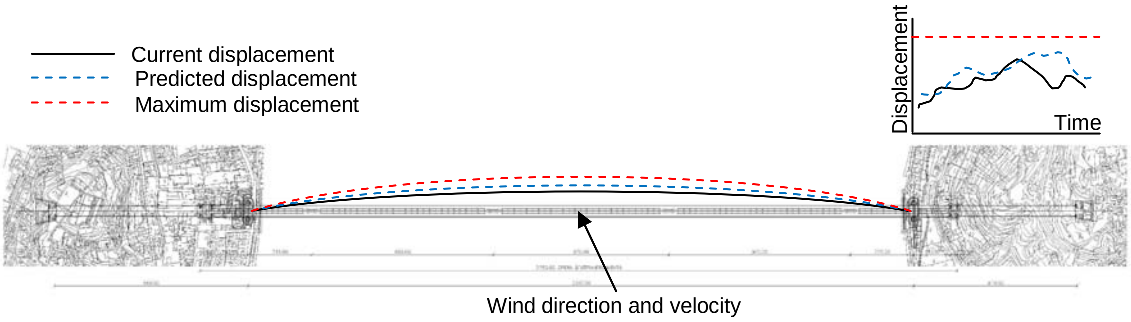


Figure 6.5 Illustrative graph of predicted deflection of the bridge deck.

- Displacements of the towers in relation to wind pressure. This will be updated at the same rate as the weather predictions are produced.
- Displacement of the expansion joints in relation to wind and temperature. This will be updated at the same rate as the weather predictions are produced.

These influence lines will be used by the CSP to estimate the displacement of all the above mentioned cases. the Influence lines will be produced from the FE-model, which is a part of the CSP system, and should be updated every time the FE-model has been calibrated to the measurements from SHMS in order to ensure the best possible predictions. Like wise the influence line will have the option of calibration in respect to the recorded data from the SHMS, meaning that a comparison between the predicted and the recorded displacement can be made in order to manually calibrate the influence line.

6.5.3 Cable Stress

Prediction of cable stress will be handled separately for the main cable and the hangers.

The stress on the main cable will be found by the use of a uniformly distributed mass together with an influence line. The uniformly distribute mass, will be calculated in CSP based on the traffic and wind load.

Hanger stress will be calculated base on the following equation

$$\text{Hanger stress} = \frac{\frac{\text{Uniformly distribute force}}{\text{Number of hangers}} + \text{Point force}}{\text{Cable area}}$$

where a "Point force" is and instant load from scheduled trains and heavy transports. This point force will be applied in the time domain when used in prediction, meaning that the point force is applied to each hanger at a different time in the prediction according to the position of the point load calculated from the speed limit for either trains or a heavy transport.

7 Maintenance Predictions

The following section describes the maintenance predictions available in CSP, and the display of maintenance predictions on CSP. Maintenance predictions shall be prepared to assist with planning of maintenance of the bridge. Predictions required include:

- Fatigue of the orthotropic deck (fatigue data)
- Fatigue of deck diaphragm cope-holes (fatigue data)
- Fatigue of deck plate corner at cross-beam (fatigue data)
- Fatigue of hanger-cables due to axial stress fluctuations (fatigue data)
- Fatigue of hanger-cables due to bending stress as well as axial stress fluctuations (fatigue data)
- Maintenance condition of expansion joints (expansion joint maintenance data)

Maintenance predictions shall establish a residual life-of the monitored component.

7.1 Fatigue predictions

The fatigue predictions shall be produced by the CSP based on rainflow count data (recorded by the SHMS) together with the use of the Palmgren-Miner sum for calculating the utilisations. The Palmgren-Miner hypothesis, states that where the component of interest is subjected to k different stress cycles, failure occurs when:

$$\sum_{i=1}^{k} \frac{n_i}{N_i} = 1$$

where n_i is a contributing stress cycles and N_i is the number of cycles to failure. N_i is a function of S-N curves as shown in Figure 5.9. By looking at the time used for logging the data used in the summation $\sum_{i=1}^{k} \frac{n_i}{N_i}$ it is possible to predict the residual life by the following expression.

$$\text{Residual life} = \frac{\text{Time used for logging data}}{\text{Palmgren} - \text{Miner sum}}$$

The above relation assumes that data have been logged since the structure of interest has been open for use.

The development of fatigue utilisations shall be calculated from all rainflow count data following the procedures presented in the design basis. The fatigue class will be user-definable. The smallest bins will contain fluctuations that are not real but due to noise. The user shall be able to define which bins are not used in the calculation of fatigue utilisations. User-definable parameters shall initially be set to values adopted in the SHMS.

Predictions of residual life-shall be calculated based on the change in utilisation:

- over the previous 24 hours
- over the previous 1 month

Fatigue predictions shall be produced every 24 hours.

The residual life-predictions, as well as the development of fatigue utilisations recorded by the SHMS, shall be plotted against time. Utilisations shall be represented by residual life-e.g. a utilisation of 0 is equivalent to a residual life-of 200 years, a utilisation of 1 is equivalent to a residual life-of 0 years. The residual life-predictions shall be presented as extensions from the current time to a residual life-of 0. The utilisations explicitly calculated by the SHMS shall also be plotted, to act as a reference.

Figure 7.1 shows an example of a plot of residual lift time plotted against years of use.

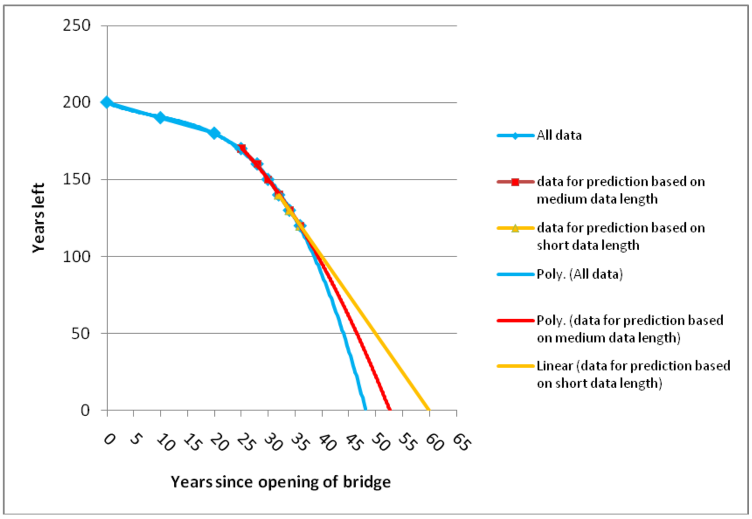


Figure 7.1 Illustrative plots of predicted remaining lift time of a non specified bridge component.

8 Communication between CSP and other systems

The following section list the different sub-system that CSP will send/received data to/from. In general the data needed for the CSP will be located in the databases located in SCADA and MMS.

All prediction made by the CSP will be save on the SCADA database for use in other sub-system under MACS unless otherwise stated.

8.1 Common databases in SCADA and MMS

CSP will have access to the databases in SCADA and MMS from were CSP will be able to receive saved data from the MMS, SHMS, BMS, ICMS and other relevant systems and sub-systems.

8.2 MMS

CSP will have the function of providing MMS with plot data. The data needed by MMS is listed in section 9. The plot data provided to the MMS will be saved permanently in MMS database, but deleted from the CSP after MMS has acknowledged that the data has been received.

8.3 SHMS

CSP will have access to the database situated in SCADA where historical data from the SHMS is stored. Furthermore the SHMS will supply data from the last entry in the database and up to the current time, where the last 10 min will be of high resolution data.

8.3.1 Output Data for the SHMS

All prediction made by the CSP will be available in the MMS database from where the SHMS can collect all prediction data relevant to a given sensor or sensor setup.

8.4 BMS

Using data from the SHMS the loads and predictions calculated by CSP will be used for interpretations and comparisons to limits given by the designers in order to grade a bridge component in the BMS point ranking system. The CSP will interface with the BMS and retrieves the current grade for the bridge component in question. The CSP calculated grade will then be assimilated with this BMS current grade in order to obtain a new total grading. A report based on the calculation and the assimilation of grades will be generated for the use in BMS.

8.4.1 Output Data for the BMS

The grading system used by the CSP will be set up in cooperation with the BMS in order to find the correct scaling for the calculated fatigue/utilization/loading etc. in relation to the 6 point grading scheme used by the BMS (0 to 5). As standard the grading will be equally divided over the range of fatigue/utilization/loading etc. Meaning for example that fatigue will be graded as shown below and the rest in a similar manner.

$$\text{CSP grade } = 5 - 0.025 * \text{residual life in years}$$

As standard the assimilation of exciting grades from the BMS system to at total grade base on the BMS grade and the calculated CSP grade will be perform as shown below. There will be an option of changing this relation later on if it is found beneficial based on experience.

$$\text{Total BMS grade} = \frac{(\text{BMS grade}) + (\text{CSP grade}) * 1.2}{2}$$

A safety factor of 1.2 is applied on the calculated CSP grade. It is possible to change this value for the individual structural component based on the recommendation of BMS inspections.

Other forms of data will for example comprise of values such as deflection curves and peak stress values as well as simple illustrations, in pdf-format.

Other examples are curves showing traffic loads, expansion joint movements and stress variations in a period. CSP can generate reports for presentation of the processed results. For this, CSP uses the report generation facilities provided in MACS. In this way the CSP carries out a simulation and prediction oriented evaluation of the registrations captured by SHMS.

8.5 ICMS

The CSP system will have the function of collecting and making a list of events, from the ICMS, which collect all the events occurring in MACS including event from out side the bridge systems, which will have and effect on the bridge and MACS systems. It will be possible to calculate correlation to different effects such as wind traffic and other effects through the use of the ICMS event list and their location. Another example apart from correlation calculation is the possibility to plot the number of events in relation to location.

9 Plot data available for other systems

Below is a list of the system which needs data from the CSP. The different sub-section for each system also contains a description of how what data is produced for that particular system.

9.1 General

The CSP will have the function of generating virtual channels. For example the integration of acceleration to displacement could be set up to be performed every time a user needs it. So instead of asking for the integration, the user will create a new permanent virtual channel which will provide the user with the displacement instead of the acceleration.

Another example could be an engineer who wants to look at the difference in movement in two displacement sensors. Here the engineer can define a new virtual channel which substract the two data sets giving the difference between to chosen displacements sensors.

If the new virtual channel at one point becomes obsolete it will be possible to delete it from the CSP.

The number of virtual channels available in the CSP is to be agreed on, based on the hardware specification at the time of programming the CSP.

In general all non virtual channels will be available for other system. The virtual channel will have a option to be a private/shared channel which means that the virtual channels only be available if the creator of the channel choose to make it a shared channel. Making it a shared channel makes it available to all systems with access to the CSP.

9.2 General Output Data by CSP

The following section lists example data needed by the MMS. All date will have a timestamp. It should be noted that the following table only illustrated the type of data needed and not the amount of data. For example the listing of temperature data means temperature data from all temperature sensors.

9.2.1 Temperature data

Time	Location/ WBS	Temperature [°C]

9.2.2 Wind data

Time	Location/ WBS	Wind speed [m/s] (10 min. mean)	Wind direction [°] (10 min. mean)	Gust wind speed [m/s]	Wind pressure [Pa]	Predicted wind speed m/s]

9.2.3 Load data

Time	Location/ WBS	Total Bridge Load [%]	Total Expected/ Predicted bridge [%]

9.2.4 Stress data

Time	Location/ WBS	Deck stress [MPa]	Tower stress [%]	Hanger stress [%]	Main cable stress [%]

9.2.5 Event data

Time	Location/ WBS	Warnings (Load)	Warnings (Displacement)	Alarms (Load)	Alarms (Displacement)

9.2.6 Displacements data

Time	Location/ WBS	North joint [%]	South joint [%]	North Tower [%]	South Tower [%]	Hangers [m]	Main cable [m]	Deck at centre node [m]

(Main cable [m] (two types: static(GPS data) and dynamic(Acc data)))

	Predicted displacements at

Time	Location/ WBS	North joint [%]	South joint [%]	North Tower [%]	South Tower [%]	Main cable [m]	Deck [m]

9.2.7 Acceleration data

Time	Location/ WBS	Acceleration of the deck [m/s^2]	Peak acceleration of the deck [m/s^2]

9.2.8 Frequency data

Time	Location/ WBS	frequency of deck vibration

9.2.9 Fatigue data

Time	Location/ WBS	Fatigue of the cables [%]	Fatigue of the steel deck [%]

9.2.10 Virtual channel data

It will be possible to make a virtual channel available for the MMS if new standard reports require data which is obtain by a new combination of the physical channels.

Time	Virtual channel 1	Virtual channel 2	…

10 List of proposed software

The following table list the standard software proposed for application within the CSP system.

Analysis	Simulation	Traffic:	Simtraffic7 or similar.
		Structural:	ADINA, Bentley RM 2000, SAP 2000 or similar.
		Weather:	Models produced by recognized weather institute.
	Data handling	All:	Examples: Labview, Matlab, Matematica or similar.

Apart form the above mentioned standard software, some customized function have to be made. These function could be produced in Matlab, C++ or similar programming language.

11 Available plot in CSP

Apart from the plots listed above, CSP will also be able to produce all plots mention in document CG1000-P-2S-D-P-IT-M4-C3-00-00-00-01_A_MACS_ANX Furthermore all data from SHMS, TMS and other relevant systems stored in the SCADA and MMS databases will be available for more in-depth analysis using the above mention analysis tools in section 5.1.

12 List of requirements

The following is a list of requirements gathered through:

- The technical specification from Stretto di Messina

ID		Requirement	Requirement Reference
1.	Determine the present-day level of service		The Present-day level of service in respect to load on the bridge can be seen from plots in the MMS/SHMS where plots of the total load is shown in relation to the SLS limit.
2.	Estimate/Simulate	The expected level of service	The expected level of service can be seen from plots in the MMS/CSP displaying data produce in CSP showing traffic plots of varies predicted cases short term, medium term and long term configuration of traffic load, rail load, total load, flow, density and etc., see section 6.3

3.		the effects of events on traffic, structure and environment	The localized effect to the traffic in respect to the bridge can be calculated by used on the traffic simulation software, see section 6.3. The apparent effects on the structure can be seen by data produced by the SHMS where as the long term effects has to be simulated by the FE- Model, see section 4.5

4.		actual traffic conditions, structure and physical environment	The actual and predicted traffic can be seen from plots in the MMS/SHMS/CSP displaying data produce in SHMS and CSP showing traffic plots of varies predicted cases short term, medium term and long term configuration of traffic load, rail load, total load, flow, density and etc., see section 6.3 The actual and predicted structure data can be seen in the MMS/SHMS/CSP displaying data produce in SHMS and CSP Predicted displacements are listed in section 6.5.2 where as fatigue and remaining life predictions are listed in section 5.3.3 and section 7.1 Prediction of the physical environment here the weather will be performed as described in section 6.2
5.	Information on the bridges current and expected state to the Bridge's concessionaire		Person in SCADA /SHMS/MMS/CSP

6.	Collected data shall also be used to build accurate models of the of-the-moment and expected state of the Bridge.	SHMS(at the moment)/CSP(expected). In the CSP the FE-model(section 4.5) will be calibrated in relation to data recoded by the SHMS. The Influence lines used to predict displacements of the varies structural elements (section 6.5.2) will then be revised bu the calibrated FE-model in order to ensure a accurate prediction.
7.	All available information (measurements, estimations, here included meteorological-climatic, seismic-tectonic and traffic ones, eventual alarm signaling, etc.) shall be used by the management and control system both for evaluating the actual state of the Bridge, and for assessing the expected state within the short (ca 10 min), medium (1 or 2 hours) and long term (one or more days).	The actual data can bee seen in MMS/SHMS, whereas the predicted data can be seen in the MMS/CSP. Examples of plot can bee seen in section 5.2.2, 5.3, 6 and 7. With the possibility of virtual channels customised plots can be generated, see section 5.1.
8.	Based on these evaluations and estimations, the maximum actual, medium and long-term admissible level of service for the Bridge shall be evaluated.	SHMS/CSP, see section 6.3

9.	The level of service will be evaluated also according to the conditions of the connected roadways/highways, such as, for example, the condition in which these latter are no longer able to guarantee adequate flow to traffic coming from the Bridge, or else the state in which the entering traffic flow might cause excessive disturbance to vehicles traveling on the Bridge.	CSP: And interface to the TMS for the road system surrounding the Bridge needs to be made and data will be save in the common database with the rest of the TMS data. The CSP will then take these external data into account when making the prediction shown in section 6.3
10.	Based on the admissible actual and expected level of service, the system shall regulate vehicular traffic on the Bridge and eventually intervene and regulate incoming fluxes, in order to guarantee safety, traffic fluidity and, in case, to prevent or limit queues' formation on the Bridge.	CSP will produce alarms events if predictions reach relevant limits. The alarms will have to be acknowledge by the operator in SCADA, which will then sent a request to TMS system of regulating the traffic flow base on an evaluation of the prediction from the CSP. see section 4.2
11.	The system will visualize in real time all information related to the events, in the most appropriate way to obtain an immediate and efficient representation (maps, tables, videos), and will grant the research, visualization and necessary elaboration related to user-specified periods or events.	ICMS/MMS/CSP: Links to live video feeds, location and sensor data should be include in the event log. CSP will present event location on maps and a correlation plot of events and a relevant chosen parameter can also be shown. see section 5.2.2 and section 5.3.1

12.	The system shall consider as an Event every signaling of anomaly, breakdown, accident, unforeseen event, intrusion, sabotage that generate an alarm, as well as all planned activities that influence the Bridge's safety, traffic or durability.	For the CSP see section 4.2
13.	Every event will be monitored by the system in its whole duration. Information related on the event's evolution might be acquired by monitoring the Bridge, the maintenance sites, the accidents, as well as through coordination with the managers of the interconnected roadways/highways and railways, and/or might be written in by the operator. All information collected on events, included localization, date and time, and on their evolution shall be recorded.	For the CSP an event comprise of a prediction reaching or crossing a relevant limit. see section 4.2 for relevant actions.

14.	The data collected and elaborated shall be visualized both in the form of reports (tables, graphs) and on a geo-referenced map. All critical data and all data useful or essential for the evaluation of the Bridge's state shall be visualized, and different scenarios shall be represented as well (of-the-moment, expected, "historical") through a GIS interface, among which: 1. The of-the-moment and expected state of the Bridge, with events' visualization (lanes' closures, traffic signals' state, maintenance sites, accidents, etc.) 2. The of-the-moment and expected state of vehicle traffic, with visualization of traffic parameters (flows, mean speed, congestion, queue and related length and expected waiting time) 3. The of-the-moment and expected railway traffic (coaches localization) 4. The of-the-moment and expected state of the structure 5. The of-the-moment and expected weather conditions	1. Can be visualised through the traffic simulation software, section 4.4 2. See SHMS and section 6.3 3. All data in the database originating from SHMS, TMS and external sources will be used in the prediction, see section 4. see section 6.5.2 and section 7.1 5. see section 6.2
15.	Furthermore, the user interface shall allow the space-time analysis of available data, through the reconstruction, also in three dimensions, of different scenarios and their evolution; this will be done for the purpose of supporting management, maintenance and planning activities.	CSP: Making virtual channels using the tool described should make it possible to do all the analysis needed. see section 5.1 and section 9.1.

16.	The system's users shall be able to define hypothetical situations, to simulate the related conditions and to observe the Bridge's reactions. Such activities are important both as regards to monitoring and to management and planning.	CSP: By the used of the software mention in section 4.4 an the statistical data it is possible to make a local prediction of a hypothetical situations.
17.	The simulation of the structure's behavior shall provide for: 1. the analysis and evaluation of phenomena influencing the structure's integrity, safety and durability 2. the evaluation and foresight of the bridge's behavior, also in correlation with the occurrence of events 3. the simulation and evaluation of maintenance and management strategies for the structure	1. Section 4.5 2. Section 4.5 and section 6.5.2 3. Section 4.5 and BMS
18.	The simulation of the physical environment shall allow: 1. the analysis and evaluation of meteorological-climatic and seismic-tectonic phenomena that influence the operation, behavior, integrity, safety and durability of the Work 2. the forecast and evaluation of meteorological-climatic and seismic-tectonic events that influence the operation, behavior, integrity, safety and durability of the Work.	1. Section 6.5 and section 4.5 2. Section 6.2, 6.4, 6.5 and section 4.5

19.	Events' management 1. Detection of the events 2. Monitoring of the events 3. Impact evaluation 4. Development of intervention strategies 5. Estimation of interventions' effects 6. Choice of the intervention to be adopted 7. Traffic management 8. Information diffusion	1. Events from the CSP will comprise of crossing preset limits in the prediction made by the CSP. Section 6 and 7 2. Monitoring of events originating from prediction will be done by the operator in SCADA. Section 4.2 3. Impact of events originating from prediction will be done by the operator in SCADA with help from the ICMS. Section 4.2 4. O&M manual 5. Intervention such as blocking a traffic lane will be entered in to the CSP system. 6. SCADA operator/managers 7. TMS 8. ICMS
20.	Combination of traffic, weather and structural conditions that limit or impede transit	Section 4.5, 6.2, 6.3 and 6.5.2

21.	Events shall be located in time and space. Signalled events shall be localized on a geo-referenced map and all related information shall be visualized (or given the possibility to be visualized). The maps might be used by the traffic management and emergency management sub-systems for the purpose of managing events.	Section 5.2.2

13 Documentation Minimum Requirements

The following documentation shall be provided with the CSP:

- Operation manual
- Maintenance manual
- System architecture guide
- Software source code guide for special developed software
- Printed software source code for special developed software
- Troubleshooting guide
- Event diagnosis guide
- Quality Control documents

Three copies of each document shall be provided. Documents shall be provided in both Italian and English.

It is recommended that the bridge owner or operator arranges for an additional manual to be created following 3 years of operation of the bridge, reporting the typical behaviour of the System.

13.1.1 Operation Manual

The operation manual shall describe the complete operation interface of the System.

13.1.2 Maintenance Manual

The maintenance manual shall set-out all of the maintenance activities required to keep the System functional for 10 years. Maintenance activities shall be divided into the following categories:

- regular general maintenance
- event-specific maintenance

The maintenance manual shall describe the maintenance activities and time intervals that are required, how the maintenance activities shall be performed, what tools are required, and what spare parts required. The maintenance manual shall also present inspection proforma.

The maintenance manual shall also identify maintenance actions required during events that require maintenance activities e.g. inspection of equipment.

13.1.3 System Architecture Guide

The system architecture guide shall present the complete layout of the hardware of the system. It shall also provide photographs and identification of all terminals and hardware.

13.1.4 Software Source Code Guide

The guide to the non commercial available software source code shall present sufficient detail of the software source code for a competent software engineer to understand and modify the system.

13.1.5 Printed software source code

Printed of non commercial available software source code, including a guide to the source code, shall be provided for the SHMS Data Conversion, Delivery, and Query Layer.

13.1.6 Troubleshooting Guide

The troubleshooting guide shall present actions to be taken to resolve basic problems with the system including: system block, system shutdown, data channel data loss, etc.

13.1.7 Event Diagnosis Guide

The event diagnosis guide shall be prepared by the System designer and shall present anticipated causes of registered events as well as advice on subsequent actions to be taken. The event diagnosis guide shall be developed around the matrix of anticipated outcomes for automatic assessment of Bridge Event Warnings.

13.1.8 Quality Control Documents

The quality control documents shall be presented in an organised file or document with reference index..

14 Quality Control Minimum Requirements

14.1 Sub-contractor Selection

Candidates for sub-contracts shall submit evidence that they operate under an approved quality system (e.g. ISO 9001). Candidates shall submit evidence of experience with Management and Information control systems and evidence of successful high quality installations, which shall be as a minimum in the form of client references, CVs of experience, and system demonstrations. The assessment of sub-contract bids shall include an assessment of experience and quality.

14.2 Testing

Testing of sensors, cabling, hardware, software and data-processing routines shall be required at key stages within the project. Testing shall include testing of function as well as testing of accuracy. All testing shall be accompanied by quality documentation. All testing shall be agreed with the designer.

14.2.1 Certificates

All equipment, including testing equipment, shall be provided with operation certificates and warranty certificates. All sensors, and testing equipment (if appropriate), shall be provided with calibration certificates.

14.2.2 Factory Acceptance Tests

All data processing and manipulation routines shall be independently tested and approved by the designer prior to delivery to site.

All software shall be independently tested and approved by the designer prior to delivery to site. The testing process shall include a full simulation of the operation of the entire network, including signal and fault testing.

All components of the system shall be independently tested for operation and approved by the designer before delivery for installation. Components provided with certification from established European accreditation bodies (e.g. UKAS) may be exempt from testing subject to the approval of the designer.

14.2.3 Site Acceptance Tests

Immediately following installation, all components of the System, including displays, shall be tested for operation and approved by the designer before delivery of the relevant structural component to site.

Before the bridge is opened to the public, and following completion of the System installation, the System shall be proof-tested. This proof-test shall demonstrate that the System runs without the development of errors. The test shall consist of continuous operation of the System, including the performing of designed operation tasks. The test shall be performed for a minimum of 30 continuous days. When an error is discovered it shall be corrected immediately. The test shall demonstrate error-free operation for a minimum of 15 continuous days. The duration of the test shall be extended if required to demonstrate this. The sub-contractor shall be required to perform the proof-test with sufficient allowance to ensure that the System will be certified prior to the opening of the bridge.

14.3 Repairs

All defects identified during testing shall be repaired. Components affected by the defects shall be tested following repair. The procedure shall be repeated until the function of the system is demonstrated to be in accordance with the monitoring requirements, and approval is provided by the designer. All defects identified and repaired shall be formally recorded as part of the quality control documents.

14.4 Labelling and Identification

All hardware shall be uniquely labelled, and shall be linked to the appropriate element references as will be described in the Inspection and Maintenance Manual for the bridge. Cables shall be labelled at each end and at regular intervals. All labels shall be applied to the equipment before installation. All labelling shall be subject to the approval of the designer. Where appropriate and feasible, sensor axis alignment shall be marked onto the adjacent steelwork. Labels and markings shall be permanent, but shall not damage the structure or protective system (e.g. paint system or similar).

All hardware shall be identified in the System Architecture Guide. Photographs shall be presented in the System Architecture Guide recording the position of each component of hardware, including the position and orientation of each sensor. Photographs shall be annotated with the appropriate labelling. The photographs shall be of sufficient quality and layout that it shall be possible to verify changes since installation.

15 Copyright Minimum Requirements

The bridge owner shall share all copyrights to source code of all customised and tailor-made software, and documentation.

16 Design Life and Warranty Minimum Requirements

The design life of the System shall be 10 years. The System shall function for 10 years provided maintenance activities detailed in the maintenance manual are carried out. During the 10 year period a rolling system update plan shall be maintained including complete system update at end of service life.

The minimum warranty on all components of the System shall be 1 year, subject to the exclusions listed below.

The warranty for all components of the System shall be 5 years provided that the SHMS is maintained in accordance with the maintenance manual.

17 Maintenance Strategy Development

17.1 Failure Modes, Effects and Criticality Analysis (FMECA)

A failure modes, effects and criticality analysis (FMECA) shall be performed on the System. This analysis shall consider:

- the function of the system in general
- the function of the system in delivering the monitoring requirements
- the components
- the importance of components within the context of the importance of the monitoring requirements, including the importance of sensors to the operation and maintenance of the bridge e.g. identification of high priority safety critical sensors

The FMECA shall drive the development of:

- recommendations for general inspection
- equipment repair and replacement strategy
- spare parts list

The FMECA shall be reviewed:

- following construction of the bridge
- after 5 years of operation of the bridge

Changes identified shall be incorporated into the recommendations for inspection, equipment repair and replacement strategy, and spare parts list.

17.2 Recommendations for General Inspection

Recommendations for general inspection for all components of the System shall be developed based on output from the FMECA.

A preliminary FMECA has identified the following recommendations for inspections:

- Perform regular function checks at 3-month intervals of the standby System
- Verify regularly at 3-month intervals that System data is backed-up from the MMS database
- Perform quick response inspection within 48hrs of lightning fuses following lightning strike

17.3 Equipment Repair and Replacement Strategy

An equipment repair and replacement strategy shall be developed based on output from the FMECA. The strategy shall include identification of importance of sensors, prioritisation of sensors to assist the operator in developing and reviewing strategic repair programmes, and permissible response times in the event of failure.