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PONTE SULLO STRETTO DI MESSINA

PROGETTO DEFINITIVO

EUROLINK S.C.p.A.

IMPREGILO S.p.A. (MANDATARIA)
SOCIETÀ ITALIANA PER CONDOTTE D'ACQUA S.p.A. (MANDANTE)
COOPERATIVA MURATORI E CEMENTISTI - C.M.C. DI RAVENNA SOC. COOP. A.R.L. (MANDANTE)
SACYR S.A.U. (MANDANTE)
ISHIKAWAJIMA - HARIMA HEAVY INDUSTRIES CO. LTD (MANDANTE)
A.C.I. S.C.P.A. - CONSORZIO STABILE (MANDANTE)

IL PROGETTISTA	IL CONTRAENTE GENERALE	STRETTO DI MESSINA	STRETTO DI MESSINA
COWI Ing. E.M. Veje Dott. Ing. E. Pagani Ordine Ingegneri Milano n° 15408 EuroLink	Project Manager (Ing. P.P. Marcheselli)	Direttore Generale e RUP Validazione (Ing. G. Fiammenghi)	Amministratore Delegato (Dott. P. Ciucci)

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Abbreviations

Abbreviations for system names:

BMS: Bridge Management System
CS: Communication System (internally/externally communication)
CSP: Computer Simulation and Prediction
EDMS: Electronical Document Management System
EMC: Electrical and Mechanical Control
ICMS: Information & Coordination Management System
MACS: Management and Control System
MMS: Management, Maintenance and Simulations
SCADA: Supervisory Control and Data Acquisition
SHMS: Structural Health Monitoring System
TMS: Traffic Management System
WSMS: Work Site Management System

Other abbreviations:

ERP: Enterprice Ressource Planning
EAP: Event Activity Plan
FMECA: Failure Mode, Effect and Criticality Analysis
I&M: Inspection and Maintenance
IMAA. Inspection and Maintenance Activity Analysis
LCC: Life Cycle Cost
O&E: Operation and Emergency
O&M: Operation and Maintenance
RBI: Reliability Based Inspection
RCM: Reliability Centered Maintenance
SOA: Service-Oriented Architecture

Executive Summary

Messina Bridge

The Messina bridge is a highly innovative bridge design for the world's longest span (3300m) to link Sicily with mainland Italy. The bridge is to be a suspension bridge formed from 4 main cables, a steel triple box girder, and steel towers with a height of 399 m. Not only are the bounds of current bridge experience being pushed to the limit with a structure that is significantly larger than the current world's longest span of 1991m (the Akashi Kaikyo bridge), the aerodynamic stability of the deck structure is reliant on the beneficial characteristics provided by the innovative triple deck box structure. Thus permanent monitoring and maintenance of the structure is desired to ensure that the structure is behaving as intended and remains safe to use. Furthermore a cluster of maintenance management systems for maintaining the structure in good condition for a long service life is provided.

In the current Progetto Definitivo project phase, the tender design is further developed in preparation for the subsequent Progetto Esecutivo phase.

The vision in BMS is to be a tool for the Operation & Maintenance Organisation of the Messina Strait Bridge which by its systematics and itc logics will ensure a safe and cost optimal maintenance of the bridge. BMS being an IT-system will be able to exchange data between other IT management systems. By this it is a major vision that BMS in its support to the Operation and Maintenance organization shall be able to operate on all data as captured by MACS and its Sub-systems during the construction stage or as captured currently during the Operation and Maintenance stage.

Management and Control System, MACS

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 installations 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 Design Specifications - Mechanical and Electrical Works doc. No. CG1001-P-2S-D-P-IT-M4-C3-00-00-00-06-A)
- Management, Maintenance & Simulations (MMS) described in the Management and Control System, doc. no. CG1000-P-2S-D-P-IT-M4-C3-00-00-00-01-A

The MACS will be the underlying software system which will control user access and rights in relation to system and data access. The MACS will also unite the different sub-system together by defining at common communication protocol trough the use of a service layer.

The MACS will be the central module for the coordination, control and management of each sub-system.

The Management and Control System will be sub-divided into two major clusters defined by:

Operation & Control operated by the SCADA

- Traffic Management System (TMS)
- E&M Control and Monitoring (EMC)
- Structural Health Monitoring System (SHMS)
- Communication System (CS)
- Railway monitoring (RTMS).

Management, Maintenance & Simulations (MMS)

- Computing of Simulations and Predictions (CSP).
- Worksite Management System (WSMS).
- Bridge Management System (BMS).
- Information and Coordination Management (ICMS).
- Electronic Document System Management (EDMS

Figure 1.1 shows the overall system architecture for the MACS.

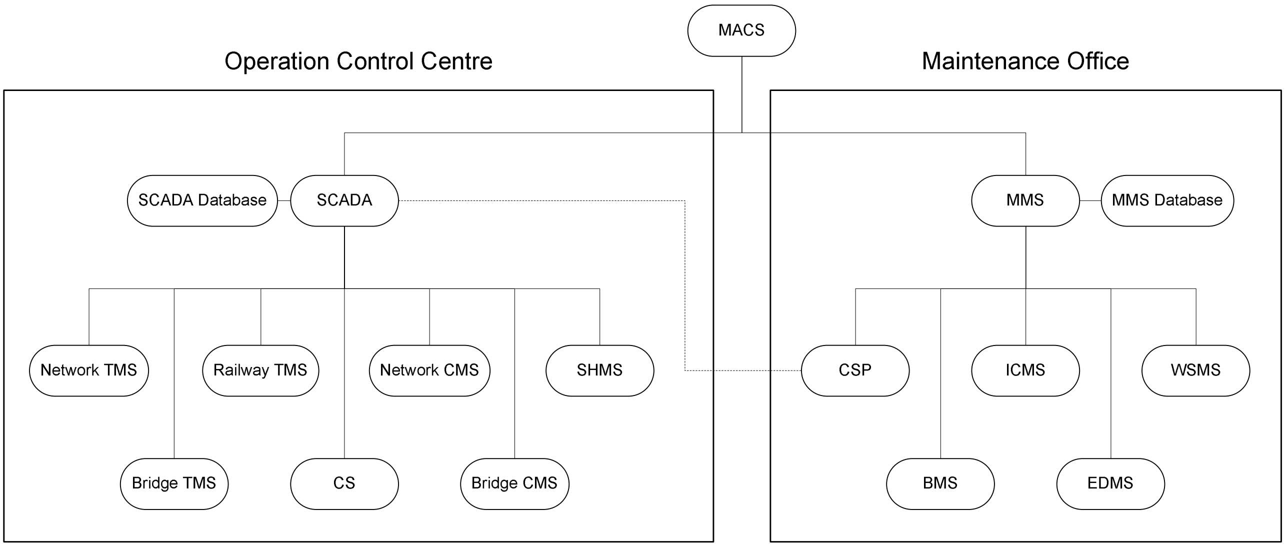

Figure 0.1 Over all system architecture.

Scope of Report

A description of functional requirements for the BMS has been developed based on the technical specifications prepared by Stretto di Messina (2004), and based on the tender submission prepared by ATI Impregilo (2005).

The objectives of this report are to specify the functional requirements for the Bridge Management System, BMS. It is intended to establish a set of requirements sufficiently specified so that they can form the basis for a later elaboration of Technical Specifications for BMS.

In order to give a sufficient description of the BMS functions and facilities the data and documents to be handled by the system are described. Moreover, a description of the various data processes to be executed by use of BMS facilities is given. The report also gives a short description of the IT-technology to be used. This technology shall be determined in common for the various technological management systems to be used in the Operation & Maintenance Stage.

Objectives of BMS

The BMS is primarily a tool for the Bridge Maintenance Organisation. Use of the BMS shall help to ensure a proper maintenance management resulting in:

- Safety of the bridge
- Regularity to the largest extent (full functionality)
- Cost optimal maintenance in the entire life period.

In order to achieve this, the BMS shall support the Bridge Maintenance Organisation in the following areas:

1. Make all Inspection and Maintenance specifications (Manuals, Procedures, Instructions, Standards, Contacts, Authorities etc) available in an easy access manner for users on all levels
2. Make all relevant infrastructure data and documents available in an easy access manner for users on all levels
3. Provide tools for easy and consistent update of data and documents
4. Provide tools for easy and consistent entering of data and documents which are generated in the O&M stage.
5. Provide tools for data processing according to the principles as described in the I & M Manual set. Hereunder tools for data processing related to updating of RBI/RCM programmes.
6. Provide tools for establishment of programs for inspections and/or maintenance works
7. Provide data and documents according to requirements as defined in other MACS Sub-systems
8. Provide tools for automatically conversion to BMS of data as generated by other MACS Sub-systems and made available for BMS by the IT Service Layer facility.
9. Provide tools for easy and safe retrievel of data and documents as needed in order to provide the Event Manager with sufficient information in any event as reasonably foreseen to occur

The BMS covers civil works, electrical and mechanical installations for the suspension bridge inclusive the main cables and anchor blocks and the Terminal Structures. Land works and toll facilities are not included.

The entire basis for the technical specifications for the BMS consists of the Operation and Maintenance System for the suspension bridge comprising manuals, procedures, instructions, document archives, models and reports.

The main basis documents are:

- Preliminary Inspection and Maintenance Manual, I & M Manual
  CG1000-P-MI-D-P-GE-A9-00-00-00-00-01
- Preliminary Operation and Emergency Manual, O & E Manual
  CG1000-P-MI-D-P-M7-00-00-00-00-00-01
- Life Cycle Cost Study (LCC)
  CG1000-P-RG-D-P-GE-L4-00-00-00-00-01
- Reliability Based Inspection (RBI) and Reliability Centred Maintenance (RCM)
  CG1000-P-RG-D-P-GE-R6-00-00-00-00-01

Data and Documents controlled by BMS

The BMS is primarily a database system. The database shall be structured so that data to be used in the maintenance stage can be retrieved in a safe and efficient way. Such data comprises intelligent data (dimensions, models etc) and data for planning of inspections and maintenance works, hereunder budgeting of the works.

The BMS database will be a dedicated partition of the MMS database. Documents will not be stored in the BMS partition of the MMS database, but in a document partition of the MMS database controlled by the EDMS and can be easily accessed from the BMS by use of a specific BMS access software which interfaces with the "Service Layer" facility in the MACS or with general document retrieval facilities included in the EDMS.

All data stored in the BMS database partition and all documents stored in the EDMS partition of the MMS database are coded and are in this way related to specific elements. The element hierarchy as defined in the Inspection and Maintenance Manual shall be used.

It shall be possible to revise the hierarchy, hereunder to expand the hierarchy, along with the maintenance period, for instance so that parts of an element which may develop in a special way with time can be treated as separate elements.

In order to be able to identify parts of an element a general system of location codes is used. The location of an element and the exact position on a face of the element can be indicated using a maximum of six locations codes, 1 to 6.

BMS handles the following data and documents:

- Specifications for execution of inspection and maintenance
  Manuals, procedures, instructions, codes, standards, standard repair methods etc.
- Inventory data and documents
  Drawings, specifications, certificates, non conformance reports etc.
- Inspection data
  Specifications related to carried out inspections
  Inspection reports, defect registration data, condition rating data etc.
- Detailed Reliability Centred Maintenance Plans and Detailed Reliability Based Inspection Plans
- Maintenance data
  Specifications related to carried out maintenance works.
  Work orders and management of maintenance works
- Monitoring data
  Mainly incorporation into inspection reports of information received from the monitoring systems
- Log file for registration of costs, inspections, maintenance works and events
- Programmes for inspections and maintenance works
  Activity, time and resource planning

Data Exchange between BMS and Other Sub-systems

Data in the BMS database are related to elements according to the element hierarchy. Data are further related to the BMS applications - the BMS modules - according to the BMS data entry facility. Documents in the EDMS partition of the MMS database are via their coded file names also related to elements. Documents shall also be related to the BMS modules. This can for instance be obtained by entrance of data in the metadata file attached to the document file.

The MACS includes a common data exchange facility, a "Service Layer", which shall be used by all Sub-systems for exchange of data with other Sub-systems.

The data exchanges between the BMS and the other MACS Sub-systems are shown in *Figure 1.2.*

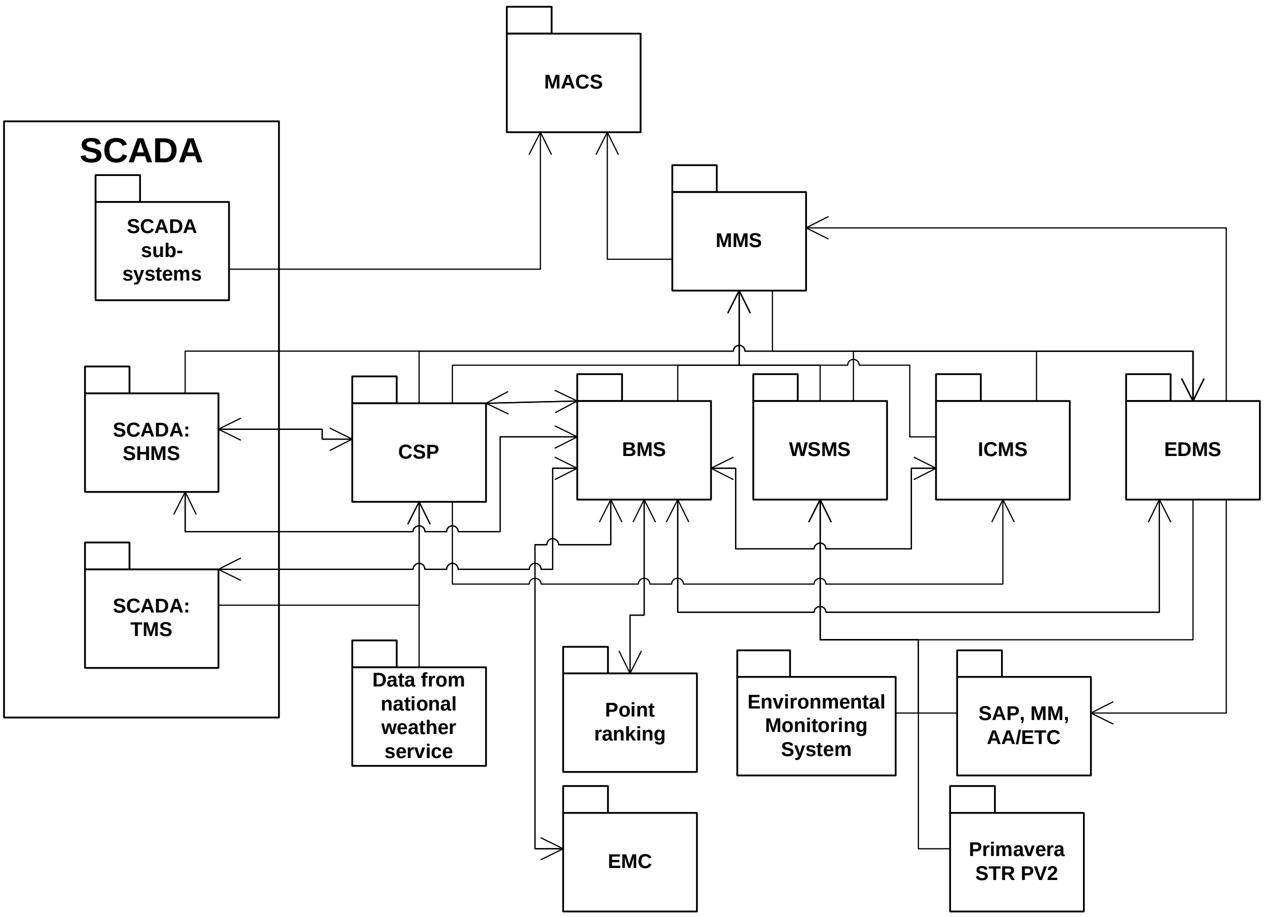

Figure 1.2 Data Exchanges between BMS and other MACS Sub-systems

Main Facilities in BMS

The Bridge Maintenance staff performs their activities according to the specifications as laid down in the O&M specifications: Manuals, procedures, instructions and standards. BMS shall support the maintenance staff in carrying out the activities. The main areas supported by BMS is shown in Figure 1.3.

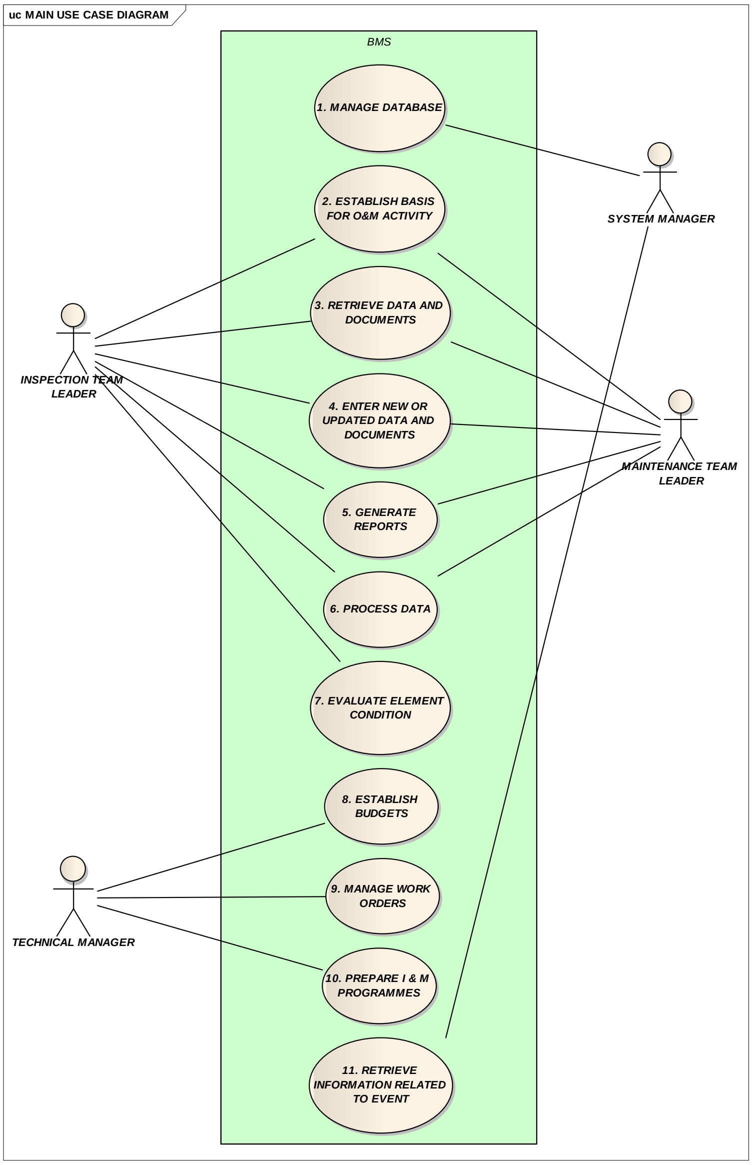

Figure 1.3 BMS supported Inspection and Maintenance Activities.

Technical Specifications for BMS

It is considered that a modular structure of BMS as indicated below would be appropriate:

1. Administration (part of a common administration for all MACS Sub-systems)
2. I & M System Specifications.
3. Inventory data
4. Spare parts
5. Inspections
6. RCM and RBI programmes
7. Maintenance
8. Budgeting
9. Management of work orders
10. Inspection and Maintenance Programmes
11. Log of Costs, Inspections, Maintenance Works and Events

Based on the specifications of the functional requirements of BMS and the technical specification of the MACS and related subsystems a set of technical specifications for BMS shall be prepared.

It is assumed that such technical specifications will be part of tender documents for a BMS delivery. It is assumed that the result of a BMS tender will be either:

- A standard Asset Management System, customised to fulfil the Messina requirements, or
- A unique IT-system developed entirely to fulfil the Messina requirements.

The database is the kernel of the BMS. It is expected that the database (of MMS) shall be a relational database, as an Oracle database, with a SQL access. However, the MMS database shall be specified in the next stage, considering all MACS Sub-system.

The specifications for the server shall be described when the entire MACS including all its Sub-systems is sufficiently defined.

The various electronic equipment to be used to access the BMS installation and its database partition shall be specified in the next stage taking all MACS Sub-systems into consideration.

It is for the time being expected that the following equipment can be used to access BMS:

- Terminal (PC), positioned in the Maintenance Office
- Terminals (PC), positioned at parties outside the Maintenance Office
  -at Authorities, Contractors, Consultants etc
- SmartPhones
- Dashboard

The user interface shall include a graphical front end which shall provide:

- Access to all components and hereby access to all relevant Inspection and Maintenance data.
- Grouping of components based on material data, manufactory data etc.
- Grouping of components based on practical considerations for inspection/maintenance in common.

See the example in Figure 1.4, which illustrates a presentation of condition ratings for a selected element group.

A non graphical front end shall mainly provide:

- Access to data which are not related to specific elements
- Access to documents which are not related to specific elements

It shall in the next stage be considered whether some of the GIS facilities as developed and used in WSMS in the construction stage can be taken over by the BMS.

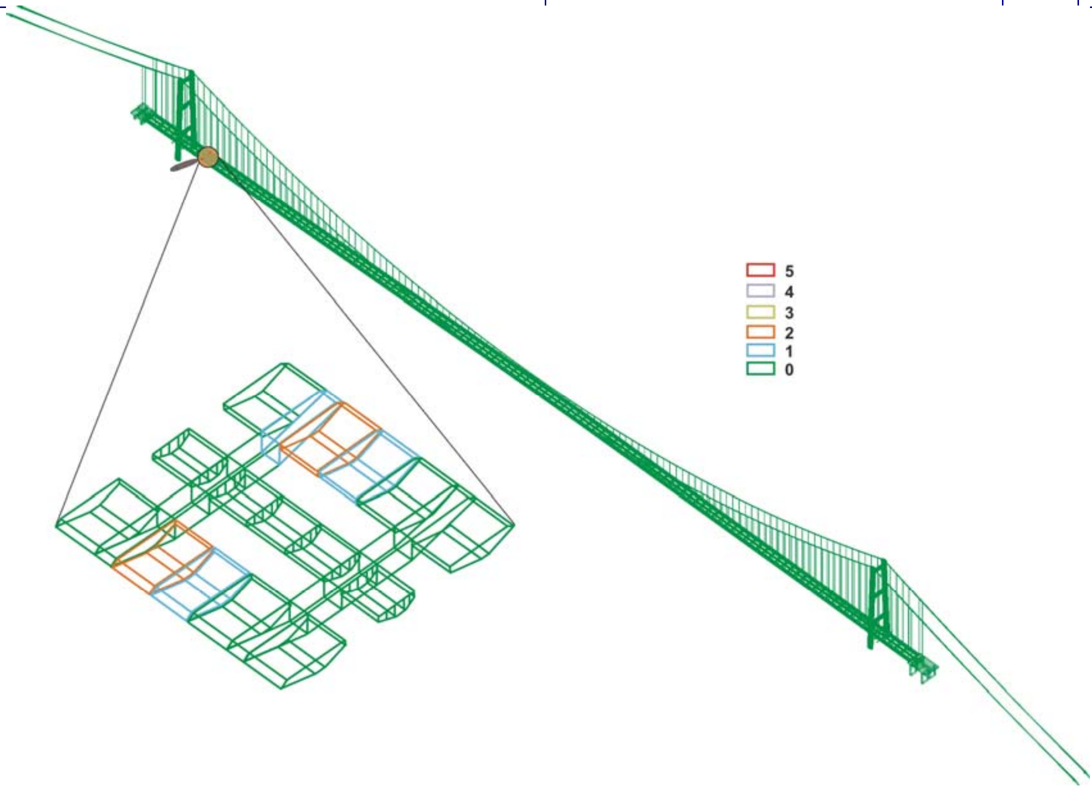

Figure 1.4 Graphical Presentation of Condition Rating Points for Girder Sections

The BMS shall include facilities to generate reports from the contents of the BMS database. This comprises reports for inspections, budgeting, inspection programmes, maintenance programmes, management etc.

Time Schedule for BMS

It is very important that the entire BMS is operational at the time for opening of the bridge.

In Figure 1.5 is shown a proposal for a time schedule covering the case that the BMS system is developed and implemented according to an IT contract between the Main Contractor and a supplier.

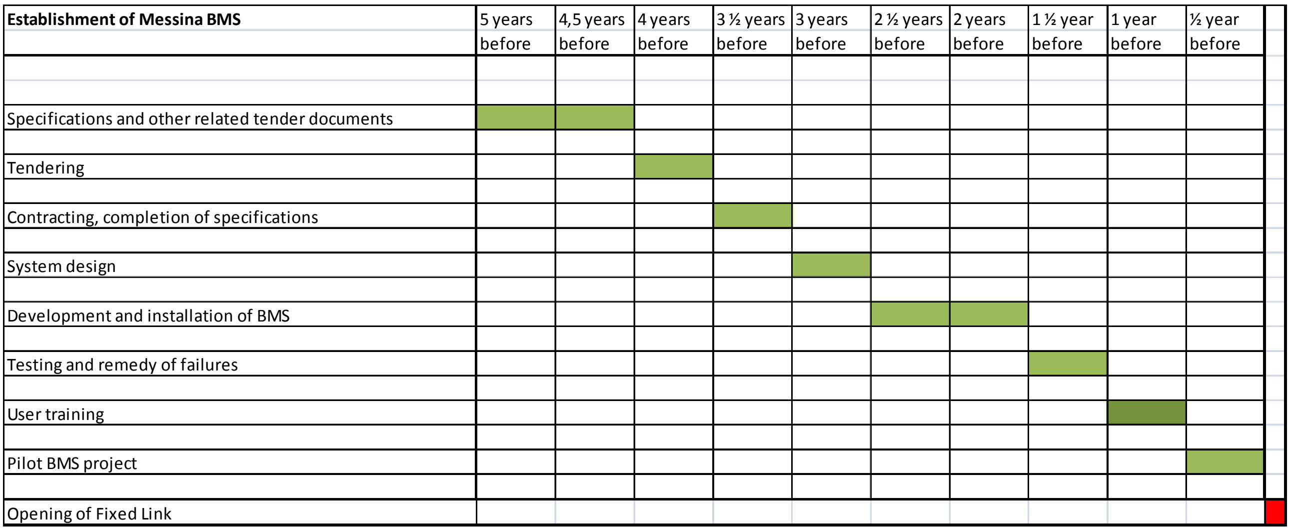

Figure 1.5 Time Schedule for BMS

Estimated Costs for BMS

The BMS is a Sub-system to MACS. The costs for BMS will to a large degree depend on how the entire MACS is structured, meaning especially which common facilities belongs to MACS and which facilities belongs to the individual Sub-systems. When this is specified a cost estimate for BMS can be elaborated.

The total costs will include contributions as:

- Consultancy (specifications, tendering, technical follow up etc)
- Suppli (according to IT-Contract)
- Education and training of users
- User support (annual cost)

It is assumed, that a cost estimate is made for the entire MACS management system. According to the break down of this cost estimate the cost contribution for the BMS Sub-system is prepared.

Introduction

The vision in BMS is to be a tool for the Operation & Maintenance Organisation of the Messina Strait Bridge which by its systematics and itc logics will ensure a safe and cost optimal maintenance of the bridge. BMS being an IT-system will be able to exchange data between other IT management systems. By this it is a major vision that BMS in its support to the Operation and Maintenance organization shall be able to operate on all data as captured by MACS and its Sub-systems during the construction stage or as captured currently during the Operation and Maintenance stage.

This section gives at short introduction to the bridge and the individual systems which are relevant for the report.

MACS:	Management and Control System
SCADA:	Supervisory Control and Data Acquisition
MMS:	Management, Maintenance and Simulations

2.0 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.

In the current Progetto Definitivo project phase, the tender design is further developed in preparation for the subsequent Progetto Esecutivo phase.

2.1 MACS

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

The MACS is subdivided in to a SCADA and MMS part where SCADA is described by the E&M design basis and MMS is described in the Management and Control System, doc. no. CG1000-P-2S-D-P-IT-M4-C3-00-00-00-01-A

2.1.1 SCADA

The description of the SCADA system is found in the E&M design basis. Figure 2.1 below shows a possible setup of the video wall user interface.

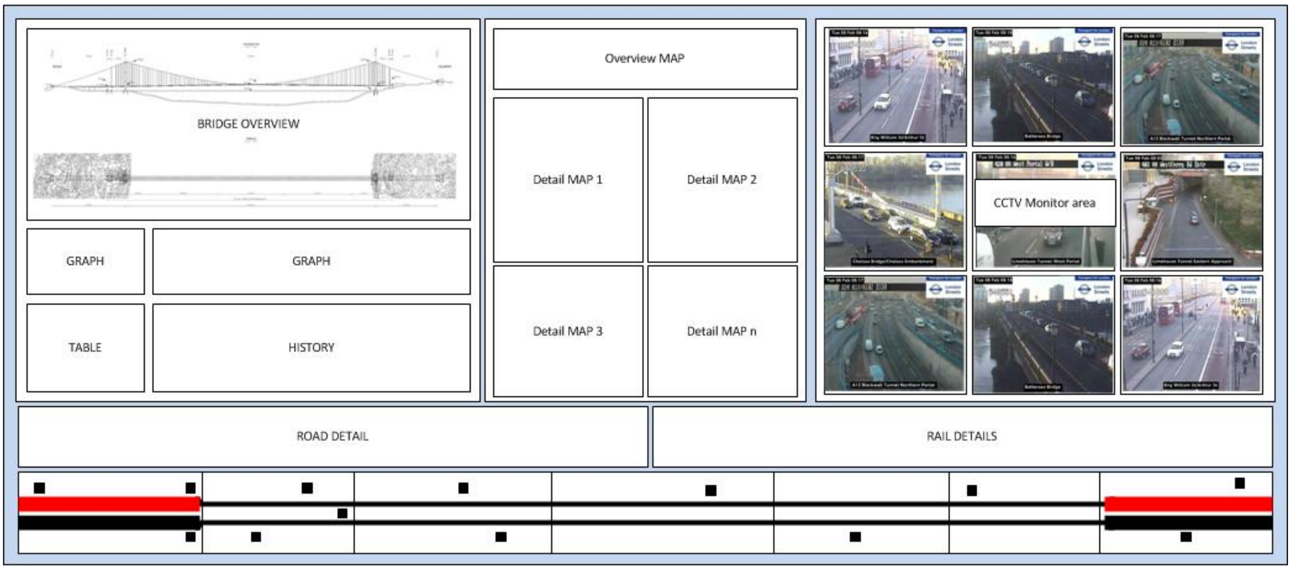

Figure 0.1 A simplified representation of a possible Video wall user interface

2.1.2 MMS

In general MACS is the overall architecture of the whole system whereas the Management, Maintenance & Simulations (MMS) is the portal as an interface to the MACS and the subsystem, where historical data and reports are available. When it comes to handling of daily analysis of data it will be the individual subsystem under the MACS which will handle this task. The result of this analysis will then be available to the MMS unless otherwise stated. The MMS system software's will be building upon standard software with the necessary extensions to achieve the required extra functionalities if possible otherwise it will have to be developed if necessary. The MMS will share the SCADA Man-Machine-Interface in form of a large Display Wall with the SCADA system. Both SCADA operators and MMS operators are allowed to use the large display wall in the bridge OCC. In general local data displays on all workstations will have possibility of being presented on the large display wall in the bridge OCC.

The MMS itself will be a data portal enabling the operator and bridge management to display data from the entire system in forms of plots, tables and standard reports. For this matter the MMS should be able to display data from other system, either data isolated to one system, or data mixed from different systems.

The MMS subsystem and the data communication are presented in 2

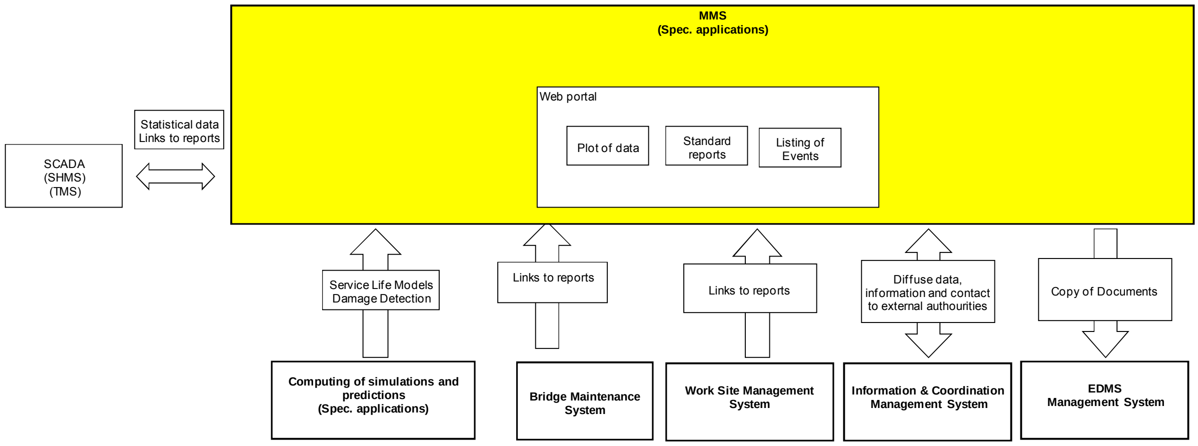

Figure 0.2 The Sub-systems will interact with each other through the SCADA and MMS databases

All systems and subsystems working under the MMS will be integrated and able to exchange data by means of web services, as well as address and provide display of information on local screens and/or the common large display wall in the OCC.

Objectives of Report

Objectives

The objectives of this report is to specify the functional requirements for the Bridge Management System, BMS. It is intended to establish a set of requirements sufficiently specified so that they can form the basis for a later elaboration of Technical Specifications for BMS.

The overall requirements to BMS is that it shall support the Maintenance Management Organization in carrying out inspection and maintenance for the suspension bridge according to the specifications as laid down in the Inspection & Maintenance Manual, the I & M Manual, and related documents.

In order to give a sufficient description of the BMS functions and facilities is in this report given a description of the data and documents to be handled by the system. Moreover is given a description of the various data processes to be executed by use of BMS facilities. The report also gives a short description of the IT-technology to be used. This technology shall be determined in common for the various technological management systems to be used in the Operation & Maintenance Stage.

Basis for BMS

All data and documents to be handled in BMS, totally or partially, as for instance:

- Inventory data
- Inspection data
- Monitoring data
- Maintenance data incl. economy data
- RBI/RCM data related to elements and systems
- Inspection reports
- Maintenance reports
- Budgeting reports
- Inspection programmes
- Maintenance programmes

are described entirely in the Inspection and Maintenance Manual and its sub-documents.

The entire basis for the technical specifications for BMS therefore consists of the Operation and Maintenance System for the suspension bridge comprising manuals, procedures, instructions, document archives, models and reports.

The main basis documents are:

i. Preliminary Inspection and Maintenance Manual, I & M Manual
CG1000-P-MI-D-P-GE-A9-00-00-00-00-01

ii. Preliminary Operation and Emergency Manual, O & E Manual
CG1000-P-MI-D-P-M7-00-00-00-00-01

iii. Life Cycle Cost Study (LCC)
CG1000-P-RG-D-P-GE-L4-00-00-00-00-01

iv. Reliability Based Inspection (RBI) and Reliability Centred Maintenance (RCM) CG1000-P-RG-D-P-GE-R6-00-00-00-00-01

Main Objectives of BMS

The BMS is primarily a tool for the Bridge Maintenance Organisation. Use of BMS shall help to ensure a proper maintenance management resulting in:

- Safety of the bridge
- Regularity to the largest extent (full functionality)
- Cost optimal maintenance in the entire life period.

In order to achieve this, BMS shall support the Bridge Maintenance Organisation in the following areas:

10. Make all Inspection and Maintenance specifications (Manuals, Procedures, Instructions, Standards, Contacts, Authorities etc) available in an easy access manner for users on all levels
11. Make all relevant infrastructure data and documents available in an easy access manner for users on all levels
12. Provide tools for easy and consistent update of data and documents
13. Provide tools for easy and consistent entering of data and documents which are generated in the O&M stage.
14. Provide tools for data manipulation according to the principles as described in the I & M Manual set. Hereunder tools for data processing related to updating of RBI/RCM programmes.
15. Provide tools for establishment of programs for inspections and/or maintenance works
16. Provide data and documents according to requirements as defined in other MACS Sub-systems

17. Provide tools for automatically conversion to BMS of data as generated by other MACS Sub-systems and made available for BMS by the IT Service Layer facility.

18. Provide tools for easy and safe retrievel of data and documents as needed in order to provide the Event Manager with sufficient information in any event as reasonably foreseen to occur

The BMS covers civil works, electrical and mechanical installations for the suspension bridge inclusive the main cables and anchor blocks and the Terminal Structures. Land works and toll facilities are not included.

For the railway bridge girder, the BMS only covers:

- Girder
- Portal structures for catenary system
- Platform
- Rail fixation
- Steel plates limiting the rails
- Anti-derailment arrangement
- Surfacing on the girder

and not

- The catenary system
- Signals and their control system
- Rails (and their embedment)
- Electrical elements.

The position of BMS in MACS

The Management and Control System (MACS) includes two main clusters, each operated from its separate control room:

1. Supervisory Control and Data Acquisition (SCADA)
   Operated in the Operation Control Room

2. Management, Maintenance and Simulations (MMS)
   Operated in the Management Control Room

Each of the clusters consists of a set of Sub-systems. The main clusters and the Sub-systems communicates internally via Local Area Networks (LAN).

All systems and sub-systems working under the MACS will be integrated and will be able to exchange data by means of web services, as well as can address and provide display of information on local screens in the Operation Control Room and in the Maintenance Control Room and/or the common large Display Wall in the Operation Control Room.

The clusters and the Sub-systems in MACS, with BMS highlighted, are shown schematically on *Figure 6.1.*

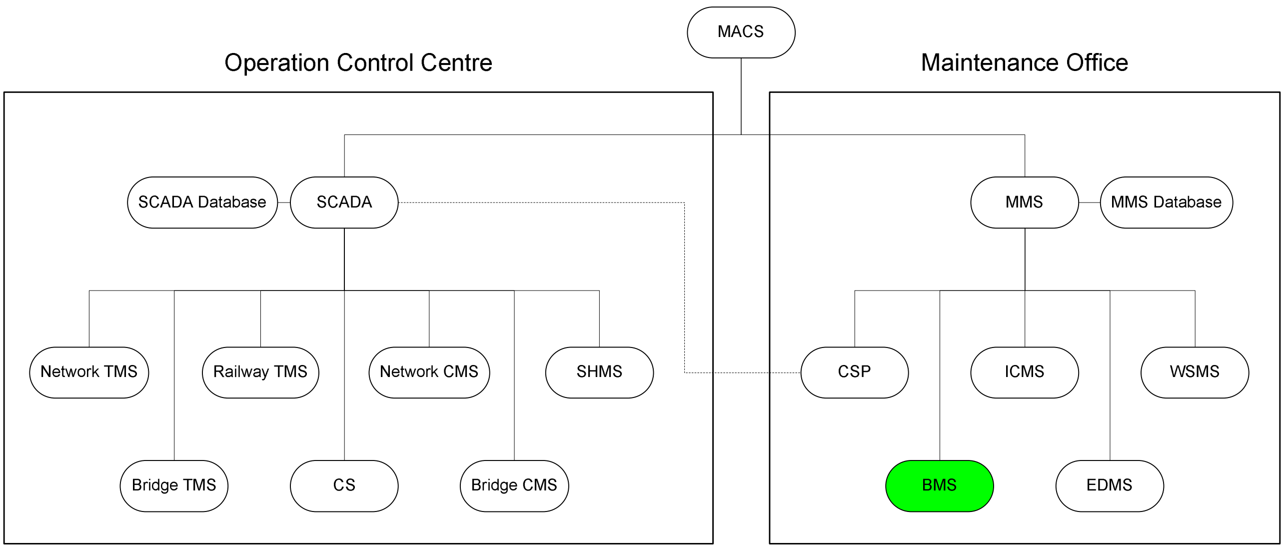

Figure 6.1 BMS's position within MACS

Data and Documents controlled by BMS

BMS Database

BMS is primarily a database system. The database shall be structured so that data to be used in the maintenance stage can be retrieved in a safe and efficient way. Such data comprises intelligent data (dimensions, models etc) and data for planning of inspections and maintenance works, hereunder budgeting of the works.

MACS will include two databases, one for SCADA and one for MMS. The database interface in MACS will consist of a general part common for all users and a number of parts which are specific for the individual Sub-system. The database administration tool in MACS consists of a set of "read-facilities" to be used in Sub-systems to extract data which are controlled by other Sub-systems. Moreover the database administration tool includes facilities for the individual Sub-system to control its partition of the database: to retrieve, process and enter data into the database.

The BMS database as described in the following will thus be a dedicated partition of the MMS database. The term "BMS database" shall be adopted in the following text to represent the expression "BMS partition of the MMS database".

Documents are not stored in the BMS database but are stored in a document partition of the MMS database controlled by the EDMS and can be easily accessed from BMS by use of a specific BMS access software which interfaces with the "Service Layer" facility in MACS or with general document retrieval facilities included in EDMS.

The contents of the BMS database, the in-service data, is described in section 10 of the I & M-Manual. A brief description of the various data types contained in the BMS database is given in the following. Furthermore a brief description of BMS related documents is given.

Element Hierarchy

All data stored in the BMS database and all documents stored in the EDMS partition of the MMS database are coded and are in this way related to specific elements. Overall data and documents which are related to the suspension bridge in general are coded either as related to this element, element no. 1, or coded as related to the relevant application area of BMS - the relevant module of BMS. This shall be settled in the detailing process.

The element hierarchy as defined in the Inspection and Maintenance Manual, hereafter named IM-manual, Section 4, shall be used.

Elements are physical units or systems. The levels in the hierarchy reflects to the largest extent the required possibilities for decompositioning of inspection and maintenance works.

It shall be possible to revise the hierarchy, hereunder to expand the hierarchy, along with the maintenance period, for instance so that parts of an element which may develop in a special way with time can be treated as separate elements.

As described in bridge maintenance systematic a very profound aspect in definition of an element hierarchy is that a physical element or group of elements should only form a separate element, if they in a manner of inspection, monitoring or maintenance constitutes an independent unit.

Moreover, it must to the largest extent possible be sought that relationships in maintenance works are reflected in relationships in the element hierarchy.

The element hierarchy is shown in Appendix A.

In order to be able to identify parts of an element a general system of location codes is used. The location of an element and the exact position on a face of the element can be indicated using a maximum of six locations codes, 1 to 6.

The location codes are:

Code 1: Stationing at start (or at centre of element, e.g. at piers) of the element.

Code 2: Stationing at end of the element.

Code 3: Number/code for the element or part of the element. The present nos. shown on the project drawings for e.g. piers, girder sections, hangers is inserted in the code no. tables to explain the code nos. Most of these numbers can be read on the overall reference drawings.

Code 4: Orientation of face, e.g. inner/outer (for towers), vertical face to the Right in direction for the stationing (for steel box girders), etc. The faces have whenever applicable been characterised by orientation seen in the direction of the stationing, since this definition always is easy to reconstruct without paying attention to weather conditions.

Code 5: Level, height in meters.

Code 6: Co-ordinates on the face characterised by individual (local) co-ordinate systems to the different elements and whether the co-ordinates shall be used for horizontal, vertical or circular faces.

The location codes are to be used for purpose of inspection and maintenance whenever there is need to describe exact position on a face of an element.

The element hierarchy shall also reflect the hierarchy of documents as used in the design and construction stages. This ensures in an optimal way that as built documentation can be stored in an appropriate manner and can thus be retrieved efficiently in the maintenance period.

It shall be possible to establish additional branches to the element hierarchy and to group elements across the hierarchy. This may for instance be the case for:

- Establishment of functional subsystems
  For example road safety barrier system, drainage system etc.
  This will be a new branch created on level 3 - but still having element 1 as master parent.
- Establishment of groups- set of elements with the same material specifications and subjected to the same loadings (traffic loads, environmental impact etc). This is done using additional metadata in the elements in order to collect all elements covered by a certain activity, a certain inspection or a certain maintenance work.

Revisions of the element hierarchy to be introduced in the operation and maintenance period shall be controlled by BMS.

Specifications for Inspection and Maintenance

This part of the database includes lists of all documents to be used for carrying out inspection and maintenance. The lists are set up in a way to ensure an efficient and safe access to all relevant documents in any situation. The documents are stored in the EDMS database.

Documents included in the lists are:

- I & M Manual and O & E Manual including appendices
- RCM and RBI Manual including appendices
- LCC Study Report
- Technical Procedures and Technical Instructions
- Codes and Standards
- Standard methods. For instance methods for standard repair
- Templates and paradigms

The documents needed in a certain situation shall be easily and safely retrieved by use of BMS's facility to establish input data related to inspection/maintenance activity and/or codes for elements included in the activity.

Inventory Data

The physics for each element is defined in the design and construction as well as in the later rehabilitation project documents related to the element:

- Drawings, showing dimensions
- Specifications, showing material data and/or manufacturing data
- Certificates, showing documentation as requested
- Suppliers specifications acc. to inspection/maintenance/replacement
- Non conformance reports from the construction phase

These documents are captured directly during the construction stage and during the operation stage along with execution of rehabilitation works. Elements comprises structures, mechanical and electrical installations and SHMS components.

Important inventory data for an element is further contained in the Components Sheet related to the element. These sheets are described in the Inspection and Maintenance Manual section 4.4. Data are filled in during the execution stage.

Further, "intelligent data" shall be entered directly into the database for use in the inspection and maintenance modules of BMS. Such data comprises for instance figures for main dimensions, material data and/or unit prices to be used for automatic calculation of quantities and budgeting of maintenance work. Data are entered into the BMS database during the construction period.

The data is updated continuously according to documentation from carried out maintenance works - replacement, strengthening, repair etc.

Inspection data

Data related to carried out inspections are recorded in BMS. Most part of inspection data will be common for the various types of inspections. Minor parts will differ from inspection type to type.

Inspections are subdivided into types according to category and nature.

Category:

- Routine Inspections
- Principal Inspections
- Special Inspections

Nature:

- Visual Inspection (V.I.)
- Close Visual Inspection (C.V.I.)
- Detailed Visual Inspection (D.V.I.)
- Functional Inspection (F.I.)
- Non-Destructive Testing (N.D.T.)
- Destructive Testing (D.T.)

- Measurements (MEAS.)
- Configuration Inspection

For further description of inspection types is referred to the IM-Manual section 5.

The inspection is reported according to specifications as described in the actual Technical Instruction. Significant defects are registered in BMS according to Record of Defect sheets. Results from evaluation of the observations, hereunder condition rating and specifications of further inspection or maintenance activities, if any, are registered according to Evaluation sheets.

All data should be entered chronologically into the inspection log related to the element hierarchy. The inspection log should be related to structural elements and technological systems at level 5/6 of the hierarchy elements.

The Team Leaders in charge of the inspection activities shall in general enter all data in the electronic inspection log. The data shall be entered as an integral part of reporting the activities.

The following data shall be recorded for each inspection activity:

- Element reference (from Element Hierarchy)
- Location reference (where only part of Element is inspected).
- Type of Inspection (routine, principal, special, works acceptance) and reference to Inspection Report No.
- Date of Inspection.
- Inspection Leader and support staff.
- Sub-contractor involvement (order reference, if applicable).
- Reference to previous associated inspection records.
- Defects Summary (reference to defect record)
- Details of any follow up activity required (defect severity 3/4, a part of the RBI/RCM framework or other reasons).
- Date for Review of follow up action taken (i.e. reminder date to check progress).

- Comments on action taken by the review date (renew Review Date if required).
- General comments relating to the inspection.
- No further action required (enter name and date).

In order here to give an indication of the type and amount of data to be recorded from an inspection in Appendix B showed the Technical Procedure for Principal Inspection and the related Technical Instruction for reporting of a Principal Inspection.

Each element has attached to it a rating point (condition rating), which describes its condition in a maintenance activity manner. Most of the elements will initially be allocated a rating point "0". However other values may be allocated if deviations have occurred during construction.

The rating point for an element is, with time, estimated as based on the condition data as registered during inspections (defect registration) and/or monitoring (censor values). Condition data based on monitoring data are taken into account via monitoring evaluation reports, ref. to section 7.8.

The condition evaluation is carried out according to the principles as described in the I& M Manual, ref. to Appendix 5.10.C, table 5.3.1 in /i/. The set of rating points are shown in Table 7.1 below.

Description	**Rating point**
No defect noted	0
Minor defect noted, no maintenance needed	1
Significant defect noted, repair within 6 months needed	2
Major defect noted, urgent repair needed	3
Special case, special inspection needed urgently	4
Condition unknown, due to unavailability	5

Table 7.1 Condition rating of defect severity

RBI/RCM data

At the time for opening of the bridge all elements and systems will have a FMECA-IMAA sheet with filled in data. For selected elements and systems are, according to the results obtained in the FMECA-IMAA analysis, established detailed RBI/RCM plans. Whether Detailed RBI/RCM-plans are relevant depends on the assessed criticality, vulnerability and life cycle costs for the actual element and system.

After an inspection or a maintenance work is carried out, the Maintenance Organization must assess whether some or all of the parameters in the FMECA-IMAA records for the elements in question shall be updated, and in case to which values.

An example of a FMECA-IMAA sheet is shown in Appendix C. The parameters to be reviewed after evaluation of an inspection are:

FMECA-IMAA analysis:

- Time for failure development, ΔT_f
- Time for damage tolerance, ΔT_d
- Mean time between failure, MTBF (RCM-elements)
- Request for inspection and/or maintenance, assessment of remaining life time
- Selected inspection interval, ΔT_i
- Year for start up of operation of the element/system (in case of rehabilitation/replacement)
- Key parameters to monitor
- Spare part requirements in order to minimize repair time (if critical)
- Mitigation measures other than maintenance (if relevant)

Detailed RCM-plans:

- Failure probability density function
- Acceptance criteria (target failure probabilities)

Detailed RBI-plans:

- Threshold value for just acceptable condition indicator for element/system, $T_{hreshold}$
- Condition indicator value (as related to the RBI-plan, see /iiii/)
- Degradation rate and associated uncertainty (RBI-elements)
- Year for start up of operation (in case of rehabilitation/replacement)
- Acceptance criteria (target failure probabilities)

It should be noted that the condition indicator, which is allocated to the Detailed RBI-plan for a RBI element/system, is different from the condition rating point, which is allocated to the element/system based on results from inspection, ref. to table 7.1. It would be appropriate if a relationship between the two condition parameters could be established. So far such a relationship has not been established.

Reviewing the above parameters includes execution of sensitivity analysis as explained in the /RBI/RCM report /iiii/. Furthermore it is noted that reviewing of the above parameters may be benchmarked against results from life cycle cost study and other operational circumstances.

Examples of assessment of these parameters as well as other parameter values as allocated during the design- and construction phase are shown in Appendix C, where an example of a RBI element as well as an example of a RCM element is shown.

It is assumed that initial RCM/RBI-models are elaborated and stored directly into the BMS database during the Design and Construction stages.

It shall here be emphasized that the initial FMECA and RCM/RBI-models shall be prepared in the construction stage. BMS is not expected to support this elaboration. However, it is assumed that BMS shall include a facility to operate and maintain (modify/expand) these models. The description of RCM, RBI and LCC analysis is in this BMS report only given to give an outline of the analysis models to be handled by BMS in the O & M phase.

The models shall be updated in the Operation and Maintenance Stage according to the results as obtained during inspections and maintenance works. This procedure is carried out manually, but may be automized to some extent in the maintenance period.

Maintenance data

Data related to carried out maintenance works are recorded in BMS. Some part of maintenance data will be common for the various types of maintenance woks. Some parts will differ from maintenance work type to type.

Maintenance works are subdivided into types as follows:

- Preventative Maintenance
  - Manufacturer Defined Maintenance (Defined Maintenance)
  - Anticipated Service Life (Defined or Planned Corrective Maintenance)
  - Managed Intervention (Planned Corrective Maintenance)
- Unplanned Corrective Maintenance (Reactive Maintenance)
- Corrective Maintenance Activities
- Condition Based Maintenance

For further description of maintenance work types is referred to the IM-Manual, section 6.

All data should be entered chronologically into the maintenance log related to the element hierarchy. The maintenance log should be related to structural elements and technological systems at level 5/6 of the hierarchy elements.

The contractors in charge of the maintenance activities, shall in general enter all data in the maintenance log (external persons shall be given limited access to enter data only). The data shall be entered as an integral part of reporting the activities.

Data related to carried out maintenance are recorded in BMS. The maintenance work is reported according to specifications as described in the actual Technical Instruction.

The following data shall be recorded for each maintenance activity:

- Work Order reference (including amendments)
- Element reference (from Element Hierarchy)
- Location reference (where only part of Element is maintained).
- Reason for Maintenance (Functional, Routine Servicing, Repair, Parts Replacement, etc)
- Date of Maintenance (include due date if appropriate).
- Maintenance Leader and support staff.
- Sub-contractor involvement (order reference, if applicable – include designer details).
- Reference to any associated inspection records (Defect Record).
- Summary of work carried out (reference to works record – defects addressed).
- Details of any follow up activity required (e.g. replacement of spare parts used).
- Track of replaceable items (e.g. an emergency telephone is replaced and send for repair, then back to storage and later used on a new location on the bridge).
- Date for Review of follow up action taken (i.e. reminder date to check progress).
- Comments on action taken by the review date (renew Review Date if required).
- General comments relating to the activity.
- Work Order complete, i.e. name and date (actions complete and comments addressed).

For each carried out maintenance work it should be analysed if findings should result in updating of the Detailed RBI and RCM plans.

Depending on the type and amount of carried out maintenance works the data and documents to be entered into the BMS database may comprise:

- Inventory data
  New data set or update of existing data
- Condition rates
  Update of condition rates for all elements included in the maintenance work
- As built documents
  Specifications, drawings, manuals from the supplier, certificates, BoQ etc
- Supervision reports
  Most important: Non compliance reports

As for carried out inspections shall be carried out an RCM/RBI-related evaluation after completion of a maintenance work. Based on the results from this evaluation some parameter values in the FMECA-IMAA sheet for the elements in question shall be reassessed and updated accordingly. For relevant elements shall moreover be carried out a revision of the corresponding Detailed RBI/RCM Plans. The procedure for this I quite similar to the procedure related to inspections. See section 7.5 and 7.6 above.

Monitoring data

The SHMS Plan has been designed around the following system objectives:

- to provide data for design, construction and performance verification.
- to provide data for review of design loading and development of assessment loading.
- to provide current information on load conditions for effective bridge operation.
- to provide current information on the condition of structural components.
- to provide data for maintenance planning.
- to provide data for trouble shooting

The main purpose of SHMS in relation to Operation Control of the bridge is to ensure that an unacceptable situation is registered immediately and action can be taken accordingly. To achieve this, information related to an unacceptable situation is brought to the immediate attention of the Operation Control Centre.

In relation to Inspection and Maintenance of the bridge the main purpose of SHMS is to assist with information on the behaviour and actual condition of structural elements. Monitoring can for instance supplement or replace comprehensive and complex inspections. For example, monitoring data can be used to monitor the continuing function of components as the buffers.

The SHMS operates through its own server, and delivers data for long-term storage to the common SCADA database. Raw data are registered through the network of sensors, calibrated and converted to relevant engineering units, and stored on the database. Also, certain data processing that is dependent on high definition of data (e.g. stress fluctuations for fatigue analysis and joint movement data for joint movement review) are processed using the data recorded at high definition. Due to the significant data quantities produced by high definition sampling, this high definition data shall not be stored on the database. The results from data processing in the SHMS shall be stored on the database. Examples of such data processing includes rainfall count data (cycle count with cycle magnitude), utilisation ratio values, and displacement data.

SHMS displays live data through the SCADA system. The system includes trigger threshold values, which raise alarms/warnings if exceeded.

SHMS generates various types of simple data reports - weekly, monthly and yearly reports. Moreover a report is generated immediately after a seismic event. A number of other reports for SHMS function shall be created automatically or at request.

The reports include presentation of monitoring data related to various subjects: seismic, fatigue, displacements etc.

The CSP system extracts data from the SCADA database and processes the data to generate results for further use in operation and maintenance of the bridge. Examples are curves showing traffic loads in a period, expansion joint movements in a period 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.

The Inspection and Maintenance organisation receives its monitoring data through the CSP facility. This comprises data values such as deflection curves and peak stress values as well as simple illustrations, in pdf-format for example.

In this way monitoring data, primary data as well as processed (monitoring) data, is used alongside inspection data, in the management of inspection and maintenance. Data created with the CSP function will, directly or as further processed, be incorporated into reports generated by I & M by use of the BMS. In this way BMS carries out an inspection and maintenance oriented evaluation of the registrations captured by SHMS.

By using BMS the Inspection & Maintenance Organization will carry out a review of the trigger values used in SHMS using monitoring data provided via the CSP function. If a trigger value is to be changed, the I & M Organization will report this immediately to SHMS.

Documents related to Inspection and Maintenance

These documents are actually stored in the "document partition of the MMS database" and are controlled by EDMS.

For each element links are stored in the BMS database to the following Documentation:

- As built documentation. Documentation generated in the design and construction stages. Links are established based on the coding procedure adopted already in the Definition Stage (Progetto Difinitivo).
- Documentation from maintenance works:
  - Replacement

- Strengthening
- Repair.

- Documentation from inspections and condition evaluation
- Inspection reports incl. condition evaluation
- History of inspections.
- Annual reports.

Log of Costs, Inspection & Maintenance Activities and Events

7.9.1 General

All inspection and maintenance activities shall be registered in a common log file. Each log is coded as related to:

- Costs
- Inspection
- Maintenance work
- Event

7.9.2 Log of Costs

For financial control, monitoring and budgetary purposes, cost details relating to inspection and maintenance activities should be entered into the database.

Wherever possible (and reasonably straightforward), costs should be allocated to the structural elements and technological systems in the element hierarchy. Where viable, the costs should be allocated to elements at Level 5, otherwise at Level 6. Experiences from other major bridges have shown that it is important to make a careful consideration of to which level costs are recorded. In case of choosing a too detailed level, costs are then not registered because it creates too much work. E.g. in case of painting (or repair of the paint) of the box girders it will be reasonable and feasible to register the cost for the railway girder and the roadway girders in each direction (Sicily and Calabria) separately and whether it is in the main span or side spans, but starting to allocate the costs for each segment is too difficult. On the other hand the level must not be chosen to high, in this case e.g. level 4 "Deck", because then the recording does not give much value for later budgeting.

Inspection and maintenance activities will incur both direct and indirect costs. Examples of direct costs would include those costs that can be clearly allocated to the task, e.g. in-house or sub-contractor operatives allocated to a task using parts or materials specifically purchased for that task. Sub-contract costs for labour and materials should be set out in the required detail on the suppliers invoice; hourly equivalent costs of in-house labour will need to be established once the selected financial management system is in place.

Examples of indirect costs would include those costs which are too general to allocate to a task, e.g. general office administration and welfare facilities, office staff, site transport; these costs should be applied as a percentage addition to the direct costs.

The exact details for inclusion on the database and the manner in which costs are allocated will depend upon the selected financial management system adopted. Costs relate mainly to carried out tasks which again relates to elements, ref. to section 9.10. However, the following data, referenced to the hierarchy elements, should be recorded to allow the necessary cost detail to be derived:

- Work Order Reference.
- Dates work undertaken.
- Record of sub contract operatives and time spent by each.
- Record of in house staff and time spent by each.
- Spare Parts taken from stores with requisition reference.
- Invoice details.
- Record of use of any moveable bridge access equipment.

For maintenance works the log of costs should include costs for:

- Road user disturbance
- Railway user disturbance

- Environmental impact

7.9.3 Log of Inspections & Maintenance

The following activities should be entered into the maintenance log:

Inspection activities

Maintenance works.

All data should be entered chronologically into the maintenance log related to the element hierarchy. The maintenance log should be related to structural elements and technological systems at level 5/6 of the hierarchy elements.

The Team Leaders in charge of the inspection activities, or the contractors in charge of the maintenance activities, shall in general enter all data in the maintenance log (external persons shall be given limited access to enter data only). The data shall be entered electronically as an integral part of reporting the activities.

7.9.4 Log of Events

A log to register all faults and periods of Out of Service will be established covering all structural elements and technological systems at level 5/6 of the hierarchy elements.

The expected use of the log will primarily be for the technological systems, while periods Out of Service for the structural elements is expected to be very limited.

The following data shall be recorded for each event (fault and period of out-of-service of bridge element):

- Type of fault
- Cause of fault
- Start of out-of-service period
- End of out of-service period

- Registered by

In the next stage, when detailing technical specifications for all technological management systems, it shall be further investigated if the events should more appropriately be logged by the Information and Coordination Management System, ICMS.

Programmes for Inspection and Maintenance

7.10.1 Inspection Programme

The proposed inspection programme is shown in Appendix D. The programme contains the following planned inspections:

- Routine Superficial Inspections
- Routine General Inspections
- Principal Inspections (determination of frequency generally based on performed Failure Mode, Effects and Criticality Analysis (FMECA) and Inspection and Maintenance Activity Analysis (IMAA), engineering judgement and experience, typically a 6 year cycle.
- Special Inspections according to Detailed RBI plans

The present programme cover Main Cables, Towers and Box Girders, but must be extended to cover all other structures. Furthermore is shown an estimate of necessary resources on the schemes appended to the programme.

In Appendix F in the Reliability Based Inspection (RBI) and Reliability Centred Maintenance (RCM) document an overall representation and ranking of elements and systems with respect to principal inspection interval is enclosed. All inspection intervals are based on Failure Mode, Effects and Criticality Analysis (FMECA) and Inspection and Maintenance Activity Analysis (IMAA).

BMS shall include a facility to set up and maintain an inspection programme. The facility shall support automatically achievement of consistency between the elements FMECA-IMAA models and the inspection programme. The inspection programme could be generated using a standard system like Primavera or MS-Project, hereunder using their gantt diagram facilities.

7.10.2 Maintenance Programmes

7.10.2.1 Maintenance Programme for Structural Elements

An initial maintenance programme as shown in Appendix E is based on the performed Life Cycle Cost Study, where the various major maintenance activities are described including a forecast of time for the specific activities.

BMS shall include a facility to set up and maintain a maintenance programme. The facility shall support automatically achievement of consistency between the elements FMECA-IMAA models and the maintenance programme. Further shall the facility support inclusion of maintenance activities which are not dictated by the FMECA-IMAA models, ref. to section 7.6. The inspection programme could be generated using a standard system like Primavera or MS-Project, hereunder using their gant diagram facilities.

7.10.2.2 Maintenance Programme for Equipment

A maintenance programme for equipment is still not developed in the IM-Manual. However, there is a foreseen yearly maintenance of equipment starting 5 years after completion of the bridge, but not stating any specific items.

It has to be noted that maintenance of the equipment is expected to amount to only a minor part of the accumulated budget.

The following provides a list of the various elements of Equipment. The maintenance programmes for the equipment will be provided from the equipment providers; these programmes will be coordinated in due course. For the fixed access equipment, inspection and maintenance will be included within the programmes for the structural inspections of the bridge elements to which the access equipment is connected.

The programme for equipment must also include the specific statutory inspections for the actual equipment.

List of equipment components:

<u>Moving access equipment:</u>

- Underdeck gantries.

- Main Cable gantries.
- Tower Leg Access Platforms
- Tower Cross Beam External Access Platforms.
- Travelling telescopic platforms (Scissor Lifts)
- Hanger Cable Basket hoist.
- Tower lifts - Internal
- Truck with aerial platform
- Climbing Gantries at terminal structures

Fixed access equipment:

- Equipment mounted on towers and Cross beams
- Equipment mounted on bridge Deck
- Platforms mounted on railway deck
- Platforms mounted at bearing locations

7.10.2.3 Maintenance programmes for Technological Systems

The following details relate to technological systems and equipment that is not part of the bridge access systems. The requirements for inspection and maintenance will need to be established for each item.

A maintenance programme for technological systems is still not developed in the I & M-Manual /i/ although the first step towards developing Detailed RBI/RCM Plans has been taken, ref. to /iv/. However, there is a foreseen yearly maintenance of technological system components starting 5 years after completion of the bridge, but not stating any specific items.

It has to be noted that maintenance of the technological systems is expected to amount to only a minor part of the accumulated budget.

The following provides a list of the various elements of technological systems. The maintenance programmes for the technological system components will be provided from the system providers; these programmes will be coordinated in due course. For the technological system components, inspection and maintenance will be included within the programmes for the structural inspections of the bridge elements to which the technological system component is connected. However, to meet the requirements for continuous functioning of the monitoring systems some components of SHMS shall probably have their own maintenance programme.

The programme for technological systems must also include the specific statutory inspections for the actual technological system component.

List of technological system components:

- Monitoring systems
- Railway systems
- Mechanical and Hydraulical systems
- Electrical systems
- Safety and Anti-Sabotage system
- Operation and Maintenance systems

Data exchange between BMS and other MACS Sub-systems

General

BMS and the other Sub-systems in MACS each operates on its dedicated partition of the common SCADA database or MMS database respectively. To avoid redundancy of data in MACS data are stored in only one partition. Data which are generated in a certain Sub-system are stored in the partition governed by the Sub-system. When data in a certain partition shall be used in another Sub-system, data are retrieved from the partition.

Data in the BMS database are related to elements according to the element hierarchy. Data are further related to the BMS applications - the BMS modules - according to the BMS data entry facility. Documents in the EDMS partition of the MMS database are via their coded file names also related to elements. Documents shall also be related to the BMS modules. This can for instance be obtained by entrance of data in the metadata file attached to the document file.

It is therefore important that all MACS Sub-systems operates with the same element hierarchy. Further, it is important that the Sub-systems operates in the same way with metadata files attached to the document files.

MACS includes a common data exchange facility, a "Service Layer", which shall be used by all Sub-systems for exchange of data with other Sub-systems.

The SCADA system and the MMS system, together with their related databases, are shown in *Figure 6.1*

The data exchanges between BMS and the other MACS Sub-systems are shown in *Figure 8.1.*

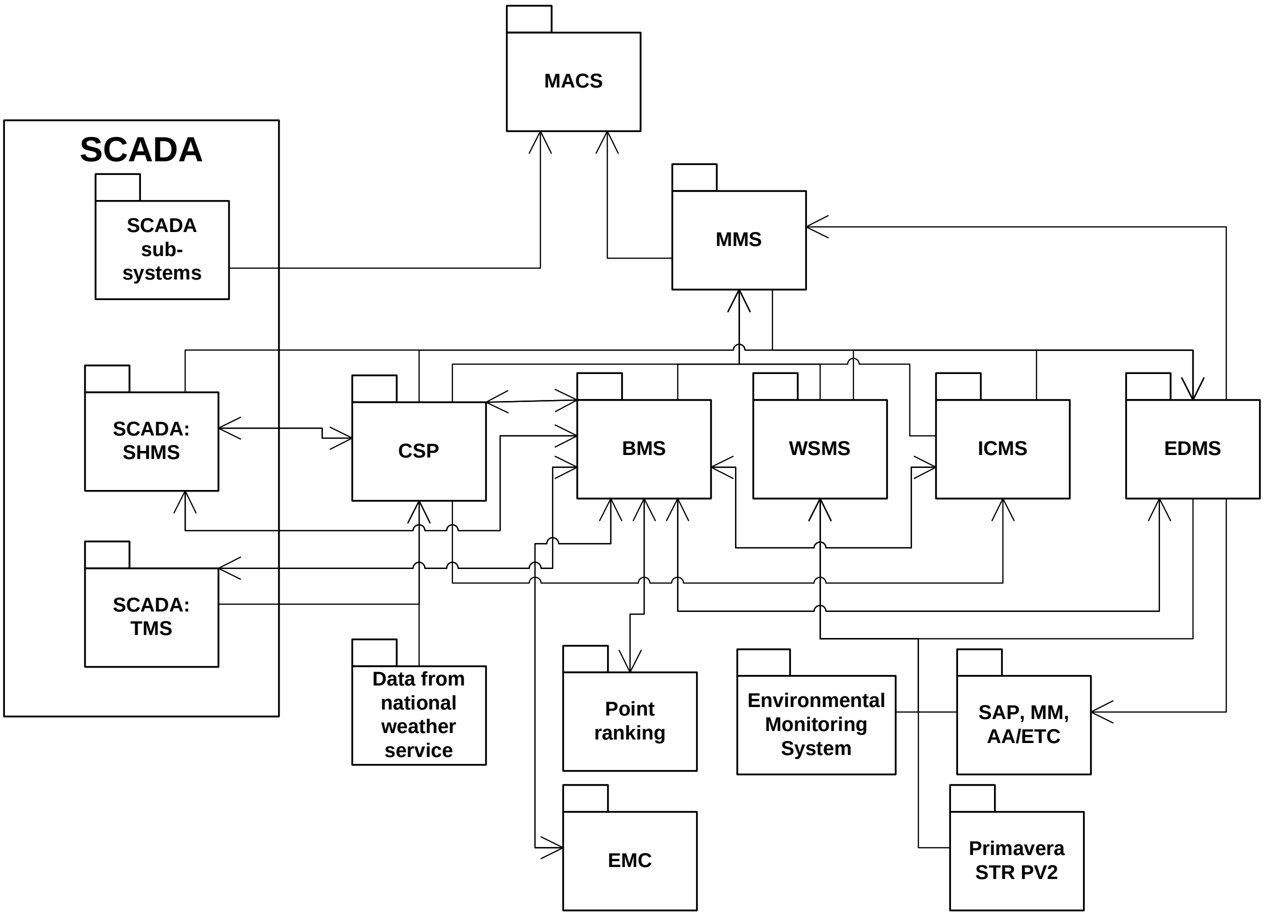

Figure 8.1 Data Exchanges between BMS and other MACS Sub-systems

Data Exchange BMS <-> SHMS

Data captured by monitoring systems are stored in the SHMS partition of the SCADA database. These data are further processed in the Computation, Simulation and Predictions (CSP) Sub-system. In this way CSP calculates condition rating point contributions for the individual structural elements based on results as obtained from monitoring. The condition rating point contribution is transferred manually to BMS but may be automated at a later stage. There shall be no data transfer from SHMS to the BMS database.

In order to establish a total condition rating for the element BMS retrieves these rating point values from CSP and supplements them with rating point contributions as based on results from inspections. Final evaluation results are presented in evaluation reports generated in BMS.

The CSP system extracts data from the SCADA database and processes the data to generate results for further use in operation and maintenance of the bridge. Examples are curves showing traffic loads in a period, expansion joint movements in a period 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.

The Inspection and Maintenance organization receives its monitoring data through the CSP facility. This comprises data values as deflection curves and peak stress values as well as simple illustrations, in pdf-format for example.

In this way monitoring data, primary data as well as processed (monitoring) data, is used alongside inspection data in the management of inspection and maintenance. Data created with the CSP function will, directly or as further processed, be incorporated into reports generated by I & M by use of the BMS. In this way BMS carries out an inspection and maintenance oriented evaluation of the registrations captured by SHMS.

By using BMS the Inspection & Maintenance Organization will carry out a review of the trigger values used in SHMS using monitoring data provided via the CSP function. If a trigger value is to be changed the I & M Organization will report this immediately to SHMS.

Data Exchange BMS <-> TMS

The Technical Manager can from his BMS computer display results as generated in TMS. He can in this way take plans for traffic regulation in consideration when he elaborates programmes for inspections and/or maintenance.

Input from BMS to TMS - for instance booking of closing of certain lanes in certain periods - is given manually.

Data Exchange BMS <-> EDMS

EDMS controls the "document partition" of the MMS database. All documents stored in this database partition can be accessed from BMS. Also documents as created or updated in BMS shall be transferred and stored in the partition controlled by EDMS.

It is assumed that EDMS at the end of the construction period is equipped with an "Inspection and Maintenance Oriented User Interface", meaning that facilities to operate with documents in the Operation and Maintenance stage is already included in EDMS. At the end of the construction stage all As Built Documents are available through EDMS.

It is assumed that EDMS operates on a direct accessible partition of the MMS database and on a set of remote accessible data stores. Documents which become outdated are moved to remote accessible data stores. Documents are never deleted in EDMS.

EDMS includes facilities, a "service layer", to support various types of users - especially users of MACS Sub-systems - to communicate with the document database:

1. To retrieve documents
2. To enter documents
3. To check out documents, revise them and enter revised documents

In order to establish a document database in which documents in the O & M phase can be searched efficiently and safely it is needed to attach further metadata to the individual files than is merged into the 26 character code of the document. This shall be done already in the detailed design and execution stages.

Therefore it should be an EDMS activity to establish and attach such metadata to all documents as entered into Aconex or SAP.

Metadata shall as minimum comprise:

1. Language
2. Document title
3. Type of document (in addition to char 8-9 in the file name)
4. Related BMS application - BMS module (if not covered by document type)
5. Month, year
6. Doc. no.
7. Date of issue
8. Prepared by (initials)
9. Checked by
10. Approved by
11. Responsible person for future update
12. Element codes for related elements (in addition to char 11 - 17 in the file name, when necessary)
13. Keywords
14. BMS-module (inventory, inspection …)

A document controller shall be assigned to the task of establishment of metadata files and entering of document and related metadata files into the "document partition" of the MMS database.

Data Exchange BMS <-> CSP

Exchange of monitoring data, raw data as well as data further processed in CSP, between BMS and CSP is described in section 8.2.

Exchange of other data between CSP and BMS shall be on request and shall be carried by use of the Service Layer facility of MACS.

For an actual computer simulation CSP shall retrieve all relevant data, such as condition rating data with influence on sectional properties, from BMS and thereby incorporate their influence on the analysis models.

BMS shall be able to retrieve all results with significance on safety and or load bearing capacity from the CSP partition of the MMS database.

Data Exchange BMS <-> EMC

BMS shall retrieve all data from EMC regarding condition and functioning of the individual electrical and mechanical element.

BMS and EMC shall otherwise be separate Sub-systems.

Data Exchange BMS <-> ICMS

There will be no direct data transfer between BMS and ICMS.

BMS can retrieve event reports generated by ICMS and stored in the document partition of the MMS database controlled by EDMS.

ICMS can retrieve BMS information related to events from the log file established by BMS. As written in section 7.10.4 it shall in the next stage be considered whether the events shall be logged under the control of BMS or under the control of ICMS.

Data Exchange BMS < - > WSMS

There will be no data exchange between BMS and WSMS since WSMS is only operational in the execution stage whereas BMS is only operational in the O & M stage.

Description of BMS Main Facilities

General

In the following subsections is given a specification of the functionality, that BMS shall provide to the Bridge Maintenance staff dealing with the various bridge maintenance activities.

The Bridge Maintenance staff performs their activities according to the specifications as laid down in the O&M specifications: Manuals, procedures, instructions and standards. BMS shall support the maintenance staff in carrying out the activities. It is therefore necessary that the facilities in BMS are in line with the O&M specifications. Hereunder that BMS operates with data and documents as specified in O&M and that BMS uses terms and a systematic which is consistent with the O&M specifications.

The main areas supported by BMS is shown in Figure 9.1

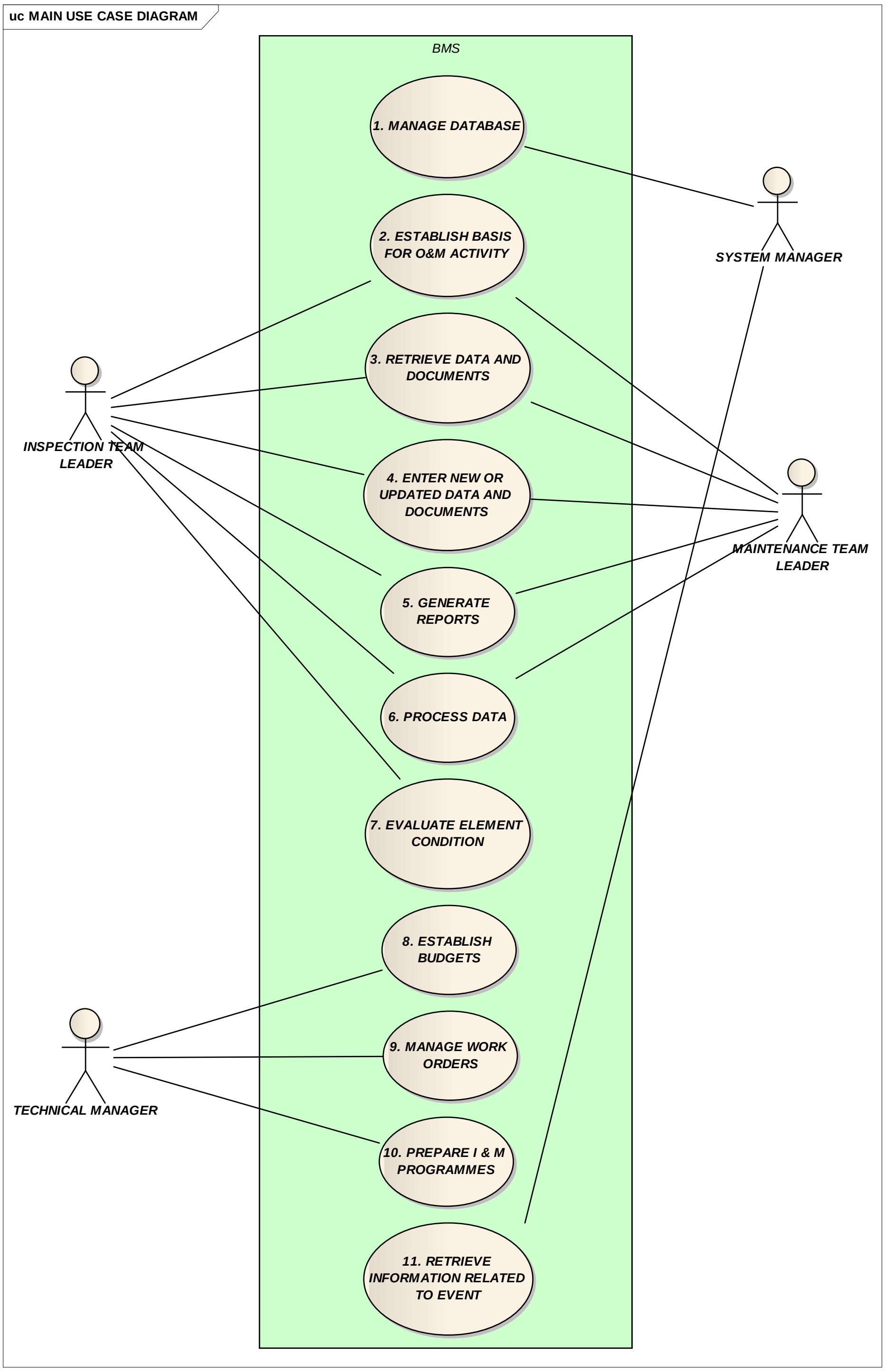

Figure 9.1 BMS supported Inspection and Maintenance Activities.

A further description of the individual maintenance activities is given in the following sections.

Data Management

BMS shall be an open system with a range of users in the Bridge Maintenance Organisation. BMS-users shall individually be given user rights for:

- Read access
- Write access, and
- Execution (data processing).

The rights shall be provided to users as differentiated to the various BMS applications - BMS modules.

If or when BMS is opened for users outside the Bridge Maintenance Organisation, special rules shall be set up and administered by the Data Manager.

The System Manager shall establish and maintain a well organised, consistent and always up to date database containing:

- Links to O&M specifications (Manuals, Procedures, Instructions, Standards, Contact Bodies, Authorities …)
- Inventory data, inclusive data related to carried out rehabilitation works.
- Links to as built documentation files.
- Links to inspection and maintenance documentation files.
- Detailed RBI/RCM and LCC models for all elements, as assessed to be relevant for RBI/RCM plans.
- Condition data for all bridge elements
- Inspection and maintenance programmes.

- Statistical data for inspection and maintenance works.

It is the System Managers responsibility to establish and maintain the BMS log file. Another of his main tasks is to maintain the element hierarchy. Further he shall ensure that all documents have attached correct metadata.

Establishment of Basis for O & M Activity

BMS shall include facilities which for a user in any situation ensures efficient and safe access to all information needed to form the necessary and optimal basis for carrying out the planned inspection and/or maintenance activities. This comprises information in:

- Specifications (Manual, procedures, instructions …)
- Equipment to be used
- Spare parts to be allocated
- Manning of job, qualifications
- Safety procedures

The request shall be according to keyed in data for element codes and for activity codes.

It is essential for all maintenance personnel to be aware of the operational constraints that will affect their activities. Reference must therefore be made to the Operations and Emergency Manual, the report "Risk evaluation principles" and other documents covering operational, safety and control measures for all users of the bridge. Inspection and Maintenance personnel will be required to work in a variety of locations throughout the structure. Several activities will need to be carried out in locations where there will be obvious and less apparent hazards. Risk assessments should be carried out as appropriate to allow Operational Procedures to be developed to address all envisaged hazards and activities.

The following is a non-exhaustive list of headings that will need to be considered during the development of the operational procedures for inclusion in the O&E Manual:

Working in confined spaces.

Working at height.

Working close to, or above, live traffic.

Working within the railway envelope.

Effect of weather on safe working.

Undertaking activities that may be a distraction to drivers.

Each of the above hazards may result in control measures being introduced that affect the way in which the inspection and maintenance personnel are allowed to work. Management may instil in their staff that such measures are in place for their safety or for the safety of others. Staff should be encouraged to contribute to reviews of the procedures to ensure not only that they understand their background and basis but also to allow them to put forward alternative views for consideration.

Table 5-3 in Operation and Emergency Manual gives the overall preliminary proposal on criteria on ambient conditions for carrying out inspections and maintenance works on the bridge.

When the traffic pattern and intensity is known the conditions for performing of various maintenance and inspection works depending of necessary traffic restrictions should be considered and defined.

Other operational constraints that should be allowed for is the development of a procedure for the management of requests from hauliers for the passage of abnormal loads. Abnormal indivisible loads (AILs) may be abnormal due to their weight, their axle configuration, their width, their height, their speed of travel or combinations of each of these. A specific procedure for passage of Special Road Vehicles is included in the O&E Manual. The Inspection & Maintenance Organization may be involved if separate assessments, e.g. structural and geometrical, have to be done if the abnormal vehicle is out with the parameters permitted by the procedure.

Retrieval of Data and Documents

9.3.1 Data related to Elements

It shall be possible for each element to retrieve the following data:

- Parameter values for Detailed RBI/RCM-plan, if relevant
- Parameter values for LCC model, if relevant
- Inspection data for carried out inspections (defects - codes and classifications)
- Monitoring data
- Rating point values

9.3.2 Documents related to Elements

It shall be possible for each element to retrieve the following documents, each in the valid version:

- As built documentation, incl. doc. for executed rehabilitation:
  - drawings
  - specifications
  - certificates
  - supplier data (e.g. information re. maintenance)
- Inspection and Maintenance Procedures and Instructions
- Inspection reports
- Supervision reports

9.3.3 Graphical Presentation

It shall be possible to extract graphical information on selected elements, selected group of elements and on selected functional systems. The graphical presentation shall be based on a full scale 3D model of the suspension bridge sufficiently structured according to the element hierarchy.

By use of the 3D model and the presentation facilities in BMS it shall be possible to present inspection and maintenance values for element and element groups as for instance:

- Hangers, with colours representing rating point values
- Girder sections, with colours representing planned time schedule for new coating
- Tower sections, with colours representing carried out inspections

As an example is in *Figure 9.2* shown a presentation of condition rating points for bridge girders in a selected part comprising 5 sections.

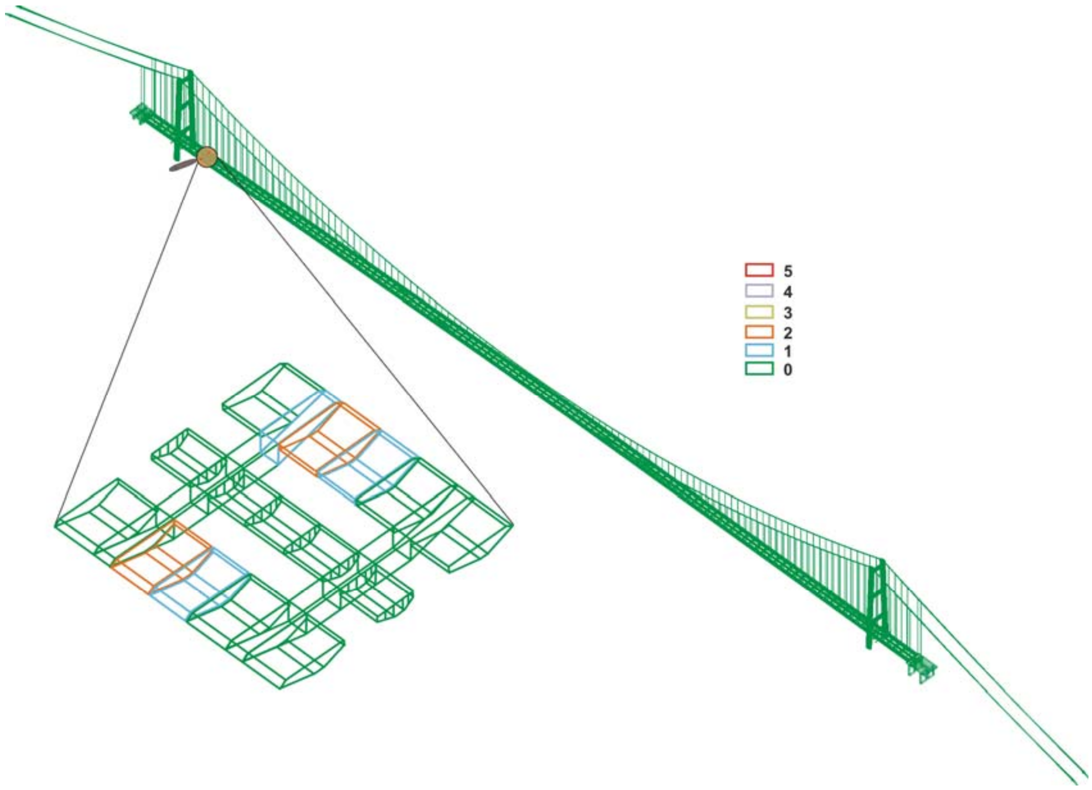

Figure 9.2: Graphical Presentation of Condition Rating Points for Girder Sections

Entrance of new or updated Data and Documents

BMS shall provide data entry facilities which ensures efficient and safe data entrance. The facility shall provide screen menus tailored to the actual situation, the actual element or element group and the actual BMS-module. The menu shall explicitly differ between request for mandatory data and request for optional data

Main data areas:

- Inventory data
  BMS to facilitate input screens tailored for various element types

- Inspection data
- Monitoring data
- Maintenance data
- Log o costs, inspections, maintenance works and events

This includes manual entry of data for updating of data or for new data related to:

- Detailed RBI/RCM-plans and LCC models
- Inspection data,
  General inspection data and defect registration (defect codes and classification)
- Condition evaluation
  Rating point values
- Automatic transfer of data from monitoring systems, if any.
- Rehabilitation works
  General rehabilitation works data. Intelligent data related to the carried out rehabilitation works such as data for quantities and costs.

As built documentation is entered via EDMS into the archive for as built documents.

Generation of Reports

BMS shall include facilities for generation of I&M reports. This includes:

- Templates for the various report types:
  <u>Management reports to be provided to the MACS:</u>
  - Yearly reports
  - Planning reports, short time as well as long time planning
  - Economy reports

  <u>Internal BMS reports:</u>
  - Principal Inspection report
  - Special Inspection report

- Maintenance works report
- Supervision report

- Automatic implementation of data as stored in the BMS database
  For example capture of defect data from the database and incorporation into the Inspection report.

For uploading into the EDMS database the facilities in EDMS shall be used.

Data processing

BMS shall support data processing activities related to inspection and maintenance activities. This comprises:

- Maintenance of element hierarchy
- Establishment and update of FMECA-IMAA sheets
- Establishment and update of Detailed RBI/RCM Plans
- Input to resource planning
- Input to budgeting
- Establishment of inspection and maintenance programmes

The various FMECA-IMAA and RBI/RCM tools as established during the execution stage shall be directly accessable from BMS for execution or for modification of the tool itself.

For inspection and maintenance programming it might be appropriate to access standard tools as Primavera or MS-Project directly from BMS.

Condition Evaluation

This condition evaluation comprises the evaluation to be carried out according to assessment of the needs for maintenance or further inspection, for instance need for special inspection. The evaluation of condition indicator is carried out in relation to update of Detailed RBI/RCM Plans, ref. to section 7.6.

The results from inspections and/or monitoring are evaluated by qualified bridge maintenance engineers. The result of the evaluation is a rating point for the element according to the evaluation procedure as described in the Inspection and Maintenance Manual. The rating points are keyed in manually.

The rating point is compared to the threshold values as set in the corresponding RBI/RCM- and LCC-models. Based on this a set of maintenance activities may be proposed/initiated by the Technical Manager.

An example of a condition evaluation process including reporting and initiation of activities, if any, is shown on *Figure 9.3.*

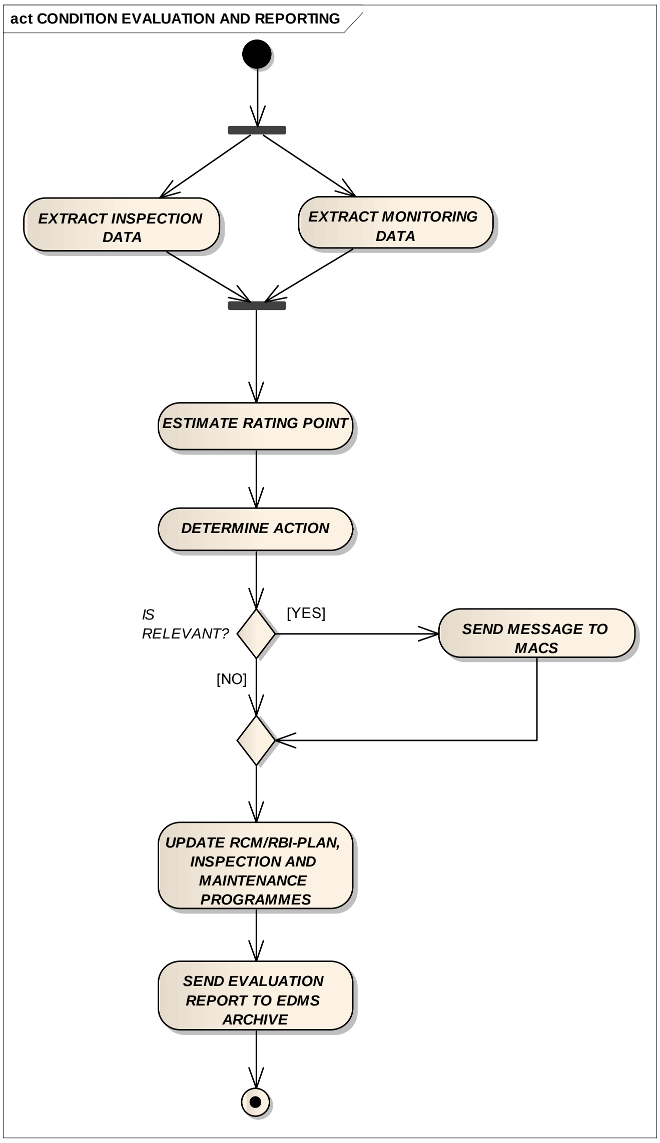

Figure 9.3 Condition evaluation and reporting

The results from the evaluation can be:

Alarm/warning: rehabilitation works to be carried out immediately.

Alarm/warning: restrictions to be put on operation of the bridge.

Request for special inspection.

Request for increased observation.

Request for establishment of monitoring.

Request for initiation of safety analysis.

Request for initiation of rehabilitation works.

Budgeting

The BMS shall store experienced data from carried out inspections and maintenance. This includes unit prices for typical inspection and maintenance activities. Based on data for main dimensions, quantities shall be estimated automatically to support budgeting.

BMS shall include facilities to support cost estimates for alternative rehabilitation methods. The estimates shall include costs for design and construction as well as costs for derived relations such as reduced toll caused by traffic restrictions.

Work Order Management

The BMS shall include a facility to support work order management. By work orders are mend inspection and maintenance tasks. This comprises inspections, monitoring activities, maintenance works, design of maintenance works, special investigations etc.

The facility shall support the activities:

- Listing of needs
- Investigation and listing of alternatives
- Prioritization
- Execution management
- Management of technical follow up
- Reporting, registration of experienced results

Preparation of Inspection and Maintenance Programmes

9.10.1 Inspection Programmes

The various types of inspections are carried out theme by theme as described in the Inspection and Maintenance Manual.

In order to ensure a planning of efficient inspections and in order to group inspections in an optimal way considering a minimum of impact on traffic the BMS shall provide facilities for the inspection planner to establish inspection programmes. This also includes establishment of equipment lists, document lists and experienced time spent for such inspections.

In *Figure 9.4* is shown the various types of inspections, which according to the actual RBI/RCM-model could be relevant for the actual element.

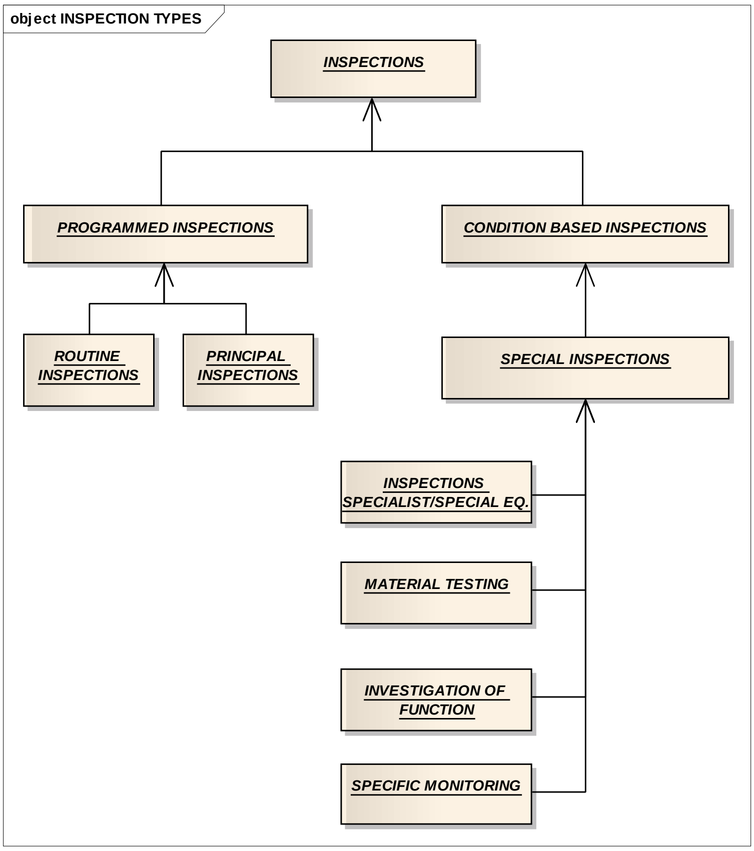

Figure 0.4 Types of inspections

Special inspections can also comprise:

- Survey
- Risk analysis (load bearing capacity).

BMS shall include a facility to monitor that the inspection activities are carried out in due time according to the as inspection programmes.

It may be appropriate to use standard IT-tools (MS-Project, Primavera, …) to create gantt-diagrams (activity-time sheets) for the individual inspection programme.

9.10.2 Maintenance Programmes

BMS shall support the assessment of various strategies, hereunder estimates of:

- Service level
- Costs
- Safety

The various types of maintenance works are often carried out theme by theme as described in the Inspection and Maintenance Manual. Examples of themes are:

- Repair of coating on tower Calabria
- Repair of wind screen, south road bridge

In order to ensure a planning of efficient rehabilitation works and in order to group rehabilitation works in an optimal way considering a minimum of impact on traffic, the BMS shall provide facilities for the maintenance planner to establish maintenance programmes. This also includes description of equipment to be used, regulation of traffic etc.

BMS shall include a facility to monitor the in time execution of the maintenance activities as planned in the maintenance programmes.

It may be appropriate to use standard IT-tools (MS-Project, Primavera, …) to create gantt-diagrams (activity-time sheets) for the individual maintenance programme.

Retrievel of Information Related to Events

When a certain event is observed by the MACS and a further action has to be taken all inventory data related to this action shall be easily retrieved from the BMS database. The BMS shall include facilities for the System Manager to identify and retrieve the actual data. The maintenance engineer assures the quality of the data and transfers them to the Event Manager.

The BMS shall also include a facility to receive information from the SCADA system, via the Event Manager, and to ensure that the needed maintenance activities are defined, planned and executed.

Spare Parts

BMS shall include a facility to support the Yard Manager in managing spare parts. The facility shall ensure that the spare part stock in the Spare Part Warehouse is consistent with the requirements as settled in the Component Sheets and the FMECA-IMAA models for the elements, all as described in the IM Manual.

Technical Specifications for IT-system

Modular structure of BMS

It is considered that a modular structure of BMS would be appropriate. A modular structure will probably facilitate the BMS-users to the largest extent. Further it will improve the possibilities of:

- Coding data and documents for easy and safe queering
- Management of differentiated user rights

The following modules are considered to be appropriate:

12. Administration (part of a common administration for all MACS Sub-systems)
    Management of:
    - users
    - database
    - element hierarchy

- general libraries
- log files

13. I & M Specifications.
    Documents comprising:
    - Manuals
    - Technical Procedures and Instructions
    - Codes and Standards
    - Standard repair methods
    - Equipment for Inspection and Maintenance
14. Inventory data
    - as built documentation
    - intelligent data for elements
15. Spare parts
16. Inspections
17. RCM and RBI programmes
18. Maintenance
19. Budgeting
20. Management of work orders
21. Inspection and Maintenance Programmes
22. Log of Costs, Inspections, Maintenance Works and Events

The above listed modules each includes facilities for data retrievel, data processing, data entrance, report generation and document control as relevant for the various modules.

Software

Based on the specifications of the functional requirements of BMS, as described in this section, and the technical specification of the MACS and related subsystems a set of technical specifications for BMS shall be prepared.

It is assumed that such technical specifications will be part of tender documents for a BMS delivery.

It is assumed that the result of a BMS tender will be either:

A standard Asset Management System, customised to fulfil the Messina requirements, or

A unique IT-system developed entirely to fulfil the Messina requirements.

The database is the kernel of the BMS. It is expected that the database (of MMS) shall be a relational database, as an Oracle database, with a SQL access. However, the MMS database shall be specified in the next stage, considering all MACS Sub-systems.

Server

The specifications for the server shall be described when the entire MACS including all its Sub-systems is sufficiently defined.

Access to BMS

The various electronic equipment to be used to access the BMS installation and its database partition shall be specified in the next stage taking all MACS Sub-systems into consideration.

It is expected that the following equipment can be used to access BMS:

- Terminal (PC), positioned in the Maintenance Office
- Terminals (PC), positioned at parties outside the Maintenance Office
  -at Authorities, Contractors, Consultants etc
- SmartPhones
- Dashboards

User Interfaces

Graphical front end

This user facility shall provide:

- Access to all components and hereby access to all relevant Inspection and Maintenance data.
- Grouping of components based on material data, manufactory data etc.
- Grouping of components based on practical considerations for inspection/maintenance in common.

See the example in *Figure 9.2*

Non-graphical front end (e.g. Windows interface, dashboards or …)

This user facility shall mainly provide:

- Access to data which are not related to specific elements
- Access to documents which are not related to specific elements

It shall in the next stage be considered whether some of the GIS facilities as developed and used in WSMS in the construction stage can be taken over by the BMS.

Report Generator

The BMS shall include facilities to generate reports from the contents of the BMS database. This comprises reports for:

- Inspections
- Budgeting
- Inspection Programmes
- Maintenance Programmes

- Management
  - yearly reports
  - planning reports (short term as well as long term planning)

Documentation for BMS

The following documentation shall be provided with the BMS

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

25-year over-haul plan

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.

11.6.1 Operation Manual

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

11.6.2 Maintenance Manual

The maintenance manual shall set-out all of the maintenance activities required to keep the System functional for 25 years. Maintenance activities shall be divided into the following categories:

regular general maintenance (including sensor re-calibration and survey of the GPS reference station)

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.

11.6.3 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.

11.6.4 Software Source Code Guide

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

11.6.5 Printed software source code

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

11.6.6 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.

11.6.7 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.

11.6.8 Quality Control Documents

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

11.6.9 25 year Over-haul Plan

The System is expected to require an over-haul at the end of the design life. As the end of the design life approaches the functionality and condition of the system and its components shall be reviewed. If required a partial over-haul or a complete over-haul shall be performed. The over-haul shall be required:

- for system maintenance
- for upgrade in view of advancement in technologies

A strategy for complete system over-haul shall be prepared, including expected sequence for replacement of the various components, and shall be presented in the 25-year over-haul plan.

Time Schedule for BMS

General

It shall in the next stage be decided how the MACS and its Sub-systems shall be developed, implemented and taken into use.

In the following is described a proposal for a time schedule covering the case that the BMS system is developed and implemented according to an IT contract between the Main Contractor and a supplier.

The overall Time Schedule is shown in Appendix F.

In the following sub-sections is given a brief description of the main activities. It is very important that the entire BMS is operational at the time for opening of the bridge. This means that:

- The BMS user facilities
- The BMS partition of the MMS database
- The BMS part of the EDMS document database
- The BMS System Manager
- The BMS users on all levels
- The BMS user support to the Maintenance Organisation

shall be ready for use of BMS "from day one".

Request from the above to the execution of the various activities are included in the texts below.

Specifications, Preparation of Tender Documents

The tender documents shall include specifications for:

- Functional requirements
- Basic IT requirements (IT-platform, standard system, type of database)
- Requirements for co-operation with other IT-systems
- General performance requirements (up-time etc)
- Evaluation criteria

Tendering

It is assumed that a limited number of suppliers submit proposals based on the tender documents.

The Main Contractor will carry out a tender evaluation and will go into negotiation with the preferred supplier.

Completion of Specifications and Contracting

The Main Contractor will, in co-operation with the supplier, update and complete the specifications to form part of the BMS Contract.

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

BMS System Design

The Supplier will prepare the BMS System Design. This will be carried out in dedicated phases with inclusion of the Main Contractor's stepwise approval.

Development and Installation of BMS

The supplier will establish the first version of the entire BMS.

Testing and Remedy of Failures

SdM will, according to the specifications in the BMS Contract, participate as a user in the testing of the BMS. The supplier will successively remedy all failures as observed.

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.

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.

BMS User Training

The supplier will provide user training for:

- SdM System Manager(s)
- SdM End Users

Pilot BMS Project

In due time before opening of the Bridge a comprehensive pilot project will be carried out. This project shall include all modules of BMS and all communications with other MACS Sub-systems.

The Pilot Project shall be carried out coordinated with the activity of establishment of the final BMS-partition in the MACS database. This included entrance of all data and entrance and set up of links to alldocuments in EDMS relevant for BMS.

Entrance of Data into the BMS Partition of the MMS Database

It shall be ensured that the design, development, implementation, testing and failure remedy is carried out according to a time schedule which meets the requirements for the Main Contractor to enter BMS data and documents so that a full operational BMS is available at day one.

Cost Estimate

The BMS is a Sub-system to MACS. The costs for BMS will to a large degree depend on how the entire MACS is structured, meaning which common facilities belongs to MACS and which facilities belongs to the individual Sub-systems. When this is specified a cost estimate for BMS can be elaborated.

The total costs will include contributions as:

- Consultancy (specifications, tendering, technical follow up etc)
- Suppli (according to IT-Contract)
- Education and training of users
- User support (annual cost)

It is assumed, that a cost estimate is made for the entire MACS management system. According to the break down of this cost estimate the cost contribution for the BMS Sub-system is prepared.

14 List of requirements

The main requirements to BMS are formulated in the I & M Manual system. The general IT-related requirements to BMS as described in the the technical specification from Stretto di Messina are addressed in this BMS Report as shown in the table below:

Requirement in the Technical Specification from Stretto di Messina	Addressed in BMS, Annex, section no.:
6.1 Language and planning of the system	6, 9.1
6.2 Activity	6, 8, 9, 11
6.3 Hardware	11
6.4 Maintenance of the system	7.11.2.3
6.5 Cost Analysis	13
6.6 Verification	12.7, 12.9

Appendix A: Element Hierarchy

Level 2	Level 3	Level 4	Level 5	Level 6	Level 7	ID	Element
1						P	Suspension Bridge
	1					ST	Substructure
		1				F3	Tower Foundation
			1			TS	Tower Sicily
				1		G1	Leg North-East
				2		G2	Leg South-West
				3		G3	Cross Beam
			2			TC	Tower Calabria
				1		G1	Leg North-East
				2		G2	Leg South-West
				3		G3	Cross Beam
		2				B4	Anchor Blocks
			1			BS	Anchor Block - Sicily
			2			BC	Anchor Block - Calabria
		3				F4	Terminal Structures Foundations
			1			VS	Terminal Structures Sicily
				1		FD	Foundation
				2		PL	Piers
			2			VC	Terminal Structures Calabria
				1		FD	Foundation
				2		PL	Piers
		4				S6	External Arrangements
			1			TS	Tower Sicily
			2			TC	Tower Calabria
			3			BS	Anchor Block - Sicily
			4			BC	Anchor Block - Calabria
			5			VS	Terminal Sructures Sicily
			6			VC	Terminal Structures Calabria
	2					SV	Superstructures
		1				T4	Towers
			1			TS	Tower Sicily
				1		G1	Leg North-East
					1	01	Segment 1
					n	nn	Segment n
					n+1	D0	Diaphragm/Stiffener
				2		G2	Leg South-West
					1	01	Segment 1
					n	nn	Segment n
					n+1	D0	Diaphragm/Stiffener
				3		TO	Cross Beams
					1	01	Cross Beam 1
					2	02	Cross Beam 2
					3	03	Cross Beam 3
					4	D0	Stiffener
			2			TC	Tower Calabria
				1		G1	Leg North-East
					1	01	Segment 1
					n	nn	Segment n
					n+1	D0	Diaphragm/Stiffener
				2		G2	Leg South-West
					1	01	Segment 1
					n	nn	Segment n
					n+1	D0	Diaphragm/Stiffener
				3		TO	Cross Beams
					1	01	Cross Beam 1
					2	02	Cross Beam 2
					3	03	Cross Beam 3
					4	D0	Stiffener
		2				S7	Suspension System
			1			CO	Cable Clamps
				1		MS	Main Span
					6	06	Cable Clamp 6
					n	nn	Cable Clamp n
				2		?	Side Span Sicily
					1	01	Cable Clamp 1
					n	nn	Cable Clamp n
				3		?	Side Span Calabria
					115	115	Cable Clamp 115
					n	nn	Cable Clamp n
			2			SL	Saddles
				1		SA	Splay Saddles
				2		ST	Tower Saddles
			3			PE	Hangers
				1		?	Main Span
					6	06	Hanger 6
					n	nn	Hanger n
				2		?	Side Span Sicily
					1	1	Hanger 1
					nn	nn	Hanger nn
				3		?	Side Span Calabria
					115	115	Hanger 115
					nn	nn	Hanger nn
			4	1		CA	Main Cables
					1	C1	Main Cable 1

Level 2	Level 3	Level 4	Level 5	Level 6	Level 7	ID	Element
					2	C2	Main Cable 2
					3	C3	Main Cable 3
					4	C4	Main Cable 4
			5	1		?	Handstrand Ropes
					1	?	Handstrand Ropes (Main Cable 1)
					2	?	Handstrand Ropes (Main Cable 2)
					3	?	Handstrand Ropes (Main Cable 3)
					4	?	Handstrand Ropes (Main Cable 4)
		3				**I3**	**Deck**
			1			CF	Railway Girder
				1		MS	Main Span
					6	06	Segment 6
					n	nn	Segment n
					n+1	D0	Diaphragm, type 1
					n+2	?	Diaphragm, type 2
				2		?	Side Span Sicily
					0	00	Segment 0
					n	nn	Segment n
					n+1	D0	Diaphragm, type 1
					n+2	?	Diaphragm, type 2
				2		?	Side Span Calabria
					116	116	Segment 116
					n	nn	Segment n
					n+1	D0	Diaphragm, type 1
					n+2	?	Diaphragm, type 2
			2			?	Roadway Girder, direction Sicily
				1		MS	Main Span
					6	06	Segment 6
					n	nn	Segment n
					n+1	D0	Diaphragm
				2		?	Side Span Sicily
					2	02	Segment 2
					n	nn	Segment n
					n+1	D0	Diaphragm
				3		?	Side Span Calabria
					116	116	Segment 116
					n	nn	Segment n
					n+1	D0	Diaphragm
			3			?	Roadway Girder, direction Calabria
				1		MS	Main Span
					6	06	Segment 6
					n	nn	Segment n
					n+1	D0	Diaphragm
				2		?	Side Span Sicily
					2	02	Segment 2
					n	nn	Segment n
					n+1	D0	Diaphragm
				3		?	Side Span Calabria
					116	116	Segment 116
					n	nn	Segment n
					n+1	D0	Diaphragm
			4			TP	Main Cross Girders
				1		MS	Main Span
					6	06	Cross Girder 6
					n	nn	Cross Girder n
					n+1	D0	Diaphragm
				2		LS	Side Span
					1	01	Cross Girder 1
					n	nn	Cross Girder n
					n+1	D0	Diaphragm
		4				**S8**	**Terminal Structures**
			1			VS	Terminal Structures Sicily
				1		SC	Longitudinal Steel
				2		S1	Slab
				3		?	Bottom Plate
			2			VC	Terminal Structures Calabria
				1		SC	Longitudinal Steel
				2		S1	Slab
				3		?	Bottom Plate
	3					**SS**	**Secondary System**
		1				**R4**	**Secondary Structures**
			1			CR	Service Lane
				1		?	Service Lane, direction Sicily
				2		?	Service Lane, direction Calabria
			2			BF	Wind Screens
				1		?	Wind Screens, direction Sicily
				2		?	Wind Screens, direction Calabria
			3			BA	Roadway Barriers
				1		?	Roadway Barriers, direction Sicily
				2		?	Roadway Barriers, direction Calabria
			4			?	Light masts
				1		?	Light masts, direction Sicily
				2		?	Light masts, direction Calabria
			5			?	Cross Overs

Level 2	Level 3	Level 4	Level 5	Level 6	Level 7	ID	Element
				1		?	Cross Overs, direction Sicily
				2		?	Cross Overs, direction Calabra
			6			?	Service Areas
				1		?	Service Areas, direction Sicily
				2		?	Service Areas, direction Calabria
			7			PA	Tower Gantries and Elevators
				1		?	Tower Gantries, Sicily Tower
				2		?	Tower Gantries, Calabria Tower
				3		?	Elevators, Sicily Tower
				4		?	Elevators, Calabria Tower
			8			?	Main Cables Carriages and Hanger Baskets
			9			?	Gantries for Suspended Deck
				1		?	Gantry for side span - Sicily
				2		?	Gantry for main span - Sicily
				3		?	Gantry for main span - Calabria
				4		?	Gantry for side span - Calabria
			10			DU	Dehumidification System
		2				**A0**	**Articulations**
			1			AP	Bearings
				1		?	Roadway Bearings, direction Sicily
				2		?	Roadway Bearings, direction Calabria
				3		FB	Railway Bearings
				4		?	Transverse support of suspended deck
			2			GE	Expansion Joints
				1		?	Roadway Joints, direction Sicily
				2		?	Roadway Joints, direction Calabria
				3		FJ	Railway Joints
			3			AM	Buffer
				1		?	Hydraulic Buffers - Tower
				2		?	Hydraulic Buffers - Terminal Structures
		3				**P2**	**Platform**
			1			SR	Roadway
				1		CS	Carriageway direction Sicily
					1	PV	Surfacing
					2	SG	Road Markings
				2		CC	Carriageway direction Calabria
					1	PV	Surfacing
					2	SG	Road Markings
			2			FE	Railway
				1		BP	Even track
					1	RT	Rail
					2	AM	Fastening System
					3	SV	Unscrewing System
				2		BD	Odd Track
					1	RT	Rail
					2	AM	Fastening System
					3	SV	Unscrewing System
	4					**IT**	**Technological Systems**
		1				**M3**	**Monitoring Systems**
			1			C1	Control & Monitoring System for Electric and Mechanic
			2			C2	Railway Monitoring System
			3			SM	SHMS Monitoring System
		2				**F5**	**Railway Systems**
			1			IS	Signal System
			2			TT	Telecommunication (Railway)
			3			TE	Overhead Electrics
		3				**M2**	**Mechanical and Hydraulical**
			1			DI	Water Supply
			2			AS	Surface Drainage
		4				**E2**	**Electrical Systems**
			1			SA	Lightning Conductor
			2			DE	Electric Supply MT/ST
			3			SI	Illumination System
				1		IN	Internal Illumination
				2		EX	External Illumination
				3		AN	Aviation and Navigation Warning Light
		5				**A3**	**Safety and Anti-Sabotage System (SSS)**
		6				**M4**	**Operation and Maintenance Systems**
			1			C3	Operational - Logistics MACS
			2			C4	DWPMS
			3			C5	WSMS
			4			C6	BMS (WMPS)
			5			C7	ICMS
			6			C8	EDMS
			7			C9	CSP
			8			GT	TMS Traffic Management
		7				**S9**	**Special Plants**
			1			SC	Communication System
				1		DS	Data Communication
				2		TC	Telecommunication

Appendix B: Procedure for Principal Inspection and Instruction for reporting of Principal Inspection

Technical Procedure No. 1.01: Principal Inspection.

Technical Procedure for Principal Inspection.

1. General

This Technical Procedure describes the procedure for *Principal Inspection* of structural elements and structures.

The inspections are carried out with the purpose:

- to monitor that the safety level of the structures of Messina Strait Bridge is maintained without significant adverse influence on the traffic flow
- to detect defects in due time so it is possible to select the optimal repair strategy (time and method to repair) for the different structural elements in order to avoid the need for unplanned corrective maintenance
- to provide a regular condition rate of all the various structural elements
- to provide basis for long term budgets for repair and replacement of elements with limited life time
- to initiate special inspections where necessary to determine the cause/extent of defects and to assess whether they need to be rectified or monitored.

The Principal Inspection Reports are also used to give important input for time and cost management.

The monitoring is performed by regular principal inspections by systematic close visual inspections of all accessible parts of the structure and - when required - using simple tools or instruments to investigate the defects on site during the inspection.

The purpose of this Technical Procedure is to ensure that anybody who is required to carry out principal inspections at the Messina Strait Bridge has at all times been appropriately instructed on how such inspections are to be undertaken and how such inspections are to be recorded and reported:

The related Technical Instructions are element-oriented documents describing in detail the activities that shall be carried out at the principal inspections.

2. Scope of Validity

This Technical Procedure contains information on Principal Inspections of structures to the inspection and maintenance staff and to other involved parties.

The procedure covers all structural elements as described in section 4 of theI&M Manual of the Messina Strait Bridge.

3. Reference Procedures and Instructions

Prior to commencing work on site, personnel are to ensure that they are familiar with all the associated manuals and procedures that have been developed for safe and effective working on the structure. Not all such documents will be directly relevant to each of the individual tasks but all staff should be familiar with the overall philosophy and background to the inspection and maintenance procedures.

The following documents should therefore be reviewed prior to undertaking the inspections covered by this Technical Procedure:

The Operation and Emergency Manual.

The Inspection and Maintenance Manual.

TPXX Health and safety, including working in confined spaces, PPE. Weather restrictions on access.

TPXX Working procedures for the bridge, e.g. radio operation, site vehicles, access routes.

TPXX Use of access equipment, e.g. gantries, lifts.

TI 1.01.1 Instruction on Reporting

4. Responsibility

The Technical Manager is responsible for the maintenance of this Technical Procedure and the associated Technical Instructions. The Technical Manager has the overall responsibility for ensuring that this procedure is followed.

The relevant Inspection and Maintenance Team Leader has responsibility for planning, coordinating and managing the activities in accordance with the Inspection Programme. After completion of the activity the Team Leader ensures that the necessary report is prepared in line with the particular instruction.

The Technical Manager will review all reports and determine any follow up action required. The reports will also be used to assess the rate of wear or deterioration of the bridge elements to enable effective planning of repair or replacement work. This will allow accurate cost forecasting and ensure that specialist spare parts or equipment can be sourced in good time.

The Team Leader has responsibility for ensuring that all persons undertaking inspection and maintenance work are appropriately trained and familiar with the operational and safety procedures associated with their tasks and that the necessary notices and permissions have been issued.

5. Activities

5.1 General

These purposes of the principal inspections are fulfilled by:

- Recording the type, extent and severity of any significant defect
- Recording the general condition of the structural main elements (at level 5 of the hierarchy) and the defects on each of its sub-elements; the condition is recorded by means of a rate from 0 to 5 See 5.3.4
- Reporting the need for any special inspections
- Reporting the need for any maintenance works – other than preventive maintenance works - to be carried out
- Determining the appropriate year for the next principal inspection, but the frequency of principal inspections should not exceed 6 years without careful consideration. Normally the frequency will either be based on performed Failure Mode, Effect and Criticality Analysis (FMECA) or based on engineering judgement depending on the condition of the element, the traffic load on the element and the expected rate of damage development.

The condition of the bridge elements and the repair works are related to the hierarchy elements at level 5.

This procedure and the related general Technical Instructions set up the general instruction on how to carry out the inspections. The specific Technical Inspections for each particular structural part further instruct on which particular type of defects the inspector shall be aware of at the individual elements. However, the inspector should use his professional knowledge also to inspect for other types of defects than those specifically indicated in the procedure and related instructions.

The Messina Strait Bridge is a large structure consisting of a number of major elements many of which consist of a large number of identical parts. Principal inspection, with close visual inspection of each of these parts may be considered as unnecessarily excessive. An alternative would be to concentrate inspections on areas where defects are more likely to develop with random inspections of other parts. Whenever the condition mark, ref. sect. 5.3.4 exceeds mark 1 the size of the random parts may be increased. However, all parts would continue to receive Routine Inspections and defects noted by these inspections may also trigger an increase in the Principal Inspection of other parts.

5.2 Principal Inspection Planning

5.2.1 Preparatory works

See the specific Technical Instruction for the structural element to inspect.

5.2.2 Review of Inventory and Inspection Reports

To make himself familiar with the particular aspects concerning the elements the inspector shall review the following documents:

- I&M Manual section 4 in particular to notice the element number system and the location codes to apply for the inspections
- This procedure and the related general technical procedures and technical instructions
- The particular inspection instructions valid for elements to inspect
- The technical instruction for Principal Inspection Reporting
- The last Maintenance Inspection Report covering the actual element
- The last Principal Inspection Records covering the actual elements (inclusive of photos)

In the inventory numbers and location codes have applied for all elements. The numbers and codes have been detailed to such a degree that no further detailing should be applied. These codes are mandatory for the records.

The inspector should browse the last Principal Inspection Report and other Inspection Reports to be aware of any previously reported significant defects, whether they have been repaired and whether the defect locations can be inspected by the planned access facilities.

For some of the principal inspections this review of earlier reports should be executed very thoroughly and carefully to ensure that cost effective use is made of the access equipment and the personnel involved. Such Inspections will include all exterior surfaces of the superstructure and particularly all areas of the suspension system.

5.3 Carrying out Principal Inspection

5.3.1 Overall inspection/orientation

The inspector should at first make himself familiar with the actual conditions for the inspection. He should also check the location codes to apply by finding reference locations as described in section 4 of the I&M Manual and appended drawings.

The required data information described in the Technical Instruction TI 1.01.1, Instruction on Reporting, should be recorded in the BMS Database**.** The reported data are divided into three sections:

- basis for inspection to be reported before the inspection
- reporting of data on site for factual registration of all individual defects
- reporting of data that should be used to summarise the defects on the record and supplement with all recommendations for repair or for Special Inspections. . This major part of data shown in this scheme may be reported after having concluded the inspection.

Overall photos each structure/element to inspect should be recorded in the BMS Database.

The dates and weather conditions at the time of inspection should be recorded too.

5.3.2 Element inspections (defect registration)

At the inspections only significant defects should be recorded in the field "Defect description". This means defects that already at the time of inspection or due to the expected development are evaluated to:

- influence on the structural safety or durability
- influence on the driving comfort
- influence on the safety for third persons

Defects, that earlier have been recorded, should be traced to:

- follow up and check if repair works have been carried out according to recommendations in the inspection reports
- if the defects have developed since the last inspection

Only defects, which may be rectified by either corrective maintenance or repair works, should be recorded. Below type of defects should e.g. not be recorded:

- Defects, which may be remedied by preventive maintenance
- Fine cracks in concrete structures except for cracks at the anchoring zones of the main cables
- Dry deposits on interior concrete faces caused by earlier water ingress

To ease the inspection a number of Technical Instructions for specific bridge parts have been prepared.

To assist the inspector on the phrasing of the report a list with defect types has been prepared, see section 5.3.3. Furthermore in section 5.3.4 guidelines for condition rating of specific defect types are given.

Each defect should be recorded by:

- the element number inspected
- a defect description (including evaluation of the cause of the defect)
- the location of the defect applying location codes of the inventory
- the extent of the defect
- the severity of the defect
- photos – also to ease evaluation of any future development

5.3.3 Classification of defects

The types of defects to be particularly looked for during inspections are to be categorised as follows:

Defect Type B – Bearings and Expansion Joints	
Description	**Code**
Debris Ingress	BDI
Loss of surface coating	BLC
Change of clearance	BCL

Defect Type B – Bearings and Expansion Joints	
Elastomer Defect	BED
Noise	BNS
Scuffing/Abrasion	BSC
Wear	BWR

Defect Type C – Corrosion	
Description	**Code**
Surface rusting	CSU
Rust staining	CST
Corrosion damage - pitting	CDP
Corrosion damage – spalling, bursting	CDA
Zinc Oxide formation	CZO

Defect Type D – Damage and Deterioration	
Description	**Code**
Bolt Failure	DBF
Bolt Loose	DBL
Deformation. - Buckling and twisting	DDE
Gouge, scar or indentation	DGS
Cracking of Weld/Steel	DCW
Defective Cable Wrapping/Sheathing	DEF
Defective Sealant	DSE
Defective Paint	DPT
Wire Fracture	DWF
Wire out of lay	DWO
Socket draw	DSD
Leak / Water Ingress	DWI

Defect Type K – Concrete Parts	
Description	**Code**
Cracking	KCR
Spalling	KSP
Exposed Reinforcement	KRE
Lack of cover	KCV
Efflorescence/Staining	KEF
Chloride Ingress and Carbonation	KCC
Water Ingress	KWI

Defect Type S - Surfacing	
Description	**Code**
Cracked	SCR

Defect Type S - Surfacing	
Lifting	SLF
Missing	SMI
Movement or Creep	SMO
Tracking or Rutting	STR
Reduced Friction	SRF
Joint Deterioration	SJT
Chemical Damage, e.g. Diesel spill	SCD
Mechanical damage - Scrape or Indentation	SMD
Fire or heat damage	SFR
Loss of ride quality	SRQ

5.3.4 Condition rates

The condition of the bridge is evaluated for each of the structural elements on level 5.

The evaluation and the condition rate of each element must be accomplished under consideration of the degree of distress or deterioration of the element and its ability to fulfil its function, i.e. the capability to meet the actual strain or load *at the date of inspection.* Moreover the condition rate shall reflect whether the defect already has caused any consequences on the functionality of any adjoining members.

The condition rate should not be influenced by the lack of minor preventive maintenance. However, if the lack of proper maintenance or cleaning has lead to damage to the structure this may influence the condition rate.

The condition rate is a figure from 0 to 5, according to the following guidelines:

Rate 0 – This provides a record that an area has been inspected and that, at the time of the inspection, there was no evidence of a defect.

Rate 1 – This provides a record that a minor defect has been noted but the inspector considers there is no need for a repair to be instigated. This may, for example, be a record of some minor deformation of a stiffener or some minor paint damage. Undertaking a repair may not be necessary or justified. However, if work of a similar nature was to be undertaken close by, then consideration could be given to addressing Rate 1 items.

Rate 2 – This reports the discovery of a defect which, in the opinion of the inspector, is something that should be addressed within about six months. The repair is not urgent but if it is not addressed then further deterioration will occur and the cost of repair will increase.

Rate 3 – Major defects are reported by an Inspector when he considers that if a repair is not carried out promptly it will result in an increased risk to safety, loss of function of the defective, or an adjacent, element or will result in the cost of repair rising rapidly.

Rate 4 – Such defects are reported when the Inspector is confused or alarmed by the nature or the cause of the defect or where he considers that further or specialist assistance (Special Inspection) is required to fully investigate the concern. Rate 4 defects may include defects reported as Rate 3 if the Inspector considers that urgent repair and further investigation are both necessary.

Rate 5 - This records that an area was not able to be inspected at the time that the Principal Inspection was undertaken, e.g. due to the element being inaccessible. As such a Special Inspection (Type A) will be required to confirm the condition of the element.

Briefly the condition rates are summarized in the following table:

Table 5.3.1 Condition rating of defect severity

Defect Severity	
Description	**Condition rate**
Area inspected – no defect noted.	0
Minor Defect - no necessity to instigate repair	1
Significant Defect - repair needed within 6 months	2
Major Defect - requires urgent repair	3
Special Case – requires urgent investigation and action	4
Unknown (Inaccessible elements)	5

Special Inspections or reducing the principal inspection interval should also be considered when giving an element condition rate 2 or higher to determine the defect cause or defect extent to select repair strategies. When choosing repair methods that remove the cause of a defect the defects should not redevelop.

The condition rate 3 should be avoided by initiating necessary inspections and identifying maintenance/repair works in good time.

It is beyond the scope of this procedure to describe in detail how to evaluate damaged structures. It is assumed that the inspector is capable of assessing the degree of distress/deterioration and to determine which parts of the bridge need close investigation. The following sections give rough general guidelines that may be used for the various defect types:

General guidelines.

If you encounter signs of inadequate carrying capacity (some of the above mentioned or others), always ask for special inspection type C, see sect. 5.6 in I&M Manual.

Road surfacing

Single type of damages even though they may be major cracks or potholes should not be paid the same attention as repetitive types of minor damages. The single types may be rectified under preventive maintenance.

- Any type of damage which indicate material disintegration or loss of stability should give condition rate 2 or higher

Reinforced concrete structures:

The influence of cracks on the bearing capacity may be harmless at the time of inspection but some cracks may initiate corrosion that later may be critical. Fine cracks in reinforced structures may be harmless unless the structure is exposed to very aggressive environment, e.g. positioned in the splash zone of saline water. Fine cracks in pre-stressed structures are more critical.

- If all the crack widths are less than 0.25 mm it may be assumed that the stresses are not too high, and no further action is to be taken. The condition rate will be 1 or 2. Make a record of the cracks in the field "Defect description" so the next inspector will know that the cracks are not new.
- If the crack width is between 0.25 and 0.5 mm the stresses may be high but they are not assumed to be dangerous. If it is possible, record the crack width, crack length and crack distance in shear and bending zones in the field "Defect description". The condition rate will normally be 2.
- If the crack width is larger than 0.5 mm it indicates that the stresses are high and that there may be a problem regarding the load carrying capacity. Record the dimensions of the girder, the crack width, crack length and crack distance in the shear and bending zones in the field "Defect description". Note that the width of the bending cracks is measured at the main reinforcement even if the crack width may be larger at a greater distance from the edge of the beam.) The condition rate will be 3 or more.

S-shaped" cracks (shear cracks) e.g. near the centre of the span or - on continuous girders - near the supports indicate very high stresses in the bending as well as the shear reinforcement. In this case, always ask for a special inspection. (See Figure 5-1).

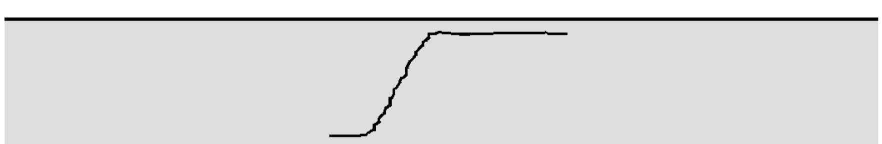

Figure 5-1 “S-shaped” cracks in girders.

- If the crack pattern is different from the “classical” picture and you are not sure that the cracks are harmless, ask for a special inspection.
- Not only main girders but also diaphragms may have serious bending and/or shear cracks indicating overload, and need for special inspections.
- Cracks or spalling at the joint between main girders and diaphragms may indicate anchorage problems due to an insufficient or erroneously placed reinforcement.
- Eccentricity between piles and columns may induce bending moments in columns (and piles). Normally the structures are not designed to resist this.
- Inclined coarse cracks crossing the whole cross section of columns/piles may indicate a compression failure (in particular if there is a displacement between the two parts on either side of the crack).

Pre-stressed concrete structures:
Defects indicating corrosion at the pre-stressing cables should be given condition rate 2 or higher and a special inspection type B should be requested

- Damages indicating medium cracks in the bending zones should be given condition rate 2, coarse cracks should be given 3 and a special inspections (type B or C) should be requested

Steel structures:
It is essential for the function of steel structures that the members (in particular members in compression) are not deformed, as compression forces in connection with deformation produce unintended bending moments and a risk of stability failure

- Even minor unintended eccentricities may induce significant bending moments in secondary members and subsequent buckling.

Guidelines for condition rating of specific defect types:
The assessment of the condition rate is based on the risk of loss of structural integrity for each category of defect. When carrying out an inspection, the severity is to be recorded at the appropriate rating.

The general rating of the condition is as described in the table above.

Type B defects - Bearings and Expansion Joints:

Defect Severity	
Description	**Condition rate**
Area inspected – no significant defect.	0
Perceptible defects but no apparent effect on performance	1

Defect Severity	
Description	**Condition rate**
Defectiveness affecting performance and causing preventive perceptive noise.	2
Seized join/bearing effectively preventing intended movement and/or very loud noise requiring immediate investigation for rating 1 & 2.	3
Special Case – requires urgent investigation and action	4

Type C defects - Corrosion:

Defect Severity	
Description	**Condition rate**
No significant defect	0
Surface discoloration only with no build-up of corrosion products or loss of section.	1
Build up of corrosion products and some loss of section by not more than 3%	2
Heavy corrosion and/or loss of material or other damage. Section of plate or capacity of element reduced by more than 3%.	3
Special Case – requires urgent investigation and action	4

Type D defects - Damage and Deterioration

Defect Severity	
Description	**Condition rate**
Area inspected – no significant defect.	0
Perceptible defects/early deterioration of seals.	1

Defect Severity	
Description	**Condition rate**
For Defect Type DDE and DGS: Maximum measured departure from intent is less than 10% of adjacent section/plate and other minor defects.	
For Defect Type DBF and DBL: Up to 10% of bolts in any connection. For type DDE: As above (for condition rate 1) but more than 10 % of adjacent plate thickness or section size. For type DGS: See Condition Rate 4 below. For type DCW: 5% - 10% of weld length or individual defects over 50 mm whichever is the less - monitor to be instituted until repaired. For type DPT: Weathering of top coat with some local failure down to undercoat or to expose galvanizing on areas larger than 0,05m^2. For type DWO: Any wires out of lay.	2
For Defect Type DBF and DBL: More than 10% of bolts in any connection. For type DDE: As above (for condition rate 1) but greater than twice the plate thickness. For type DGS: See Condition Rate 4 below. For type DCW: More than 10% of weld length and/or individual weld failures over 100 mm long whichever is the less. For type DEF and DSE: Any leakage against dehumidified area	3

Defect Severity	
Description	**Condition rate**
For type DPT: Failure of coating system down to bare metal including loss of galvanising. For type DWF: Any wire fractures. For type DSD: More than 10 mm.	
For defect Type DGS: Any gouge, scar or indentation deeper than on the surface, requires a further investigation by a specialist to evaluate the defect, make a determination of the condition rate and a description of the defect in order to make it possible for the principal inspector to evaluate any further deterioration of the defect at the next principal inspection. If there is no development the principal inspector can give the defect the previous condition rate without any further consultation. Special Case – requires urgent investigation and action	4

Type K defects - Concrete Parts:

Defect Severity	
Description	**Condition rate**
Area inspected – no detectable defect.	0
Perceptible defects with negligible effect on structural performance.	1
Potential effect on structural performance, traffic and/or long term effect on structural life including cracks > 0.25 mm in width and loss of concrete cover to reinforcement.	2
Sufficient to influence structural integrity.	3
Special Case – requires urgent investigation and action	4

Defect Severity	
Description	**Condition rate**

Type S defects - Surfacing:

Defect Severity	
Description	**Condition rate**
Area inspected – no detectable defect.	0
Perceptible defects but no reduction in ride quality.	1
Significant defect with perceptible reduction in ride quality and/or adhesion value over area greater than 10 m long.	2
Obvious immediate danger to traffic and/or structure requiring immediate diversion of traffic.	3
Special Case – requires urgent investigation and action	4

5.3.5 Extent of Defects

In the previous section, 5.3.4, the Condition Rating or severity of each defect was established so as to allow the more severe defects to be highlighted in any report. This section, 5.3.5, sets out the way in which the extent of each defect is to be reported and recorded so as to enable easy comparison with previous inspections thus allowing the deterioration of any part to be measured over a period of time.

Type B defects - Bearings and Expansion Joints

Type	Description of extent
BDI	Give dimensions of area affected
BLC	Give dimensions of area affected
BCL	Give measured clearance
BED	Give dimensions of area affected

Type	Description of extent
BNS	Describe noise source and intensity
BSC	Give dimensions of area affected
BWR	Give dimensions of area affected

Type C defects – Corrosion

Type	Description of extent
CSU CST CDP CDA CZO	Extent N - No significant defect. Extent S - Slight, not more than 5% of area affected. Extent M - Moderate - 5 to 20% affected. Extent E - Extensive - more than 20% affected Note: Dimensions of area inspected to be noted where percentages recorded.

Type D defects - Damage and Deterioration

Code	Description of extent
DBF	Record number and location of bolts affected
DBL	Record number and location of bolts affected
DDE	Give dimensions of defect in millimetres
DGS	Give dimensions of defect in millimetres
DCW	Record location, length and nature of each crack
DEF	Describe extent and location of defect
DSE	Describe extent and location of defect
DPT	As for type C defects

Code	Description of extent
DWF	Record numbers and location of observed or suspected fractures
DWO	Record numbers and location of wires out of lay
DSO	Record extent of draw
DWI	Describe extent

Type K defects - Concrete Parts

Code	Description of extent
KCR	Describe extent and nature
KSP	Plot extent and parameters from specified tests
KRE	Describe extent and nature
KEF	Describe extent and nature
KCC	Describe extent and nature
KWI	Describe extent and nature

Type S defects - Surfacing

Code	Description of extent
SCR	Describe orientation and whether failure is full depth to steel.
SLF	Describe extent and depth of failure.
SMI	Describe depth and dimensions of area affected.
SMO	Describe extent and dimensions of area affected.
STR	Describe which lane, depth and length affected.
SRF	Describe which lane and length affected.
SJT	Describe evidence/extent of water ingress.

Code	Description of extent
SCD	Describe dimensions of area affected.
SMD	Describe depth of damage and dimensions of area affected.
SRQ	Describe nature of deterioration.

5.3.6 Special Inspection

If the inspector is uncertain regarding the evaluation of the elements, the causes and the extent of defects, or if he is not certain which repair strategy to recommend he should ask for a special inspection type B. This is reported by writing a “B” in the field, see Appendix 2 to TI 1.01.1, Instruction on Reporting. Otherwise the field is left blank.

Special Inspections should always be considered when giving an element the condition rate 2 or higher to prevent the defect to develop out of control.

Other types than above Special inspections type B of special inspections may also be requested, refer section 5.6 in the I&M Manual.

5.3.7 Photos

All photos should be recorded:

- each photo is recorded in the BMS database referenced to the defect it illustrates
- in field of the report in the database the number of photos taken regarding the actual element is entered.

A camera, which is able to print photo identification on the photos, should be used. The identification (normally the date (day number) and time (hour and minute)) is written in the principal inspection record form in the field and is later used for identifying the photos belonging to the specific inspection. The identification is only entered into the report if it is necessary to refer to a specific photo of an element (see “Defect description” sect. 5.3.2).

As help in identifying the photos from a specific element it may be useful always to start with a photo of the element identification no. written by chalk on the element according to the inventory. But do not include such photo in the report. A defect must be numbered with its "Defect Number" and then photographed.

Photos should be used to:

- Illustrate defects which may be difficult to describe

- Show development of defects between two inspections. In these cases the photographs of the defects should be recorded from the same positions

Whenever it may help to understand the defect the inspector should place a folding or a crack width gauge and/or a sign “up” next to the defect before taking the photograph.

For particular defects other kind of cameras should be used e.g. video cameras to illustrate vibration or movements phenomena.

6. Reporting

The principal inspection reports should be prepared by entering the data into the database as stated in the Technical Instruction:

- TI 1.01.1: Principal Inspection, Instruction on Reporting

The data to be entered are divided into three sections:

- the basis for inspection which should be entered before the inspection
- entering of data used on site for factual registration of all individual defects
- entering of data to summarise the defects on the record and supplement with all recommendations that may be entered after having concluded the inspection

Technical Procedure TP No. 1.01

Technical Instruction TI 1.01.1

TECHNICAL INSTRUCTION FOR REPORTING OF PRINCIPAL INSPECTION

1. User of Instruction

This instruction is prepared to instruct inspectors on how to report by the *Principal Inspection Report.*

2. References to Inspection Procedures and Instructions

TP 1.01: Technical Procedure, Principal Inspection

3. Instruction on Reporting

All Principal Inspections shall be concluded by entering the data according to the attached scheme "Principal Inspection Report"

Below is a brief instruction on which data to be reported:

Cell	Explanation
Principal Inspection Report	
Document no. XXXX	No. given according to the relevant QA document numbering system
Date	The date the Principal Inspection Report is issued
Subject of inspection	Hierarchy number and description of element (upper levels)
Inspector	Name and position of the inspector to be indicated
Period of inspection	The period is summarised from the inspection records
Requisition of Inspection	Normally this cell is filled in with the position of an employee of the Inspection & Maintenance Organisation.

Cell	Explanation
Required inspection frequency	Frequency according to TP zzz to be indicated
Date of last Inspections	The reports from Principal Inspections and other inspections to be browsed before the inspection. The date to be indicated.
Brief summary of last observations of inspections	A brief summary should be made of defects recorded the inspections since the last principal inspection. The inspector should investigate and note later agreements on rectification of the defects.
Brief summary of last observations of principal inspection	A brief summary should be made of defects recorded the last principal inspection. The inspector should investigate and note later agreements on rectification of the defects.
References to O&E and I&M manuals	References to Procedures and Instructions in Operation & Maintenance and Inspection & Maintenance Manuals to be indicated
Safety Instructions	Nos. should be indicated of the Safety Instructions to observe at the particular inspection
Traffic Restrictions	Nos. should be indicated of the Traffic Restriction Plans to observe at the particular inspection
Principal Inspection Records	The table shall indicate information on each individual inspected element given by the upper covering level.
Principal Inspection Record, ref. attached Appendix 1	
Report No.	No. of attached Principal Inspection Record to be indicated
Element no.	Element identification no. at the upper three levels to be indicated each level four element
Defect no.	Reference number for each defect description. These numbers do not necessarily need to be related to the individual damage nos. noted in the defect record.

Cell	Explanation
Defect description	A summary of the defect descriptions indicated in the defect record should be indicated each element at level 4
Defect cause	A summary of the defect causes indicated in the defect record should be indicated each element at level 4
Condition rating	Condition rating should be indicated according to the inspector's engineering judgement from the principles indicated in TP 1.01 sect. 5.3.4.
Special Inspection	If a special inspection is required to investigate the defects in more detail, the type of special investigation should be indicated according to the types explained in TP 1.01 sect. 5.3.6
Repair work	Type, quantity, year for performance, and according cost + time estimate should be indicated according to the inspector's engineering judgement for repair works needed to rectify the actual damages.
Photos	For each type of defect the number of photos should be indicated. The number is counted in the attached defect records.
Next year of inspection	The inspector's recommendation on next year of inspection should be indicated.
Defect Record, ref. attached Appendix 2	
Principal Inspection Report	The number of the report should be indicated on the record
Appendix no.	Number to be indicated by level and element number
Date	Date of inspection of specified element
Inspector	Initials
Inspected element	The findings are recorded on site by element level nos. and location nos. in the sequence they are observed. Element nos. and location codes according to I&M Manual section 4.
Defect no.	Each defect to be given sequential numbers within each element
Defect	Defect types to be recorded by their codes only if they are

Cell	Explanation
type/description	identical to those described in the TP 1.01 sect. 5.3.3 Classification of defects. Other defects should be indicated by a brief description.
Defect cause	The likely cause of the defect should be indicated according to the inspector's engineering judgement. Defects, which have been recorded in earlier reports, should be repeated whenever they have not been rectified or the defect has been required no action. Also any development, if any, in the extent of damage should be recorded.
Defect extent	Extent of defects to be indicated, reference to TP 1.01, sect. 5.3.5, Extent of Defects.
Condition rating	Condition rating should be indicated according to the inspector's engineering judgement from the principles indicated in TP 1.01 sect. 5.3.4.
Photo no.	Identification should be indicated by element no. and time.
Quantity	Quantities should be estimated/measured to such a detail that they can form basis for a requisition to a contractor.

Principal Inspection Report no. XXXX Date dd.mm.yy

Subject of Inspection				
Element No.				
Inspector	Department:			
Position:		Name:		
Period of Inspection :				

Requisition of Inspection

Required by		Date of Requisition:	
Department	Position	Name	

Principal Inspection Planning

Required Inspection frequency:		
Date of last Inspection:	Principal Inspection.	Other Inspection
Brief summary of last observations:		

Reference to Inspection & Maintenance Manual

Technical Procedure ID	**Technical instruction ID**	**Technical instruction ID**		

References to Operation & Emergency Manual

Element no.	Unit	Supplier	Manual ID

Reference to Safety Precaution Instruction and Traffic Restriction requirements from Operation & Emergency Manual

Instruction ID	Subject

Principal Inspection Records

Date	Weather conditions	Inspected elements	Element no.

Appendices:

Appendix 1: Principal Inspection Record

Appendix 2: Record of Defects

Element no.					**Description**	**Defect**			**Condition**	**Special**	**Repair Work**					**Photos**	**Next**
L 1	L 2	L 3	L4	L5	Hierarchy	No	Description	Cause	Rating	Inspection						Ref.	Insp.
ID	ID	ID	ID	ID					(1-5)	A/B/C/D	Type	Labour	Time	Materi als	Cost	Nos	Year

Maintenance and Inspection - Principal Inspection
Record of Defects

Inspection Report no.		Date		Inspector	
Inspected element level 5		Inspected element	level 1 / level 2 / level 3 / level 4	Appendix no.	

Inspected element			Defect						Photo	Location codes						Repair Work		
level 6	level 7	level 8	No.	Type	Description	Defect cause	Extent	Condition Rating	No.	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	Labour	Time	Materials

Appendix C: FMECA-IMAA Analysis, Detailed RBI-Plan and Detailed RCM-Plan

Messina Strait Bridge - Progetto Definitivo - FMECA_Basis

How to fill in the FMECA and IMAA sheets

1) Define and describe the system/element

2) Failure mode: Determine a single functional failure

3) Criticality matrix

3a) Describe the consequences for the bridge regarding unavailability, cost, fatalities and environmental damage given functional failure
3b) Assess qualitatively the probability of the worst consequence happening, given the functional failure has occurred

			Consequence of failure					
			Insignificant	*Marginal*	*Serious*	*Severe*	*Very severe*	*Disastrous**
			0	1	2	3	4	5
Likelihood	*Very unlikely*	1	0	0	0	1	1	3
	Unlikely	2	0	0	1	2	2	3
	Occasional	3	0	1	2	2	3	4
	Likely	4	0	1	2	3	4	4
	Very likely	5	0	2	3	4	4	4

Criticality class

Class	Criticality	Default inspection Interval
0	Inconsiderable	(6 or more)
1	Low	(6)
2	Medium	(2)
3	High	(1)
4	Very High	(0,5)

4) Vulnerability matrix

4a) Assess the Time for failure development. How long time does it take for the failure mode to evolve from "not detectable" to a predefined failure limit (hours, days, weeks, months, quarters, years)?

			Time for Failure Development					
			Years	*Quarters*	*Months*	*Weeks*	*Days*	*Hours*
			1	2	3	4	5	6
Criticality	*Inconsiderable*	0	0	0	0	0	0	0
	Low	1	0	1	1	2	2	2
	Medium	2	1	2	2	2	3	3
	High	3	1	2	2	3	3	4
	Very High	4	2	2	3	3	4	4

Vunerability class

Class	Vulnerability	Default inspection Interval
0	Very Robust	(6 or more)
1	Robust	(6)
2	Semi-Robust	(2)
3	Vulnerable	(1)
4	Very vulnerable	(0,5)

5) Fill out failure and detection analysis

6) Inspection and Maintenance Activity Analysis (IMAA)

6a) Assess the time for damage tolerance. How long time can a predefined failure of the element/system be tolerated?
6b) Assess inspection interval based on proposed default inspection interval or experience.
6c) Assess the Mean Time Between Failure (if RCM element).
6d) Assess spare parts and key parameters to monitor.

Important information:

- Regarding RCM and RBI reliability evaluation please refer to selected sub-sheets.
- All default parameters should be verified by supplier information or other relevant reference.
- All IMAA analysis results should be benchmarked against LCC and I&M manual and to related to supplier information on warranty issues.

Messina Strait Bridge - Progetto Definitivo - FMECA_Structures

Failure Mode, Effects and Criticality Analysis (FMECA) and Inspection and Maintenance Activity Analysis (IMAA)

Structural elements

Current year **2018** (see sheet "FMECA_Basis")

Criticality matrix:

Likelihood of occurrence	Consequence of failure: Insignificant 0	Marginal 1	Serious 2	Severe 3	Very severe 4	Disastrous* 5
Very unlikely	Inconsiderable	Inconsiderable	Inconsiderable	Low	Low	High
Unlikely	Inconsiderable	Inconsiderable	Low	Medium	Medium	High
Occasional	Inconsiderable	Low	Medium	Medium	High	Very High
Likely	Inconsiderable	Low	Medium	High	Very High	Very High
Very likely	Inconsiderable	Medium	High	Very High	Very High	Very High

Vulnerability matrix:

Criticality	Time for failure development: Years	Quarters	Months	Weeks	Days	Hours
Inconsiderable	Very Robust	Very Robust	Very Robust	Very Robust	Very Robust	Very Robust
Low	Very Robust	Robust	Robust	Semi-Robust	Semi-Robust	Semi-Robust
Medium	Robust	Semi-Robust	Semi-Robust	Semi-Robust	Vulnerable	Vulnerable
High	Robust	Semi-Robust	Semi-Robust	Vulnerable	Vulnerable	Very vulnerable
Very High	Semi-Robust	Semi-Robust	Vulnerable	Vulnerable	Very vulnerable	Very vulnerable

Element number	Element name	Element description: Main function	Parts or composition	Part function	Failure Mode (FM): Causes of functional failure	Failure Effect (E), Criticality (CA) and Vulnerability Analysis*: Describe failure effect	Consequence: Unavailability	Costs	Fatalities	Environmental damage	Likelihood of occurrence of max(consequence)	Criticality	Comments	Time for Failure Development** (Hours, Days, Weeks, Months, Quarters, Years)	Failure Development class	Vulnerability	Failure and detection analysis: Failure Detection Yes/No	Detection Method	Mitigation measures other than maintenance	Recommendations - Can failure be eliminated or managed in ways other than maintenance?	Inspection and Maintenance Activity Analysis (IMAA): Time for Failure Development**, [ΔT_f] (Years)	Time for Damage Tolerance***, [ΔT_d] (Years)	Default Inspection Interval, based on criticality (RCM) or vulnerability (RBI) [Years]	Selected Inspection Interval, [ΔT_i] (Years)	RCM or RBI	Year for start up of operation period for element/system [year no.]	Mean Time Between Failures, MTBF [Years]	System age [years]	Recommended Inspection strategy*****	Recommended Maintenance strategy*****	Link to detailed RCM plan****	Link to detailed RBI plan****	Comments to inspection/ maintenance strategy	Spares part requirement in order to minimize repair time (if critical)	Key parameters to monitor
1.2.2.4	Main cables	Main cables are carrying the hangers which are carrying the suspended deck.	The main cables consist of 41,148 (at main span) number of galvanized wires (each with a diam. of 5.33 mm) and are composed of more critical and less critical parts based on experience.		Corrosion	Steel degradation caused by corrosion could lead to failure of the suspended deck.	5	5	5	3	1		Loss of main cable is disastrous, however considered very unlikely. Failure development period, assuming there is no prot. systems available, (From corrosion starts to critical) is assumed to be more than 10 years.	10 Y	1		YES	Inspection	- Neoprene wrapping incl. caulking (assumed as preferred strategy). - Dehumidification system - Electrical and Mechanical Control System (EMC) - Structural Health Monitoring System (SHMS)	-	10	6	(6)	6	RBI	2018	-	0	Periodic Inspection every 6 years	Periodic corrective/preventive maintenance (PIBM)			Corrosion is a consequence of a failing protection system. Time for damage tolerance is therefore set to 6 years, which is the same as the protection system. Due to the number and nature of protection systems this interval may be increased.	None	Dehumidification system. Corrosion is unacceptable and a sign of a failing protection system.
1.2.2.4	Galvanisation of wires in main cable	Secondary protection of main cables against corrosion.	Galvanisation of wires in main cable		Degradation of galvanisation.	Loss of galvanisation starts corrosion of wires	0	3	0	0	2		Loss of galv. happens before corrosion and therefore only relates to extra costs due to extra analyses and inspections. If primary prot. system function 100% correct galv. will not degrade.	10 Y	1		YES	Inspection	None	-	10	6	(6)	6	RBI	2018	-	0	Periodic Inspection every 6 years	Periodic corrective/preventive maintenance (PIBM)			Corrosion is a consequence of a failing protection system. Time for damage tolerance is therefore set to 6 years, which is the same as the protection system. Due to the number and nature of protection systems this interval may be increased.	None	Dehumidification system.
1.2.2.4.1.3	Elastomeric wrapping for main cables	Primary protection of main cables against corrosion.	Elastomeric wrapping and caulking.		Weather conditions and material durability causing degradation.	Degradation of galvanisation of wires (could last approx. 10 years without dehumidification).	0	1	1	0	3		There are no speakable consequences given that dehumidification is reestablished within few months.	10 Y	1		YES	EMC	EMC surveillance graphs are checked by expert once a year.	None	10	6	(6 or more)	6	RBI	2018	-	0	Periodic Inspection every 6 years	Periodic corrective/preventive maintenance (PIBM)			EMC surveillance graphs are checked by expert once a year.	Repair kits.	Relative humidity inside cable.
1.2.2.4.1.3	Elastomeric wrapping - Caulking	Primary protection of main cables against corrosion.	Caulking		Tear and wear	Degradation of galvanisation of wires (could last approx. 10 years without dehumidification).	0	1	1	0	3		There are no speakable consequences given that dehumidification is reestablished within few months.	10 Y	1		YES	EMC	EMC surveillance graphs are checked by expert once a year.	None	10	6	(6 or more)	6	RBI	2018	-	0	Periodic Inspection every 6 years	Periodic corrective/preventive maintenance (PIBM)			EMC surveillance graphs are checked by expert once a year.	Repair kits.	Relative humidity inside cable.
1.2.3.1.1.2	Hanger system - hangers	Carrying load from suspended deck to the main cables.			Corrosion, hangers: Hangers are subject to corrosion from weather variations.	Loss of X wires leads to a loss of 1 strand followed by others which leads to loss of a full hanger system in A years that leads to failure of suspended deck.	5	5	5	3	1		Consequences of hanger failure is disastrous, however considered very unlikely.	10 Y	1		YES	Inspection	- SHMS		10	6	(6)	6	RBI	2018	-	0	Periodic Inspection every 6 years	Periodic corrective/preventive maintenance (PIBM)			Corrosion is a consequence of a failing protection system. Time for damage tolerance is therefore set to 6 years, which is the same as the protection system.		Corrosion is unacceptable and a sign of a failing protection system.
1.2.3.1.1.1	HDPE Sheaths for Hangers	Primary protection of hangers against corrosion.	Not elaborated		Weather conditions and material durability causing degradation.	Degradation of galvanisation of wires (could last approx. 10 years without protection of HDPE sheaths).	0	2	1	0	2		Economical consequences could be serious in terms of extra analyses and inspections.	10 Y	1		YES	Inspection	None		10	6	(6 or more)	6	RBI	2018	-	0	Periodic Inspection every 6 years	Periodic corrective/preventive maintenance (PIBM)				Repair kits for sheath damage.	
1.2.3.1.1.2	Galvanisation of wires in hangers	Secondary protection of hangers against corrosion.			Degradation of galvanisation.	Loss of galvanisation starts corrosion of wires	0	3	0	0	2		Loss of galv. happens before corrosion and therefore only relates to extra costs due to extra analyses and inspections. If primary prot. system function 100% correct galv. will not degrade.	10 Y	1		YES	Inspection	None		10	6	(6)	6	RBI	2018	-	0	Periodic Inspection every 6 years	Periodic corrective/preventive maintenance (PIBM)					
1.2.2.1	Hanger system - clamps	Carrying load from hangers to the main cables.	Clamps are made with stainless steel grade A5		Loss of prestress in bolts causing fatigue in bolts and/or clamp slipage.	Y number of high stress fatigue cycles, caused by loss of prestress in bolts, leads to reduced lifetime of bolts which leads to loss of Z cable clamps next to each other which leads to a loss of a full hanger system and eventually could lead to failure of suspended deck in A years.	5	5	5	3	3		Consequences of hanger clamp failure could be disastrous. Loss of prestress could happen occasional, but not within a 2 year period.	2 Y	1		YES	Inspection	None		2	2	(2)	2	RBI	2018	-	0	Periodic Inspection every 2 years	Periodic corrective/preventive maintenance (PIBM)			It is assumed that prestress less than a predefined service threshold still have capacity for another 2 years and time for damage tolerance is therefore set to 2 years.	- Clamp bolts. - Seals at cable clamps.	Prestress in bolts are measured with ultrasonic equipment.
1.2.2.3	Hanger system - anchorage	Carrying load from the suspended deck to the hangers.			Corrosion, hanger anchorage: Hanger anchorages in deck are subjected to corrosion from weather variations.	Loss of Y mm steel in B years leads to failure of X cable clamps next to each other which leads to a loss of a full hanger system leads to failure of suspended deck.	5	5	5	3	1		Consequences of hanger anchorage failure caused by corrosion could be disastrous, however considered very unlikely.	10 Y	1		YES	Inspection	Coating system		10	6	(6)	6	RBI	2018	-	0	Periodic Inspection every 6 years	Periodic corrective/preventive maintenance (PIBM)			Corrosion is a consequence of a failing protection system. Time for damage tolerance is therefore set to 6 years, which is the same as the protection system.		
1.2.2.3	Hanger system - anchorage	Carrying load from the suspended deck to the hangers.			Fatigue in welds: Hanger anchorages in deck are subjected to fatigue from traffic, wind, etc..	X number of high stress fatigue cycles leads to loss of Y cable clamps next to each other leads to a loss of a full hanger system leads to failure of suspended deck.	5	5	5	3	3		Consequences of hanger anchorage failure caused by fatigue could be disastrous, and could happen occasionally.	2 Y	1		YES	Inspection	SHMS ?		2	0	(2)	2	RBI	2018	-	0	Continuous Monitoring with inspection/evaluation every 2 years	Immediately plan or perform corrective/ periodic preventive maintenance (CBM)			Continuous monitoring should be installed, however this can only be carried out at selected spots.		
1.2.2.3	Coating system on hanger anchorage	Protection of steel against corrosion.	380 μm zinc-rich Ethyl-silicate primer, Epoxy intermediate coating and acrylic top coat or likewise.	Total coating system giving protection of steel against corrosion.	Weather conditions and material durability causing degradation.	Failure of primer starts surface corrosion. Loss of X mm steel in A years in an accelerating rate. Cost of repair increases.	0	4	1	0	2		Economical consequences of failing coating system could be severe in terms of extra costs to sandblasting and preparing of surface.	10 Y	1		YES	Inspection	None	Stainless steel, however this is not cost optimal.	10	6	(6)	6	RBI	2018	-	0	Periodic Inspection every 6 years	Periodic corrective/preventive maintenance (PIBM)				X amount of Coating system for spot repairs.	Adhesion and Cross-cut test.
1.2.2.3	Top coat on hanger anchorage	-	Acrylic top coat (integrated part of total coating system)	Renewable top coat giving mechanical protection, UV-protection, shine and colour to the coating system	Weather conditions and material durability causing degradation.	Loss of ability to renew topcoat. Cost of repair increases.	0	4	1	0	3		Economical consequences of failing coating system could be severe in terms of loss of ability to renew topcoat -> full coating system is necessary.	10 Y	1		YES	Inspection	None	Stainless steel, however this is not cost optimal.	10	6	(6)	6	RBI	2018	30	0	Perform periodic special inspection every 6 years according to the RBI plan. Principal inspection should be performed in year 2045, based on 20% of a lognormal distribution (27 years after appliance).	Topcoat needs to be maintained in year 2048 (30 years after appliance).		X		X amount of Coating system for spot repairs.	Visual inspection and assessment of Coating Condition Indicator, CC.

Element number	Element name	Main function	Parts or composition	Part function	Failure Mode (FM): Causes of functional failure	Describe failure effect	Failure Effect (E), Criticality (CA) and Vulnerability Analysis* – Consequence: Unavailability	Costs	Fatalities	Environmental damage	Likelihood of occurrence of max(consequence)	Criticality	Comments	Time for Failure Development** (Hours, Days, Weeks, Months, Quarters, Years)	Failure Development class	Vulnerability
1.2.3.2 1.2.3.3	Roadway Steel Girders	Carrying road traffic (2 lanes + emergency lane).	see drawings.		Corrosion, internal: Roadway girders are subject to internal corrosion.	Loss of Y mm steel in B years leads to failure of roadway girders.	5	5	5	3	1		Consequences of steel failure caused by corrosion could be disastrous, however considered very unlikely.	10 Y	1	
1.2.3.2 1.2.3.3	Roadway Steel Girders	-			Corrosion, external: Roadway girders are subject to external corrosion from weather variations.	Loss of Y mm steel in B years leads to failure of roadway girders.	5	5	5	3	1		Consequences of steel failure caused by corrosion could be disastrous, however considered very unlikely.	10 Y	1	
1.2.3.2 1.2.3.3	Roadway Steel Girders	-			Fatigue in welds: Roadway girders are subject to fatigue from traffic, wind, etc..	X number of high stress fatigue cycles leads to failure of roadway girders.	5	5	5	3	3		Consequences of weld failure caused by fatigue could be disastrous, and could happen occasionally.	2 Y	1	
1.2.3.2 1.2.3.3	Coating system on Roadway Steel Girders	Protection of steel against corrosion.	380 µm zinc-rich Ethyl-silicate primer, Epoxy intermediate coating and acrylic top coat or likewise.	Total coating system giving protection of steel against corrosion.	Weather conditions and material durability causing degradation.	Failure of primer starts surface corrosion. Loss of X mm steel in A years in an accelerating rate. Cost of repair increases.	0	4	1	0	1		Economical consequences of failing coating system could be severe in terms of extra costs to sandblasting and preparing of surface.	10 Y	1	
1.2.3.2 1.2.3.3	Top coat on Roadway Steel Girders	-	Acrylic top coat (integrated part of total coating system)	Renewable top coat giving mechanical protection, UV-protection, shine and colour to the coating system	Weather conditions and material durability causing degradation.	Loss of ability to renew topcoat. Cost of repair increases.	0	4	1	0	2		Economical consequences of failing coating system could be severe in terms of loss of ability to renew topcoat -> full coating system is necessary.	10 Y	1	
1.3.3.1	Roadway surfacing and marking on roadway Steel Girders	Ensuring correct traffic grip and protection of steel girder below it			Permeability of surfacing causing corrosion of steel girder.	Loss of Y mm steel in B years leads to failure of roadway girders.	5	5	5	3	1		Consequences of steel failure caused by corrosion could be disastrous, however considered very unlikely.	10 Y	1	
1.3.3.1	Roadway surfacing and marking on roadway Steel Girders	-	12 mm polymer resin.		Loss of integrity	Car accidents may happen.	1	1	4	0	4		Consequences of fatalities are severe and loss of integrity are likely to occur. Failure development caused by i.e. freeze-thaw could be within 1 day.	1 D	5	
1.2.3.1	Railway Steel Girder	Carrying rail traffic (two tracks)	see drawings.		Corrosion, internal: Roadway girders are subject to internal corrosion.	Loss of Y mm steel in B years leads to failure of railway girder which leads to derailment.	5	5	5	3	1		Consequences of steel failure caused by corrosion could be disastrous, however considered very unlikely.	10 Y	1	
1.2.3.1	Railway Steel Girder	-			Corrosion, external: Roadway girders are subject to external corrosion from weather variations.	Loss of Y mm steel in B years leads to failure of railway girder which leads to derailment.	5	5	5	3	1		Consequences of steel failure caused by corrosion could be disastrous, however considered very unlikely.	10 Y	1	
1.2.3.1	Railway Steel Girder	-			Fatigue in welds: Railway girder is subject to fatigue from traffic, wind, etc..	X number of high stress fatigue cycles leads to failure of railway girder which leads to derailment.	5	5	5	3	3		Consequences of weld failure caused by fatigue could be disastrous, and could happen occasionally.	2 Y	1	
1.2.3.1	Coating system on Railway Steel Girders	Protection of steel against corrosion.	380 µm zinc-rich Ethyl-silicate primer, Epoxy intermediate coating and acrylic top coat or likewise.	Total coating system giving protection of steel against corrosion.	Weather conditions and material durability causing degradation.	Failure of primer starts surface corrosion. Loss of X mm steel in A years in an accelerating rate. Cost of repair increases.	0	4	1	0	1		Economical consequences of failing coating system could be severe in terms of extra costs to sandblasting and preparing of surface.	10 Y	1	
1.2.1.3	Top coat on Railway Steel Girders	-	Acrylic top coat (integrated part of total coating system)	Renewable top coat giving mechanical protection, UV-protection, shine and colour to the coating system	Weather conditions and material durability causing degradation.	Loss of ability to renew topcoat. Cost of repair increases.	0	4	1	0	2		Economical consequences of failing coating system could be severe in terms of loss of ability to renew topcoat -> full coating system is necessary.	10 Y	1	
1.2.1.3	Railway surfacing	Ensuring corrosion protection of steel girder below it	12 mm polymer resin.		Permeability of surfacing causing corrosion of steel girder.	Loss of Y mm steel in B years leads to failure of railway girders.	5	5	5	3	1		Consequences of steel failure caused by corrosion could be disastrous, however considered very unlikely.	10 Y	1	
1.2.1.4	Cross Girders (steel)	Ensuring load transfer from road- and railway girder to hangers.	see drawings.		Corrosion, internal: Cross girders are subject to internal corrosion.	Loss of Y mm steel in B years leads to failure of crossgirder, railway and roadway girder which leads to derailment and car accidents.	5	5	5	3	1		Consequences of steel failure caused by corrosion could be disastrous, however considered very unlikely.	10 Y	1	
1.2.1.4	Cross Girders (steel)	-			Corrosion, external: Cross girders are subject to external corrosion from weather variations.	Loss of Y mm steel in B years leads to failure of cross girder, railway and roadway girder which leads to derailment or car accidents.	5	5	5	3	1		Consequences of steel failure caused by corrosion could be disastrous, however considered very unlikely.	10 Y	1	

Element number	Failure and detection analysis: Failure Detection Yes/No	Detection Method	Mitigation measures other than maintenance	Recommendations - Can failure be eliminated or managed in ways other than maintenance?	Inspection and Maintenance Activity Analysis (IMAA): Time for Failure Development**, [ΔT$_f$] (Years)	Time for Damage Tolerance***, [ΔT$_d$] (Years)	Default Inspection Interval, based on criticality (RCM) or vulnerability (RBI) [Years]	Selected Inspection Interval, [ΔT$_i$] (Years)	RCM or RBI	Year for start up of operation period for element/system [year no.]	Mean Time Between Failures, MTBF [Years]	System age [years]
1.2.3.2 1.2.3.3	YES	Inspection	- Dehumidification system - EMC System	Stainless steel, however this is not cost optimal.	10	6	(6)	6	RBI	2018	-	0
1.2.3.2 1.2.3.3	YES	Inspection	- Coating system		10	6	(6)	6	RBI	2018	-	0
1.2.3.2 1.2.3.3	YES	Inspection	- SHMS, measuring loads on bridge (fatigue levels and cycles)		2	0	(2)	2	RBI	2018	-	0
1.2.3.2 1.2.3.3	YES	Inspection	None	Stainless steel, however this is not cost optimal.	10	6	(6 or more)	6	RBI	2018	-	0
1.2.3.2 1.2.3.3	YES	Inspection	None	Stainless steel, however this is not cost optimal.	10	6	(6)	6	RBI	2018	30	0
1.3.3.1	YES	Inspection	None		10	6	(6)	6	RBI	2018	-	0
1.3.3.1	YES	Inspection	None		0,003	0,003	(0,5)	0,003	RBI	2018	-	0
1.2.3.1	YES	Inspection	- Dehumidification system - EMC System	Stainless steel, however this is not cost optimal.	10	6	(6)	6	RBI	2018	-	0
1.2.3.1	YES	Inspection	- Coating system		10	6	(6)	6	RBI	2018	-	0
1.2.3.1	YES	Inspection	- SHMS, measuring loads on bridge (fatigue levels and cycles)		2	0	(2)	2	RBI	2018	-	0
1.2.3.1	YES	Inspection	None	Stainless steel, however this is not cost optimal.	10	6	(6 or more)	6	RBI	2018	-	0
1.2.1.3	YES	Inspection	None	Stainless steel, however this is not cost optimal.	10	6	(6)	6	RBI	2010	30	8
1.2.1.3	YES	Inspection	None		10	6	(6)	6	RBI	2018	-	0
1.2.1.4	YES	Inspection	- Dehumidification system - EMC System	Stainless steel, however this is not cost optimal.	10	6	(6)	6	RBI	2018	-	0
1.2.1.4	YES	Inspection	- Coating system		10	6	(6)	6	RBI	2018	-	0

Element number	Recommended Inspection strategy*****	Recommended Maintenance strategy*****	Link to detailed RCM plan****	Link to detailed RBI plan****	Comments to inspection/ maintenance strategy	Spares part requirement in order to minimize repair time (if critical)	Key parameters to monitor
1.2.3.2 1.2.3.3	Periodic Inspection every 6 years	Periodic corrective/preventive maintenance (PIBM)			Corrosion is a consequence of a failing protection system. Time for damage tolerance is therefore set to 6 years, which is the same as the protection system.		Relative humidity inside girder.
1.2.3.2 1.2.3.3	Periodic Inspection every 6 years	Periodic corrective/preventive maintenance (PIBM)			Corrosion is a consequence of a failing protection system. Time for damage tolerance is therefore set to 6 years, which is the same as the protection system.		Visual inspection and assessment of Coating Condition Indicator, CC.
1.2.3.2 1.2.3.3	Continuous Monitoring with inspection/evaluation every 2 years	Immediately plan or perform corrective/ periodic preventive maintenance (CBM)			Continuous monitoring should be installed, however this can only be carried out at selected spots.		Hot spots (i.e. areas under wheel/railtracks) identified during design. Cracklength.
1.2.3.2 1.2.3.3	Periodic Inspection every 6 years	Periodic corrective/preventive maintenance (PIBM)				X amount of Coating system for spot repairs.	Adhesion and Cross-cut test.
1.2.3.2 1.2.3.3	Perform periodic special inspection every 6 years according to the RBI plan. Principal inspection should be performed in year 2045, based on 20% of a lognormal distribution (27 years after appliance).	Topcoat needs to be maintained in year 2048 (30 years after appliance).		x		X amount of Coating system for spot repairs.	Visual inspection and assessment of Coating Condition Indicator, CC.
1.3.3.1	Periodic Inspection every 6 years	Periodic corrective/preventive maintenance (PIBM)			Corrosion is a consequence of a failing protection system. Time for damage tolerance is therefore set to 6 years, which is the same as the protection system.		
1.3.3.1	Periodic Inspection every 0,003 years	Periodic corrective/preventive maintenance (PIBM)			0,003 year = 1 day Continuous monitoring should be installed, if possible.		
1.2.3.1	Periodic Inspection every 6 years	Periodic corrective/preventive maintenance (PIBM)			Corrosion is a consequence of a failing protection system. Time for damage tolerance is therefore set to 6 years, which is the same as the protection system.		Relative humidity inside girder.
1.2.3.1	Periodic Inspection every 6 years	Periodic corrective/preventive maintenance (PIBM)			Corrosion is a consequence of a failing protection system. Time for damage tolerance is therefore set to 6 years, which is the same as the protection system.		Visual inspection and assessment of Coating Condition Indicator, CC.
1.2.3.1	Continuous Monitoring with inspection/evaluation every 2 years	Immediately plan or perform corrective/ periodic preventive maintenance (CBM)			Continuous monitoring should be installed, however this can only be carried out at selected spots.		Hot spots (i.e. areas under heavy wheels) identified during design. Cracklength.
1.2.3.1	Periodic Inspection every 6 years	Periodic corrective/preventive maintenance (PIBM)				X amount of Coating system for spot repairs.	Adhesion and Cross-cut test.
1.2.1.3	Perform periodic special inspection every 6 years according to the RBI plan. Principal inspection should be performed in year 2037, based on 20% of a lognormal distribution (27 years after appliance).	Topcoat needs to be maintained in year 2040 (30 years after appliance).		x		X amount of Coating system for spot repairs.	Visual inspection and assessment of Coating Condition Indicator, CC.
1.2.1.3	Periodic Inspection every 6 years	Periodic corrective/preventive maintenance (PIBM)			Corrosion is a consequence of a failing protection system. Time for damage tolerance is therefore set to 6 years, which is the same as the protection system.		
1.2.1.4	Periodic Inspection every 6 years	Periodic corrective/preventive maintenance (PIBM)			Corrosion is a consequence of a failing protection system. Time for damage tolerance is therefore set to 6 years, which is the same as the protection system.		Relative humidity inside girder.
1.2.1.4	Periodic Inspection every 6 years	Periodic corrective/preventive maintenance (PIBM)			Corrosion is a consequence of a failing protection system. Time for damage tolerance is therefore set to 6 years, which is the same as the protection system.		Visual inspection and assessment of Coating Condition Indicator, CC.

Element number	Element name	Element description			Failure Mode (FM)	Failure Effect (E), Criticality (CA) and Vulnerability Analysis*											Failure and detection analysis				Inspection and Maintenance Activity Analysis (IMAA)														
							Consequence																												
		Main function	Parts or composition	Part function	Causes of functional failure	Describe failure effect	Unavailability	Costs	Fatalities	Environmental damage	Likelihood of occurrence of max(consequence)	Criticality	Comments	Time for Failure Development** (Hours, Days, Weeks, Months, Quarters, Years)	Failure Development class	Vulnerability	Failure Detection Yes/No	Detection Method	Mitigation measures other than maintenance	Recommendations - Can failure be eliminated or managed in ways other than maintenance?	Time for Failure Development**, [ΔT$_1$] (Years)	Time for Damage Tolerance***, [ΔT$_2$] (Years)	Default Inspection Interval, based on criticality (RCM) or vulnerability (RBI) [Years]	Selected Inspection Interval, [ΔT] (Years)	RCM or RBI	Year for start up of operation period for element/system [year no.]	Mean Time Between Failures, MTBF [Years]	System age [years]	Recommended Inspection strategy*****	Recommended Maintenance strategy*****	Link to detailed RCM plan****	Link to detailed RBI plan****	Comments to inspection/ maintenance strategy	Spares part requirement in order to minimize repair time (if critical)	Key parameters to monitor
1.2.1.4	Cross Girders (steel)	-			Fatigue in welds: Cross girder is subject to fatigue from traffic, wind, etc..	X number of high stress fatigue cycles leads to failure of cross girder, railway and roadway girder which leads to derailment or car accidents.	5	5	5	3	3		Consequences of weld failure caused by fatigue could be disastrous, and could happen occasionally.	2 Y	1		YES	Inspection	- SHMS, measuring loads on bridge (fatigue levels and cycles)		2	0	(2)	2	RBI	2018	-	0	Continuous Monitoring with inspection/evaluation every 2 years	Immediately plan or perform corrective/ periodic preventive maintenance (CBM)			Continuous monitoring should be installed, however this can only be carried out at selected spots.		Hot spots (i.e. areas under railtracks) identified during design. Cracklength.
1.2.1.4	Coating system on Cross Girders	Protection of steel against corrosion.	380 µm zinc-rich Ethyl-silicate primer, Epoxy intermediate coating and acrylic top coat or likewise.	Total coating system giving protection of steel against corrosion.	Weather conditions and material durability causing degradation.	Failure of primer starts surface corrosion. Loss of X mm steel in A years in an accelerating rate. Cost of repair increases.	0	4	1	0	1		Economical consequences of failing coating system could be severe in terms of extra costs to sandblasting and preparing of surface.	10 Y	1		YES	Inspection	None	Stainless steel, however this is not cost optimal.	10	6	(6 or more)	6	RBI	2018	-	0	Periodic Inspection every 6 years	Periodic corrective/preventive maintenance (PIBM)				X amount of Coating system for spot repairs.	Adhesion and Cross-cut test.
1.2.1.4	Top coat on Cross Girders	-	Acrylic top coat (integrated part of total coating system)	Renewable top coat giving mechanical protection, UV-protection, shine and colour to the coating system	Weather conditions and material durability causing degradation.	Loss of ability to renew topcoat. Cost of repair increases.	0	4	1	0	2		Economical consequences of failing coating system could be severe in terms of loss of ability to renew topcoat -> full coating system is necessary.	10 Y	1		YES	Inspection	None	Stainless steel, however this is not cost optimal.	10	6	(6)	6	RBI	2018	-	0	Periodic Inspection every 6 years	Periodic corrective/preventive maintenance (PIBM)		x		X amount of Coating system for spot repairs.	Visual inspection and assessment of Coating Condition Indicator, CC.
1.2.1	Towers	Carrying main cables.			Corrosion, internal: Towers are subject to internal corrosion.	Loss of Y mm steel in B years leads to failure of Tower leads to failure of suspended deck.	5	5	5	3	1		Consequences of steel failure caused by corrosion could be disastrous, however considered very unlikely.	10 Y	1		YES	Inspection	- Dehumidification system - EMC System	Stainless steel, however this is not cost optimal.	10	6	(6)	6	RBI	2018	-	0	Periodic Inspection every 6 years	Periodic corrective/preventive maintenance (PIBM)			Corrosion is a consequence of a failing protection system. Time for damage tolerance is therefore set to 6 years, which is the same as the protection system.		Relative humidity inside girder.
1.2.1	Towers	-			Corrosion, external: Towers are subject to external corrosion from weather variations.	Loss of Y mm steel in B years leads to failure of Tower leads to failure of suspended deck.	5	5	5	3	1		Consequences of steel failure caused by corrosion could be disastrous, however considered very unlikely.	10 Y	1		YES	Inspection	- Coating system		10	6	(6)	6	RBI	2018	-	0	Periodic Inspection every 6 years	Periodic corrective/preventive maintenance (PIBM)			Corrosion is a consequence of a failing protection system. Time for damage tolerance is therefore set to 6 years, which is the same as the protection system.		Visual inspection and assessment of Coating Condition Indicator, CC.
1.2.1	Towers	-			Fatigue in welds: Towers are subject to fatigue from traffic, wind, etc..	X number of fatigue cycles leads to failure of towers which leads to failure of suspended deck.	5	5	5	3	3		Consequences of weld failure caused by fatigue could be disastrous, and could happen occasionally.	2 Y	1		YES	Inspection	- (SHMS), measuring loads on bridge (fatigue levels and cycles)		2	6	(2)	2	RBI	2018	-	0	Periodic Inspection every 2 years	Periodic corrective/preventive maintenance (PIBM)			Continuous monitoring should be installed, however this can only be carried out at selected spots.		Hot spots identified during design. Connection between crossbeams and tower legs.
1.2.1	Coating system on Towers	Protection of steel against corrosion.	380 µm zinc-rich Ethyl-silicate primer, Epoxy intermediate coating and acrylic top coat or likewise.	Total coating system giving protection of steel against corrosion.	Weather conditions and material durability causing degradation.	Failure of primer starts surface corrosion. Loss of X mm steel in A years in an accelerating rate. Cost of repair increases.	0	4	1	0	1		Economical consequences of failing coating system could be severe in terms of extra costs to sandblasting and preparing of surface.	10 Y	1		YES	Inspection	None	Stainless steel, however this is not cost optimal.	10	6	(6 or more)	6	RBI	2018	-	0	Periodic Inspection every 6 years	Periodic corrective/preventive maintenance (PIBM)				X amount of Coating system for spot repairs.	Adhesion and Cross-cut test.
1.2.1	Top coat on Towers	-	Acrylic top coat (integrated part of total coating system)	Renewable top coat giving mechanical protection, UV-protection, shine and colour to the coating system	Weather conditions and material durability causing degradation.	Loss of ability to renew topcoat. Cost of repair increases.	0	4	1	0	2		Economical consequences of failing coating system could be severe in terms of loss of ability to renew topcoat -> full coating system is necessary.	10 Y	1		YES	Inspection	None	Stainless steel, however this is not cost optimal.	10	6	(6)	6	RBI	2018	30	0	Perform periodic special inspection every 6 years according to the RBI plan. Principal inspection should be performed in year 2045, based on 20% of a lognormal distribution (27 years after appliance).	Topcoat needs to be maintained in year 2048 (30 years after appliance).		x		X amount of Coating system for spot repairs.	Visual inspection and assessment of Coating Condition Indicator, CC.
1.1.1	Tower foundations (reinforcement)	Supporting of towers.			Corrosion of reinforcement	Loss of Y number of reinforcement bars in B years leads to failure of tower foundations which leads to failure of tower that leads to failure of suspended deck.	5	5	5	3	2		Consequences of reinforcement failure caused by corrosion could be disastrous, however is considered unlikely.	10 Y	1		YES	Test probes established during the building of the bridge.		- Necessary preparations for future cathodic protection system	10	6	(6)	6	RBI	2018	-	0	Periodic Inspection every 6 years	Periodic corrective/preventive maintenance (PIBM)			Corrosion is a consequence of a failing protection system. Time for damage tolerance is therefore set to 6 years, which is the same as the protection system.		
1.1.1	Tower foundations (concrete)	-			Degradation of concrete	Degradation of concrete in B years leads to failure of tower which leads to failure of suspended deck.	5	5	5	3	2		Consequences of concrete failure could be disastrous, however is considered unlikely.	20 Y	1		NO	Possible hidden failure is handled by robustness in design.	None		20	6	(6)	6	RBI	2018	-	0	Periodic Inspection every 6 years	Periodic corrective/preventive maintenance (PIBM)					Cracks and concrete degradation in general.
1.1.1	Tower foundations (concrete)	-			Fatigue in bolts in tie-down: Bolts are subject to fatigue from traffic, wind, etc..	Y number of fatigue cycles, caused by loss of prestress in bolts, leads to reduced lifetime of bolts which leads to loss failure of tower in A years.	5	5	5	3	3		Consequences of bolts failure caused by fatigue could be disastrous, and could happen occasionally.	2 Y	1		YES	Inspection	Prestress of bolts		2	2	(2)	2	RBI	2018	-	0	Periodic Inspection every 2 years	Periodic corrective/preventive maintenance (PIBM)			It is assumed that prestress less than a predefined service threshold still have capacity for another 2 years and time damage tolerance is therefore set to 2 years.	bolts/nuts	Prestress in bolts are measured with ultrasonic equipment.
1.1.2	Anchor Blocks (concrete)	Anchoring main cable.			Corrosion of reinforcement	Loss of Y number of reinforcement bars in B years leads to failure of anchors blocks leads to failure of suspended deck.	5	5	5	3	2		Consequences of reinforcement failure caused by corrosion could be disastrous, however is considered unlikely.	10 Y	1		YES	Test probes established during the building of the bridge.	- water proofing	- Necessary preparations for future cathodic protection system	10	6	(6)	6	RBI	2018	-	0	Periodic Inspection every 6 years	Periodic corrective/preventive maintenance (PIBM)					
1.1.2	Anchor Blocks (concrete)	-			Degradation of concrete	Degradation of concrete in B years leads to failure of anchor blocks leads to failure of suspended deck.	5	5	5	3	2		Consequences of concrete failure could be disastrous, however is considered unlikely.	20 Y	1		NO	Possible hidden failure is handled by robustness in design.	- water proofing		20	6	(6)	6	RBI	2018	-	0	Periodic Inspection every 6 years	Periodic corrective/preventive maintenance (PIBM)					Cracks and concrete degradation in general.
1.1.2	Anchor Blocks	-			Ground water level drainage malfunction.	Faster degradation of concrete in B years leads to failure of anchor blocks leads to failure of suspended deck.	5	5	5	3	2		Consequences of drainage malfunction could be disastrous, however is considered unlikely.	4 Y	1		NO	Inspection should observe water ingress, otherwise hidden failure.	None	Detection of ground water level!	4	6	(1)	6	RCM	2018	-	0	Periodic Inspection every 6 years	Periodic corrective/preventive maintenance (PIBM)					Water ingress.
1.1.2	Membrane on anchor blocks	Protection of outer (horisontal) concrete surfaces against moist/water ingress and faster degradation.			Degradation during time.	Faster degradation of concrete in B years leads to failure of anchor blocks leads to failure of suspended deck.	5	5	5	3	2		Consequences of membrane failure could be disastrous, however is considered unlikely.	10 Y	1		NO	Inspection should observe water ingress, otherwise hidden failure.	None		10	6	(6)	6	RBI	2018	-	0	Periodic Inspection every 6 years	Periodic corrective/preventive maintenance (PIBM)					Water ingress.
1.2.2.2	Tower and splay saddles	Ensuring load transfer from main cables to towers and spreading of main cable (allowing it to be anchored)			Corrosion: Tower and splay saddles are subject to corrosion from weather variations.	Loss of Y mm steel in B years leads to failure of splay saddles leads to failure of suspended bridge.	5	5	5	3	1		Consequences of steel failure caused by corrosion could be disastrous, however considered very unlikely.	10 Y	1		NO	Hidden failure for some unavailable parts	None	Avoid hidden parts to the largest possible extent.	10	6	(6)	6	RBI	2018	-	0	Periodic Inspection every 6 years	Periodic corrective/preventive maintenance (PIBM)					
1.2.2.2	Tower and splay saddles	-			Fatigue in bolts: Bolts are subject to fatigue from traffic, wind, etc.	Y number of high stress fatigue cycles, caused by loss of prestress in bolts, leads to reduced lifetime of bolts which leads to failure of saddles leads to failure of suspended bridge.	5	5	5	3	3		Consequences of bolts failure caused by fatigue could be disastrous, and could happen occasionally.	2 Y	1		YES	Inspection	Prestress of bolts		2	2	(2)	2	RBI	2018	-	0	Periodic Inspection every 2 years	Periodic corrective/preventive maintenance (PIBM)				- Bolts/nuts	Prestress in bolts are measured with ultrasonic equipment.
1.3.1.3	Crash barriers	Preventing vehicles falling from the bridge.			Corrosion: Crash Barriers are subject to external corrosion from weather variations.	Loss of Y mm steel in B years leads to failure during impact from car which leads to increased casualties.	2	1	4	0	1		Consequences of fatalities are severe, however considered very unlikely.	10 Y	1		YES	Inspection	Galvanisation	Stainless steel, however this is not cost optimal.	10	0,003	(6 or more)	6	RBI	2018	-	0	Continuous Monitoring with inspection/evaluation every 6 years	Immediately plan or perform corrective/ periodic preventive maintenance (CBM)			Continuous monitoring means, in this case -> drive by every day to see if everything looks fine. 0,003 year = 1 day	- Bolts/nuts - Crash barrier segments all included.	Thickness of galvanisation

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Element number	Element name	Element description			Failure Mode (FM)	Failure Effect (E), Criticality (CA) and Vulnerability Analysis*	Consequence										Failure and detection analysis				Inspection and Maintenance Activity Analysis (IMAA)														
		Main function	Parts or composition	Part function	Causes of functional failure	Describe failure effect	Unavailability	Costs	Fatalities	Environmental damage	Likelihood of occurrence of max(consequence)	Criticality	Comments	Time for Failure Development** (Hours, Days, Weeks, Months, Quarters, Years)	Failure Development class	Vulnerability	Failure Detection Yes/No	Detection Method	Mitigation measures other than maintenance	Recommendations - Can failure be eliminated or managed in ways other than maintenance?	Time for Failure Development**, [ΔT_f] (Years)	Time for Damage Tolerance***, [ΔT_d] (Years)	Default Inspection Interval, based on criticality (RCM) or vulnerability (RBI) [Years]	Selected Inspection Interval, [ΔT_i] (Years)	RCM or RBI	Year for start up of operation period for element/system [year no.]	Mean Time Between Failures, MTBF [Years]	System age [years]	Recommended Inspection strategy*****	Recommended Maintenance strategy*****	Link to detailed RCM plan****	Link to detailed RBI plan****	Comments to inspection/ maintenance strategy	Spares part requirement in order to minimize repair time (if critical)	Key parameters to monitor
1.3.1.3	Galvanisation of crash Barriers	Protection of crash barriers against corrosion.	Galvanisation		Degradation of galvanisation.	Loss of galvanisation	1	2	1	0	2		There are no speakable consequences given that galvanisation is reestablished within few years. Costs of renewal would slightly increase.	10 Y	1		YES	Inspection	None	-	10	6	(6 or more)	6	RBI	2018	-	0	Periodic Inspection every 6 years	Periodic corrective/preventive maintenance (PIBM)				None	Thickness of galvanisation
1.3.1.2	Wind screens	Provide accessibility at high winds.			Corrosion: Wind screens are subject to external corrosion from weather variations.	Loss of Y mm steel in B years leads to failure during high wind speeds which leads to unintended bridge vibrations and closedown of bridge.	4	3	1	0	1		Consequences of loss of wind screens could cause very severe unavailability for bridge users, however this is considered very unlikely.	10 Y	1		YES	Inspection	Galvanisation	Stainless steel, however this is not cost optimal.	10	0,003	(6 or more)	6	RBI	2018	-	0	Continuous Monitoring with inspection/evaluation every 6 years	Immediately plan or perform corrective/ periodic preventive maintenance (CBM)			Continuous monitoring means, in this case -> drive by every day to see if everything looks fine. 0,003 year = 1 day	- Bolts/nuts - Wind screen segments all included.	Thickness of galvanisation
1.3.1.2	Galvanisation of wind screens	Protection of wind screens against corrosion.	115 µm galvanisation (hot-dipped)		Degradation of galvanisation.	Loss of galvanisation	0	1	1	0	3		There are no speakable consequences given that prot. system is reestablished within few years. Loss of galvanisation is assumed to attend occasionally.	10 Y	1		YES	Inspection	None		10	6	(6 or more)	6	RBI	2018	-	0	Periodic Inspection every 6 years	Periodic corrective/preventive maintenance (PIBM)				None	Thickness of galvanisation
1.3.2.1	Bearings	Support of road- and railway girder at terminal structure.			Wear and tear: Bearings are subject to wear and tear.	Sliding surfaces are worn out, resulting in costful damages to bearings. No actual failure is foreseen.	1	4	0	0	2		Lack of maintenance of sliding parts could have costful results. This is however considered unlikely.	4 Y	1		YES	Inspection	None		4	2	(6)	2	RBI	2018	-	0	Periodic Inspection every 2 years	Periodic corrective/preventive maintenance (PIBM)			Inspection interval is set to 2 years, which is the same as damage tolerance period.		Correct behaviour/movements. Thickness of sliding material
1.3.2.2	Roadway expansion joints	Allowing longitudinal movements of roadway girder at towers.	(see separate page for break-down of system)	(see separate page for break-down of system)	Wear and tear	Sealing strips are most vulnerable.	3	4	4	0	4		Lack of maintenance of sealing strips/lamellas could have costful and fatal consequences. This is considered very likely, based on the fast failure development.	1 Q	2		YES	Inspection	None	Monitoring of movements: - all distances between lamellas. - position of expansion joint.	0,25	0	(2)	0,25	RBI	2018	-	0	Continuous Monitoring with inspection/evaluation every 0,25 years	Immediately plan or perform corrective/ periodic preventive maintenance (CBM)	x		A full monitoring system for expansion joint would be adviseable, however it is assessed that quarterly inspections is sufficient.	- Sliding plates, springs, lamellas, etc.	Correct behaviour/movements. Dirt or water entering the girder. Wear and tear
1.3.2.2	Roadway expansion joints	Allowing longitudinal movements of roadway girder at towers.	(see separate page for break-down of system)	(see separate page for break-down of system)	Wear and tear	Sliding parts.	3	3	4	0	3		Loss of expansion joint elements could have very severe consequences. Failure development is considered to be years.	1 Y	1		YES	Inspection	None		1	0	(6)	1	RBI	2018	-	0	Continuous Monitoring with inspection/evaluation every 1 years	Immediately plan or perform corrective/ periodic preventive maintenance (CBM)				- All replaceable parts.	Unexpected tearing or cracks.
1.3.2.2	Railway expansion joints	Allowing longitudinal movements of railway girder at bridge ends.	(see separate page for break-down of system)	(see separate page for break-down of system)	Wear and tear	Sliding parts are most vulnerable.	4	4	5	0	3		Lack of maintenance of sliding parts could have costful and fatal consequences. This is could happen occasionally, based on the fast failure development.	2 Q	2		YES	Inspection	None	Full monitoring system - Movements - Sledge twisting - Temperature	0,5	0	(2)	0,5	RBI	2018	-	0	Continuous Monitoring with inspection/evaluation every 0,5 years	Immediately plan or perform corrective/ periodic preventive maintenance (CBM)	x			- Sliding plates, springs, lamellas, etc.	Correct behaviour/movements. Dirt or water entering the girder. Wear and tear
1.4.3.2	Drainage system	Ensuring drainage of surface water incl. removal of accidental oil and petrol.			Malfunction	Malfunction could cause car accidents.	1	1	4	1	3		A failure of the drainage system could have fatal consequences. This could happen occasionally.	12 H	6		YES	Inspection	System test		0,001	0	(1)	1	RCM	2018	-	0	Continuous Monitoring with inspection/evaluation every 1 years	Immediately plan or perform corrective/ periodic preventive maintenance (CBM)			Continuous monitoring means, in this case -> keep road clean daily/weekly and drive by whenever heavy rain appears and see if drainage system works.		
1.3.3.2	Railway track system	Ensuring railway traffic serviceablility.			Wear and tear	Failure could cause derailment.	4	3	5	0	1		Failure of railway track is disastrous, however considered very unlikely.	2 Y	1		YES	Inspection	None		2	0	(6)	2	RBI	2018	-	0	Continuous Monitoring with inspection/evaluation every 2 years	Immediately plan or perform corrective/ periodic preventive maintenance (CBM)			Continuous monitoring includes electronic track survaillance with monthly inspections.		
1.3.3.2	Railway track system	Ensuring railway traffic serviceablility.			Fatigue	Failure could cause derailment.	4	3	5	0	1		Failure of railway track is disastrous, however considered very unlikely.	2 Y	1		YES	Inspection	None		2	0	(6)	2	RBI	2018	-	0	Continuous Monitoring with inspection/evaluation every 2 years	Immediately plan or perform corrective/ periodic preventive maintenance (CBM)			Continuous monitoring includes electronic track survaillance with monthly inspections.		
1.3 1.4	Access facilities	(permanent inside and outside, tower gantries, main cable carriage, gantries for suspended deck, elevators)			Wear and tear		1	1	1	0	3		Access facilities could occasionally fail, however this has very little consequence.	6 Y	1		YES	Inspection	None		6	6	(6 or more)	6	RBI	2018	-	0	Periodic Inspection every 6 years	Periodic corrective/preventive maintenance (PIBM)					According to supplier info.

* The Criticality Analysis for the system/element is evaluated with the questions:
Question 1) What are the consequences for the bridge regarding unavailability, cost, fatalities and environmental damage given functional failure?
Question 2) What is the probability of the worst consequence happening, given the functional failure has occurred ?

** How long time does it take for the failure mode to evolve from "not detectable" to predefined failure limit (hours, days, weeks, months, quarters, years).

*** How long time can a predefined failure of the element/system be tolerated.

**** Blank cells indicate that no subsheet has yet been established.

***** May be superseed be suppliers information/recommendations

Messina Strait Bridge - Progetto Definitivo - RBI_Top_Coat_girders

RBI plan for top coat on girders

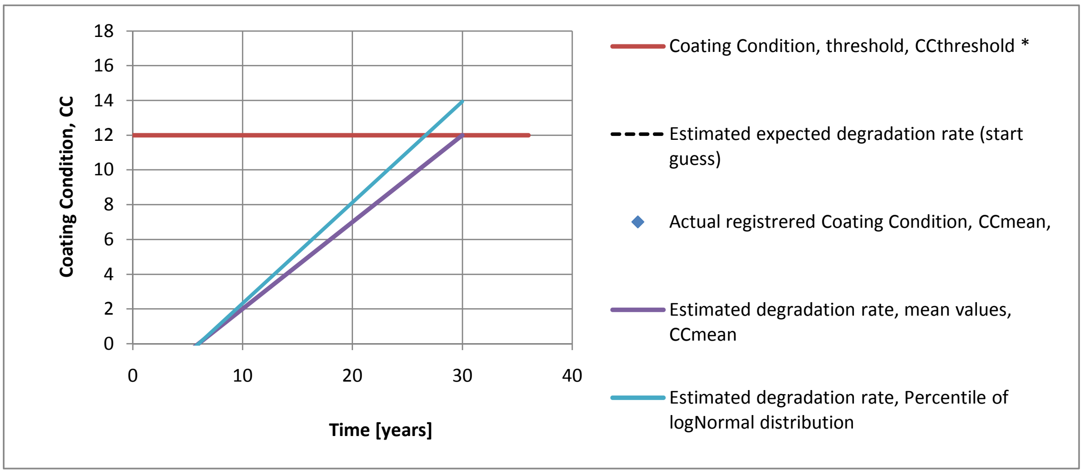
...to be elaborated into 1 sheet for each element (Towers, girders, hanger anchorage etc.)

Coating Condition, threshold, $CC_{threshold}$ *	12	
Periodic Inspect/Cont. monitoring:	1	(1= periodic inspection; 2= Continuous monitoring)
Vulnerability class (see FMECA sheet):	1	
Coefficient of variation, cov	20%	
Percentile of a lognormal distribution	20%	0,854

	Using mean values			
Time, t [years]	Actual registrered Coating Condition, CC_{mean},	Estimated time before reaching max. allowable Coating Condition, $CC_{threshold}$	Criticality based Special Inspection plan, (retrieving CC_{mean} values for selected areas)	Estimated Reliability Based Principal Inspection plan
0		30,0	X (R)	As-built (R)
1		29,0		
2		28,0		
3		27,0		
4		26,0		
5		25,0		
6		24,0	X (R)	Warranty (R)
7		23,0		
8		22,0		
9		21,0		
10		20,0		
11		19,0		
12		18,0	X (R)	
13		17,0		
14		16,0		
15		15,0		
16		14,0		
17		13,0		
18		12,0	X (R)	
19		11,0		
20		10,0		
21		9,0		
22		8,0		
23		7,0		
24		6,0	X (R)	
25		5,0		
26		4,0		
27		3,0		Reliability Based Inspection (N)
28		2,0		
29		1,0		
30		Maintain	X (R)	
31				
32				
33				
34				
35				
36			X (R)	

(R) = Recommended inspections

(N) = Necessary inspection according to calculated percentile of the distribution of a guessed lifetime of the coating.



Calculation of degradation rate after initiation phase:**

Linear trendline for Coating Condition: CC=a*t+b

	Start guess	Calculated trendlines	
	$CC_{expected(start\ guess)}$	CC_{mean}	$CC_{0.20}$
a =	0,5	0,5	0,6
b =	-3,0	-3,0	-3,5
R^2 =	-	-	-

Estimated service life of corrosion protection system before Coating condition threshold is reached:

Life time using mean values	**30,0 years**
Life time using percentile of the distribution	**26,7 years**

* Coating Condition is determined as:
classification according to ISO 4628-2, 4628-3, 4628-4, 4628-5 multiplied by degree of attack. See example of classification in separate appendix.

** The estimated degradation rate cannot be accurate until there are actual visual/detectable degradation. Degradation rate/slope is therefore not calculated until 10 % of the allowable severity class has been exceeded.

Failure Mode, Effects and Criticality Analysis (FMECA) and Inspection and Maintenance Activity Analysis (IMAA)

Dehumidification system

Current year **2018** (see sheet "FMECA_Basis")

Criticality matrix:

Likelihood of occurrence	Consequence of failure: Insignificant 0	Marginal 1	Serious 2	Severe 3	Very severe 4	Disastrous* 5
Very unlikely	Inconsiderable	Inconsiderable	Inconsiderable	Low	Low	High
Unlikely	Inconsiderable	Inconsiderable	Low	Medium	Medium	High
Occasional	Inconsiderable	Low	Medium	Medium	High	Very High
Likely	Inconsiderable	Low	Medium	High	Very High	Very High
Very likely	Inconsiderable	Medium	High	Very High	Very High	Very High

Vulnerability matrix:

Criticality	Time for failure development: Years	Quarters	Months	Weeks	Days	Hours
Inconsiderable	Very Robust	Very Robust	Very Robust	Very Robust	Very Robust	Very Robust
Low	Very Robust	Robust	Robust	Semi-Robust	Semi-Robust	Semi-Robust
Medium	Robust	Semi-Robust	Semi-Robust	Semi-Robust	Vulnerable	Vulnerable
High	Robust	Semi-Robust	Semi-Robust	Vulnerable	Vulnerable	Very vulnerable
Very High	Semi-Robust	Semi-Robust	Vulnerable	Vulnerable	Very vulnerable	Very vulnerable

Element number	Element name	Element description			Failure Mode (FM)	Failure Effect (E), Criticality (CA) and Vulnerability Analysis*											Failure and detection analysis			
		Main function	Parts or composition	Part function	Causes of functional failure	Describe failure effect	Consequence: Unavailability	Costs	Fatalities	Environmental damage	Likelihood of occurrence of max(consequence)	Criticality	Comments	Time for Failure Development** (Hours, Days, Weeks, Months, Quarters, Years)	Failure Development class	Vulnerability	Failure Detection Yes/No	Detection Method	Mitigation measures other than maintenance	Recommendations - Can failure be eliminated or managed in ways other than maintenance?
1.3.1.4	Dehumidification system - Main cables and saddles	Dehumidification system provides dehumidified air to the cables which protects against corrosion.	The Dehumidification system for main cables** is composed of:		Failure of dehumidification system								In general: Consequence numbers are set acc. to the system, in order to get the correct picture regarding failure of a subcomponent for the system as a whole.							
1.3.1.4 part 1 (see attached drawing)			Air filter with local pressure indicator and pressure switch, for outside air	Removes particles from outside air when entering dry air buffer.	Polluting particles causing clogged-up filter.	Eventually there will be a breakdown of the dehumidification system. Damp air comes into the the cable wrapping.	5	1	1	1	5		The component is vital for for the function of the dehumidification system.	1 Q	2		YES	Local panel and/or EMC	System test/calibration.	None
1.3.1.4 part 2	Dehumidification system - Main cables and saddles		Damper (with motor), for outside air	Regulates the intake of outside air into the dry air buffer.	Tear and wear	Complete or no damping of outside air leads to under pressure in the dry air buffer. No balance in system.	5	1	1	1	2		The component is vital for for the function of the dehumidification system.	1 D	5					
					Power breakdown		5	1	1	1	2		The component is vital for for the function of the dehumidification system.	1 D	5					
1.3.1.4 part 3			Temperature transmitter, for outside air	Reads and transmit outside air temperature to EMC system.	Lack of calibration	Misreading of system behaviour	3	1	1	1	2		The component is not immediately vital, however will become it after some time.	1 W	4		YES	Local panel and/or EMC	System test/calibration.	No
					Power breakdown		3	1	1	1	2		The component is not immediately vital, however will become it after some time.	1 W	4				-	-
1.3.1.4 part 4			Rel. humidity transmitter, for outside air	Reads and transmit rel. humidity of outside air to EMC system.	Lack of calibration	Misreading of system behaviour	3	1	1	1	2		The component is not immediately vital, however will become it after some time.	1 W	4		YES	Local panel and/or EMC	System test/calibration.	No
					Power breakdown		3	1	1	1	2		The component is not immediately vital, however will become it after some time.	1 W	4				-	-
1.3.1.4 part 5			Rel. humidity indicator (local), for outside air	Reads rel. humidity of ourtide air (local)	Lack of calibration	Misreading of system behaviour (locally)	3	1	1	1	2		The component is not immediately vital, however will become it after some time.	1 W	4		YES	Local panel and/or EMC	System test/calibration.	No
					Power breakdown		3	1	1	1	2		The component is not immediately vital, however will become it after some time.	1 W	4				-	-
1.3.1.4 part 6		Dehumidification Unit	Damper (with motor), for reactivation air	Regulates intake of reactivation air, i.e. outside air that through the dissicant rotor removes humidity.	Tear and wear	Malfunction of damper leads to malfunction of dehumidification system.	5	1	1	1	2		The component is vital for for the function of the dehumidification system.	1 H	6		YES	Local panel and/or EMC	System test.	Full back up unit - if cost optimal.
					Power breakdown		5	1	1	1	2		The component is vital for for the function of the dehumidification system.	1 H	6				-	
1.3.1.4 part 7			Air filter with local pressure indicator and pressure switch, for reactvation air	Removes particles from outside air when entering dry air buffer.	Polluting particles causing clogged-up filter.	Eventually there will be a breakdown of the dehumidification system.	5	1	1	1	5		The component is vital for for the function of the dehumidification system.	1 H	6		YES	Local panel and/or EMC	Spare parts ready.	
1.3.1.4 part 8			Heating element	Ensures that reactivation air is able to remove humidity in the desiccant rotor.	Tear and wear	No function of dehumidification system.	5	1	1	1	1		The component is vital for for the function of the dehumidification system.	1 H	6		YES	Local panel and/or EMC	System test.	
					Power breakdown		5	1	1	1	1		The component is vital for for the function of the dehumidification system.	1 H	6					
1.3.1.4 part 9			Desiccant rotor (both reactivation air and dry air buffer intake)	Dehumidification of air from the buffer.	Tear and wear	No function of dehumidification system.	5	1	1	1	1		The component is vital for for the function of the dehumidification system.	1 H	6		YES	Local panel and/or EMC	System test.	
					Power breakdown		5	1	1	1	1		The component is vital for for the function of the dehumidification system.	1 H	6					
1.3.1.4 part 10			Fan with pressure switch, for wet air	Ensure blow out of wet air from the desiccant rotor	Tear and wear	No function of dehumidification system.	5	1	1	1	1		The component is vital for for the function of the dehumidification system.	1 H	6		YES	Local panel and/or EMC	System test.	
					Power breakdown		5	1	1	1	1		The component is vital for for the function of the dehumidification system.	1 H	6					
1.3.1.4 part 11			Damper (with motor), for wet air	Regulates air.		No function of dehumidification system.	5	1	1	1	2		The component is vital for for the function of the dehumidification system.	1 H	6		YES	Local panel and/or EMC	System test.	
					Power breakdown		5	1	1	1	2		The component is vital for for the function of the dehumidification system.	1 H	6					

Element number	Inspection and Maintenance Activity Analysis (IMAA)														
	Time for Failure Development**, [ΔTf] (Years)	Time for Damage Tolerance***, [ΔTd] (Years)	Default Inspection Interval, based on criticality (RCM) or vulnerability (RBI) [Years]	Selected Inspection Interval, [ΔT] (Years)	RCM or RBI	Year for start up of operation period for element/system [year no.]	Mean Time Between Failures, MTBF [Years]	System age [years]	Recommended Inspection strategy*****	Recommended Maintenance strategy*****	Link to detailed RCM plan****	Link to detailed RBI plan****	Comments to inspection/ maintenance strategy	Spares part requirement in order to minimize repair time (if critical)	Key parameters to monitor
1.3.1.4													In general: Time for damage tolerance is set to 0,167 year = 2 months because corrosion is a very slow process, however dehumidification should be aimed at running at all time if possible.		
1.3.1.4 part 1 (see attached drawing)	0,25	0,1667	(0,5)	**0,5**	**RCM**	2018	1	0	Continuous Monitoring with inspection/evaluation every 0,5 year	Probability of failure = 0,025>=0,01 => Immediately plan or perform periodic preventive maintenance	x		Air filter should be changed every 6 months. Based on low cost and high criticality.		
1.3.1.4 part 2	0,003	0,1667	(1)	**1**	**RCM**	2018	25	0	Continuous Monitoring with inspection/evaluation every 1 year	Periodic corrective/preventive maintenance (Expected lifetime of component is 19 years, based on 5% of a normal distribution)	x				
	0,003	0,167	(1)	**1**	**RCM**	2018		0	-	-					
1.3.1.4 part 3	0,019	0,167	(2)	**2**	**RCM**	2018	25	0	Continuous Monitoring with inspection/evaluation every 2 year	Periodic corrective/preventive maintenance (Expected lifetime of component is 21 years, based on 10% of a normal distribution)	x			Spare parts whole unit.	Failure yes/no feedback to EMC
	0,019	0,167	(2)	**2**	**RCM**	2018		0	-	-				-	-
1.3.1.4 part 4	0,019	0,167	(2)	**2**	**RCM**	2018	25	0	Continuous Monitoring with inspection/evaluation every 2 year	Periodic corrective/preventive maintenance (Expected lifetime of component is 21 years, based on 10% of a normal distribution)	x			Spare parts whole unit.	Failure yes/no feedback to EMC
	0,019	0,167	(2)	**2**	**RCM**	2018		0	-	-				-	-
1.3.1.4 part 5	0,019	0,167	(2)	**2**	**RCM**	2018	25	0	Continuous Monitoring with inspection/evaluation every 2 year	Periodic corrective/preventive maintenance (Expected lifetime of component is 21 years, based on 10% of a normal distribution)	x			Spare parts whole unit.	Failure yes/no feedback to EMC
	0,019	0,167	(2)	**2**	**RCM**	2018		0	-	-				-	-
1.3.1.4 part 6	1E-04	0,1667	(1)	**1**	**RCM**	2018	25	0	Continuous Monitoring with inspection/evaluation every 1 year	Periodic corrective/preventive maintenance (Expected lifetime of component is 19 years, based on 5% of a normal distribution)	x		Maintenance strategy is currently linked to item 1.3.1.4 part 2.	Spare parts whole unit.	Degradation of damper and/or EMC readings of rel. humidity
	1E-04	0,1667	(1)	**1**	**RCM**	2018		0	-	-				-	-
1.3.1.4 part 7	1E-04	0,1667	(0,5)	**0,5**	**RCM**	2018	1	0	Continuous Monitoring with inspection/evaluation every 0,5 year	Probability of failure = 0,025>=0,01 => Immediately plan or perform periodic preventive maintenance	x		Maintenance strategy is currently linked to item 1.3.1.4 part 1.	Filters (low costs)	Degradation of filter and/or EMC readings of rel. humidity and pressure
1.3.1.4 part 8	1E-04	0,1667	(1)	**1**	**RCM**	2018	35	0	Continuous Monitoring with inspection/evaluation every 1 year	Periodic corrective/preventive maintenance (Expected lifetime of component is 21 years, based on 10% of a normal distribution)				None	Failure yes/no feedback to EMC
	1E-04	0,1667	(1)	**1**	**RCM**	2018		0	-	-					
1.3.1.4 part 9	1E-04	0,1667	(1)	**1**	**RCM**	2018	35	0	Continuous Monitoring with inspection/evaluation every 1 year	Periodic corrective/preventive maintenance (Expected lifetime of component is 27 years, based on 5% of a normal distribution)	x			None	Failure yes/no feedback to EMC
	1E-04	0,1667	(1)	**1**	**RCM**	2018		0	-	-					
1.3.1.4 part 10	1E-04	0,1667	(1)	**1**	**RCM**	2018	35	0	Continuous Monitoring with inspection/evaluation every 1 year	Periodic corrective/preventive maintenance (Expected lifetime of component is 27 years, based on 5% of a normal distribution)	x			None	Failure yes/no feedback to EMC
	1E-04	0,1667	(1)	**1**	**RCM**	2018		0	-	-					
1.3.1.4 part 11	1E-04	0,1667	(1)	**1**	**RCM**	2018	25	0	Continuous Monitoring with inspection/evaluation every 1 year	Periodic corrective/preventive maintenance (Expected lifetime of component is 19 years, based on 5% of a normal distribution)	x		Maintenance strategy is currently linked to item 1.3.1.4 part 2.	Spare parts whole unit.	Degradation of damper and/or EMC readings of rel. humidity
	1E-04	0,1667	(1)	**1**	**RCM**	2018		0	-	-					

Messina Strait Bridge - Progetto Definitivo - FMECA_Dehumid_system

		Main function	Parts or composition	Part function	Causes of functional failure	Describe failure effect	Consequence						Comments	Time for Failure Development** (Hours, Days, Weeks, Months, Quarters, Years)	Failure Development class	Vulnerability	Failure Detection Yes/No	Detection Method	Mitigation measures other than maintenance	Recommendations - Can failure be eliminated or managed in ways other than maintenance?	Time for Failure Development**, $[\Delta T_f]$ (Years)	Time for Damage Tolerance***, $[\Delta T_d]$ (Years)	Default Inspection Interval, based on criticality (RCM) or vulnerabaility (RBI) [Years]	Selected Inspection Interval, $[\Delta T_i]$ (Years)	RCM or RBI	Year for start up of operation period for element/system [year no.]	Mean Time Between Failures, MTBF [Years]	System age [years]	Recommended Inspection strategy*****	Recommended Maintenance strategy*****	Link to detailed RCM plan****	Link to detailed RBI plan****	Comments to inspection/ maintenance strategy	Spares part requirement in order to minimize repair time (if critical)	Key parameters to monitor
							Unavailability	Costs	Fatalities	Environmental damage	Likelihood of occurrence of max(consequence)	Criticality																							
1.3.1.4 part 12			Damper (with motor), dry air buffer	Regulates intake of air from buffer to the dissicant rotor for dehumidification	Tear and wear	No function of dehumidification system.	5	1	1	1	2		The component is vital for for the function of the dehumidification system.	1 H	6		YES	Local panel and/or EMC	System test.		1E-04	0,1667	(1)	1	RCM	2018	25	0	Continuous Monitoring with inspection/evaluation every 1 year	Periodic corrective/preventive maintenance (Expected lifetime of component is 19 years, based on 5% of a normal distribution)	x		Maintenance strategy is currently linked to item 1.3.1.4 part 2.	Spare parts whole unit.	Degradation of damper and/or EMC readings of rel. humidity
					Power breakdown		5	1	1	1	2		The component is vital for for the function of the dehumidification system.	1 H	6						1E-04	0,1667	(1)	1	RCM	2018		0	-	-					
1.3.1.4 part 13			Air filter with local pressure indicator and pressure switch, for dry air buffer	Removes particles from buffer air when entering the desiccant rotor	Polluting particles causing clogged-up filter.	Eventually there will be a breakdown of the dehumidification system.	5	1	1	1	5		The component is vital for for the function of the dehumidification system.	1 Q	2		YES	Local panel and/or EMC	Spare parts ready.		0,25	0,1667	(0,5)	0,5	RCM	2018	1	0	Continuous Monitoring with inspection/evaluation every 0,5 year	Probability of failure = 0,025>=0,01 => Immediately plan or perform periodic preventive maintenance	X		Maintenance strategy is currently linked to item 1.3.1.4 part 1.	Filters (low costs)	Degradation of filter and/or EMC readings of rel. humidity and pressure
1.3.1.4 part 14			Fan with pressure switch, for dry air	Ensure blow out of dehumidified air from the desiccant rotor to the dry air buffer	Tear and wear	No function of dehumidification system.	5	1	1	1	1		The component is vital for for the function of the dehumidification system.	1 H	6		YES	Local panel and/or EMC	System test.		1E-04	0,1667	(1)	1	RCM	2018	35	0	Continuous Monitoring with inspection/evaluation every 1 year	Periodic corrective/preventive maintenance (Expected lifetime of component is 27 years, based on 5% of a normal distribution)	x		Maintenance strategy is currently linked to item 1.3.1.4 part 10.	None	Failure yes/no feedback to EMC
					Power breakdown		5	1	1	1	1		The component is vital for for the function of the dehumidification system.	1 H	6						1E-04	0,1667	(1)	1	RCM	2018		0	-	-					
1.3.1.4 part 15			Rel. humidity transmitter, dry air buffer	Reads and transmit rel. humidity of dry air buffer to EMC system	Tear and wear	No function of dehumidification system.	5	1	1	1	2		The component is vital for for the function of the dehumidification system.	1 W	4		YES	Local panel and/or EMC	System test/calibration.	No	0,019	0,1667	(1)	1	RCM	2018	25	0	Continuous Monitoring with inspection/evaluation every 1 year	Periodic corrective/preventive maintenance (Expected lifetime of component is 21 years, based on 10% of a normal distribution)	x		Maintenance strategy is currently linked to item 1.3.1.4 part 3.	Spare parts whole unit.	Failure yes/no feedback to EMC
					Power breakdown		5	1	1	1	2		The component is vital for for the function of the dehumidification system.	1 W	4						0,019	0,1667	(1)	1	RCM	2018		0	-	-					
1.3.1.4 part 16			Temperature transmitter, dry air buffer	Reads and transmit temperature of dry air buffer to EMC system.	Tear and wear	No function of dehumidification system.	5	1	1	1	2		The component is vital for for the function of the dehumidification system.	1 W	4		YES	Local panel and/or EMC	System test/calibration.	No	0,019	0,1667	(1)	1	RCM	2018	25	0	Continuous Monitoring with inspection/evaluation every 1 year	Periodic corrective/preventive maintenance (Expected lifetime of component is 21 years, based on 10% of a normal distribution)	x		Maintenance strategy is currently linked to item 1.3.1.4 part 3.	Spare parts whole unit.	Failure yes/no feedback to EMC
					Power breakdown		5	1	1	1	2		The component is vital for for the function of the dehumidification system.	1 W	4						0,019	0,1667	(1)	1	RCM	2018		0	-	-					
1.3.1.4 part 17			Air filter with local pressure indicator and pressure switch, for dry air supply to saddles and cables	Removes particles from buffer air when entering the main cables	Polluting particles causing clogged-up filter.	Eventually there will be a breakdown of the dehumidification system.	5	1	1	1	5		The component is vital for for the function of the dehumidification system.	1 Q	2		YES	Local panel and/or EMC	Spare parts ready.	None	0,25	0,1667	(0,5)	0,5	RCM	2018	1	0	Continuous Monitoring with inspection/evaluation every 0,5 year	Probability of failure = 0,025>=0,01 => Immediately plan or perform periodic preventive maintenance	x		Maintenance strategy is currently linked to item 1.3.1.4 part 1.	Filters (low costs)	Degradation of filter and/or EMC readings of rel. humidity and pressure
1.3.1.4 part 18			Fan with pressure switch, dry air to saddles and cables	Ensure blow out of dehumidified air from the dry air buffer to the main cables	Tear and wear (incl. particles in the system)	No function of dehumidification system.	5	1	1	1	1		The component is vital for for the function of the dehumidification system.	1 H	6		YES	Local panel and/or EMC	System test.	None	1E-04	0,1667	(1)	0,5	RCM	2018	35	0	Continuous Monitoring with inspection/evaluation every 0,5 year	Periodic corrective/preventive maintenance (Expected lifetime of component is 27 years, based on 5% of a normal distribution)	x		Maintenance strategy is currently linked to item 1.3.1.4 part 10.	None	Failure yes/no feedback to EMC
					Power breakdown		5	1	1	1	1		The component is vital for for the function of the dehumidification system.	1 H	6						1E-04	0,1667	(1)	0,5	RCM	2018		0	-	-					
1.3.1.4 part 19			Duct system	Transport of air in a close circuit	Corrosion	No function of dehumidification system.	3	1	1	1	1		The component is not immediately vital, however will become it after some time.	4 Y	1		NO	None	EMC survaillance graphs are checked by expert once a year and visual inspection every X years	None	4	0,1667	(6)	6	RCM	2018	50	0	Periodic Inspection every 6 year	Periodic corrective/preventive maintenance (PIBM)			Exception form the rule!! Although the damage tolerance period is lower than the inspection interval, the duct system should not be monitored. Periodic inspection would be sufficient.	None	None
1.3.1.4 part 20			Damper (no motor), air exhaust from cables	Regulates exhaust air from main cables at central node.	Tear and wear	Less important - damper position is set manually when system is implemented. Later on it has no influence to the system.	1	1	1	1	2		The component is not vital, as it is set manually if it fails it has no influence on the system.	4 Y	1		NO	None	EMC survaillance graphs are checked by expert once a year and visual inspection every X years	None	4	0,1667	(6 or more)	6	RCM	2018	25	0	Continuous Monitoring with inspection/evaluation every 6 year	Periodic corrective/preventive maintenance (Expected lifetime of component is 19 years, based on 5% of a normal distribution)	x		Maintenance strategy is currently linked to item 1.3.1.4 part 2.	None	None
1.3.1.4 part 21			5 nos. Temperature transmitters along each cable	Reads and transmit temperature of air in main cables	Tear and wear	Misreading of system behaviour	4	1	1	1	2		The component is not immediately vital, however will become it after some time.	1 W	4		YES	EMC	System test/calibration.	No	0,019	0,1667	(2)	2	RCM	2018	25	0	Continuous Monitoring with inspection/evaluation every 2 year	Periodic corrective/preventive maintenance (Expected lifetime of component is 21 years, based on 10% of a normal distribution)	x		Maintenance strategy is currently linked to item 1.3.1.4 part 3.	Spare parts all units.	Failure yes/no feedback to EMC
1.3.1.4 part 22			5 nos. Pressure transmitters along each cable	Reads and transmit pressure of air in main cables	Tear and wear	Misreading of system behaviour	4	1	1	1	2		The component is not immediately vital, however will become it after some time.	1 W	4		YES	EMC	System test/calibration.	No	0,019	0,1667	(2)	2	RCM	2018	25	0	Continuous Monitoring with inspection/evaluation every 2 year	Periodic corrective/preventive maintenance (Expected lifetime of component is 21 years, based on 10% of a normal distribution)	x		Maintenance strategy is currently linked to item 1.3.1.4 part 3.	Spare parts all units.	Failure yes/no feedback to EMC
1.3.1.4 part 23			4 nos. Rel. humidity transmitters along each cable	Reads and transmit rel. humidity of air in main cables	Tear and wear	Misreading of system behaviour	4	1	1	1	2		The component is not immediately vital, however will become it after some time.	1 W	4		YES	EMC	System test/calibration.	No	0,019	0,1667	(2)	2	RCM	2018	25	0	Continuous Monitoring with inspection/evaluation every 2 year	Periodic corrective/preventive maintenance (Expected lifetime of component is 21 years, based on 10% of a normal distribution)	x		Maintenance strategy is currently linked to item 1.3.1.4 part 3.	Spare parts all units.	Failure yes/no feedback to EMC

* The Criticality Analysis for the system/element is evaluated with the questions:
Question 1) What are the consequences for the bridge regarding unavailability, cost, fatalities and environmental damage given functional failure?
Question 2) What is the probability of the worst consequence happening, given the functional failure has occurred ?

** How long time does it take for the failure mode to evolve from "not detectable" to predefined failure limit (hours, days, weeks, months, quarters, years).

*** How long time can a predefined failure of the element/system be tolerated.

**** Blank cells indicate that no subsheet has yet been established.

***** May be superseed be suppliers information/recommendations

Reliability Centred Maintenance - Maintenance strategy estimation
Air filter

NB! Input parameters from FMECA sheet

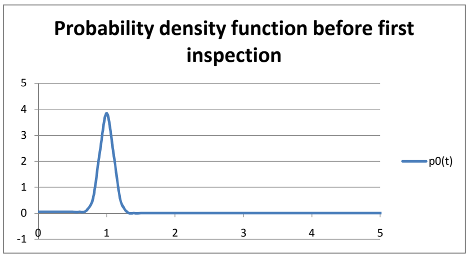
Start up of operation period for system	$Y_{initial}$	2018	
Current year		2018	(Should be automatically calculated =YEAR(NOW()))
Age of system (inspection time)	t1	0	year
MTBF	μ	1	years
Inspection interval	ΔT_I	0,5	years
Time for failure development	ΔT_f	0,25	years
Time for damage tolerance	ΔT_d	0,166667	years

RCM or RBI component:	**RCM**	
Periodic Inspection or Continous Monitoring:	**Continuous Monitoring**	2
Inspection criticality (RCM) or vulnerability (RBI):	**4**	
Threshold value:	**0,01**	
Probability of failure between first and second inspection:	**0,025**	
Periodic Preventative Maintenance or Periodic Evaluation:	**Probability of failure = 0,025>=0,01 => Immediately plan or perform periodic preventive maintenance**	
	0,1	

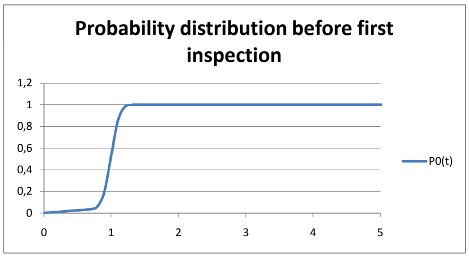
Probability input values:
Input values need to be updated based on suppliers information/best guess of MTBF and Std. dev. Sensitivity analysis are always relevant.

Start	b	0		
Decay parameter	d	0		
Uniform	a	0,05		
Period	tu	1	years	defalut = MTBF
Std. dev.	σ	0,1	years	default = 0,1*MTBF
Integration interval	ii	0,1	years	

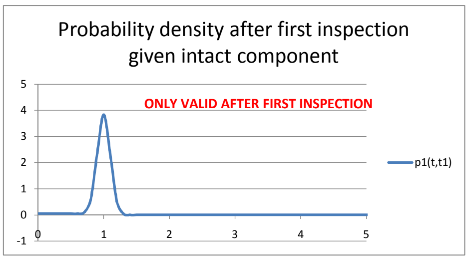
Probability density function before first inspection: p0(t)



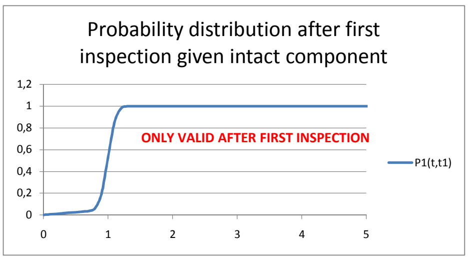
Probability distribution before first inspection: P0(t)



Probability density after first inspection given intact component: p1(t,t1)



Probability distribution after first inspection given intact component: P1(t,t1)



time, t	p0(t)	P0(t)	P0(t1)	p1(t,t1)	P1(t,t1)	Mean value p1(t,t1) and p1(t+1,t1) - starting at t=t1+ii, ending at t=t1+ΔT_I
0	0,05	7,23886E-24	7,23886E-24	0,05	0	
0,1	0,05	0,005	7,23886E-24	0,05	0,00499995	0,05
0,2	0,05	0,01	7,23886E-24	0,05	0,0099999	0,05
0,3	0,05	0,015	7,23886E-24	0,05	0,01499985	0,05
0,4	0,050000058	0,020000001	7,23886E-24	0,050000058	0,019999801	0,050000029
0,5	0,050014124	0,025000272	7,23886E-24	0,050014124	0,025000022	0,050007091
0,6	0,051271387	0,030030088	7,23886E-24	0,051271387	0,030029787	0
0,7	0,09210256	0,036282403	7,23886E-24	0,09210256	0,03628204	0
0,8	0,562914182	0,061612625	7,23886E-24	0,562914182	0,061612009	0
0,9	2,348721883	0,195722491	7,23886E-24	2,348721883	0,195720534	0
1	3,839951664	0,525	7,23886E-24	3,839951663	0,52499475	0
1,1	2,298721883	0,849277509	7,23886E-24	2,298721883	0,849269016	0
1,2	0,512914182	0,978387375	7,23886E-24	0,512914182	0,978377591	0
1,3	0,04210256	0,998717597	7,23886E-24	0,04210256	0,99870761	0
1,4	0,001271387	0,999969912	7,23886E-24	0,001271387	0,999959913	0
1,5	1,41238E-05	0,999999728	7,23886E-24	1,41238E-05	0,999989728	0
1,6	5,77209E-08	0,999999999	7,23886E-24	5,77209E-08	0,999989999	0
1,7	0,000000001	1	7,23886E-24	1E-09	0,99999	0
1,8	0,000000001	1	7,23886E-24	1E-09	0,99999	0
1,9	0,000000001	1	7,23886E-24	1E-09	0,99999	0
2	0,000000001	1	7,23886E-24	1E-09	0,99999	0
2,1	0,000000001	1	7,23886E-24	1E-09	0,99999	0
2,2	0,000000001	1	7,23886E-24	1E-09	0,99999	0
2,3	0,000000001	1	7,23886E-24	1E-09	0,99999	0
2,4	0,000000001	1	7,23886E-24	1E-09	0,99999	0
2,5	0,000000001	1	7,23886E-24	1E-09	0,99999	0
2,6	0,000000001	1	7,23886E-24	1E-09	0,99999	0
2,7	0,000000001	1	7,23886E-24	1E-09	0,99999	0
2,8	0,000000001	1	7,23886E-24	1E-09	0,99999	0
2,9	0,000000001	1	7,23886E-24	1E-09	0,99999	0
3	0,000000001	1	7,23886E-24	1E-09	0,99999	0
3,1	0,000000001	1	7,23886E-24	1E-09	0,99999	0
3,2	0,000000001	1	7,23886E-24	1E-09	0,99999	0
3,3	0,000000001	1	7,23886E-24	1E-09	0,99999	0
3,4	0,000000001	1	7,23886E-24	1E-09	0,99999	0
3,5	0,000000001	1	7,23886E-24	1E-09	0,99999	0
3,6	0,000000001	1	7,23886E-24	1E-09	0,99999	0
3,7	0,000000001	1	7,23886E-24	1E-09	0,99999	0
3,8	0,000000001	1	7,23886E-24	1E-09	0,99999	0
3,9	0,000000001	1	7,23886E-24	1E-09	0,99999	0
4	0,000000001	1	7,23886E-24	1E-09	0,99999	0
4,1	0,000000001	1	7,23886E-24	1E-09	0,99999	0
4,2	0,000000001	1	7,23886E-24	1E-09	0,99999	0
4,3	0,000000001	1	7,23886E-24	1E-09	0,99999	0
4,4	0,000000001	1	7,23886E-24	1E-09	0,99999	0
4,5	0,000000001	1	7,23886E-24	1E-09	0,99999	0
4,6	0,000000001	1	7,23886E-24	1E-09	0,99999	0
4,7	0,000000001	1	7,23886E-24	1E-09	0,99999	0
4,8	0,000000001	1	7,23886E-24	1E-09	0,99999	0
4,9	0,000000001	1	7,23886E-24	1E-09	0,99999	0
5	0,000000001	1	7,23886E-24	1E-09	0,99999	0
5,1	0,000000001	1	7,23886E-24	1E-09	0,99999	0
5,2	0,000000001	1	7,23886E-24	1E-09	0,99999	0
5,3	0,000000001	1	7,23886E-24	1E-09	0,99999	0
5,4	0,000000001	1	7,23886E-24	1E-09	0,99999	0
5,5	0,000000001	1	7,23886E-24	1E-09	0,99999	0
5,6	0,000000001	1	7,23886E-24	1E-09	0,99999	0
5,7	0,000000001	1	7,23886E-24	1E-09	0,99999	0
5,8	0,000000001	1	7,23886E-24	1E-09	0,99999	0
5,9	0,000000001	1	7,23886E-24	1E-09	0,99999	0
6	0,000000001	1	7,23886E-24	1E-09	0,99999	0
6,1	0,000000001	1	7,23886E-24	1E-09	0,99999	0
6,2	0,000000001	1	7,23886E-24	1E-09	0,99999	0
6,3	0,000000001	1	7,23886E-24	1E-09	0,99999	0
6,4	0,000000001	1	7,23886E-24	1E-09	0,99999	0
6,5	0,000000001	1	7,23886E-24	1E-09	0,99999	0
6,6	0,000000001	1	7,23886E-24	1E-09	0,99999	0
6,7	0,000000001	1	7,23886E-24	1E-09	0,99999	0
6,8	0,000000001	1	7,23886E-24	1E-09	0,99999	0
6,9	0,000000001	1	7,23886E-24	1E-09	0,99999	0
7	0,000000001	1	7,23886E-24	1E-09	0,99999	0
7,1	0,000000001	1	7,23886E-24	1E-09	0,99999	0
7,2	0,000000001	1	7,23886E-24	1E-09	0,99999	0
7,3	0,000000001	1	7,23886E-24	1E-09	0,99999	0
7,4	0,000000001	1	7,23886E-24	1E-09	0,99999	0
7,5	0,000000001	1	7,23886E-24	1E-09	0,99999	0
7,6	0,000000001	1	7,23886E-24	1E-09	0,99999	0
7,7	0,000000001	1	7,23886E-24	1E-09	0,99999	0
7,8	0,000000001	1	7,23886E-24	1E-09	0,99999	0
7,9	0,000000001	1	7,23886E-24	1E-09	0,99999	0

Appendix D: Inspection Programmes

STRUCTURAL STEELWORK INSPECTIONS
6 YEAR CYCLE
RESOURCE ESTIMATION

Routine Superficial - 3 months until first PI		(blue)
Routine General - 2 year cycle		(orange)
Principal Inspection - 6 year cycle		(yellow)
Special Inspections - assume Avge 1 man per month.		(green)
Special Inspections derived from RBI		(light blue)

			Year 1											
Main Cable	West side				1			1						1
External	East side										8			
Main Cable	West side													
Internal	East side										4			
Tower Sicily	Internal								6					
	External							1						
Tower Calabria	Internal													
	External													
Deck Boxes	Internal - GI and PI spread over 6 yr cycle.				5	4								
Deck Boxes	External - GI and PI spread over 6 yr cycle.		5	4										
Deck Boxes	Special areas - GI and PI spread over 6 yr cycle.						4	3						
Special Inspect	Structural - allow 1 man week per month Avge						3			3		3		3
	i.e. allow average of 3 man weeks per quarter													
Special Inspect	Derived from Reliability Based Inspection analysis													
	Allow 4 man weeks in year 6.for paint													
		Avge												
	Man weeks per month Inspectors	6	5	4	6	4	7	5	6	3	12	3	0	4

		Year 2											
Main Cable	West side			1			1			8			1
External	East side												
Main Cable	West side									4			
Internal	East side												
Tower Sicily	Internal												
	External												
Tower Calabria	Internal							6					
	External						1						
Deck Boxes	Internal - GI and PI spread over 6 yr cycle.			5	4								
Deck Boxes	External - GI and PI spread over 6 yr cycle.	5	4										
Deck Boxes	Special areas - GI and PI spread over 6 yr cycle.					4	3						
Special Inspect	Structural - allow 1 man week per month Avge					3			3		3		3
	i.e. allow average of 3 man weeks per quarter												
Special Inspect	Derived from Reliability Based Inspection analysis												
	Allow 4 man weeks in year 6.for paint												
	Man weeks per month Inspectors	5	4	6	4	7	5	6	3	12	3	0	4

		Year 3											
Main Cable	West side			1			1						
External	East side									12	12	4	
Main Cable	West side												
Internal	East side									4			
Tower Sicily	Internal							6	6				
	External						12						
Tower Calabria	Internal												
	External												
Deck Boxes	Internal - GI and PI spread over 6 yr cycle.			5	4								
Deck Boxes	External - GI and PI spread over 6 yr cycle.	5	4										
Deck Boxes	Special areas - GI and PI spread over 6 yr cycle.					4	3						
Special Inspect	Structural - allow 1 man week per month Avge					3						3	3
	i.e. allow average of 3 man weeks per quarter												
Special Inspect	Derived from Reliability Based Inspection analysis												
	Allow 4 man weeks in year 6.for paint												
	Man weeks per month Inspectors	5	4	6	4	7	16	6	6	16	12	7	3

		Year 4											
Main Cable	West side			1						8			
External	East side												
Main Cable	West side									4			
Internal	East side												
Tower Sicily	Internal												
	External												
Tower Calabria	Internal							6					
	External						1						
Deck Boxes	Internal - GI and PI spread over 6 yr cycle.			5	4								
Deck Boxes	External - GI and PI spread over 6 yr cycle.	5	4										
Deck Boxes	Special areas - GI and PI spread over 6 yr cycle.					4	3						
Special Inspect	Structural - allow 1 man week per month Avge					3			3		3	3	3
	i.e. allow average of 3 man weeks per quarter												
Special Inspect	Derived from Reliability Based Inspection analysis												
	Allow 4 man weeks in year 6.for paint												
	Man weeks per month Inspectors	5	4	6	4	7	4	6	3	12	3	3	3

		Year 5											
Main Cable	West side			1									
External	East side									8			
Main Cable	West side												
Internal	East side									4			
Tower Sicily	Internal							6					
	External						1						
Tower Calabria	Internal												
	External												
Deck Boxes	Internal - GI and PI spread over 6 yr cycle.			5	4								
Deck Boxes	External - GI and PI spread over 6 yr cycle.	5	4										
Deck Boxes	Special areas - GI and PI spread over 6 yr cycle.					4	3						
Special Inspect	Structural - allow 1 man week per month Avge					3			3		3	3	3
	i.e. allow average of 3 man weeks per quarter												
Special Inspect	Derived from Reliability Based Inspection analysis												
	Allow 4 man weeks in year 6.for paint												
	Man weeks per month Inspectors	5	4	6	4	7	4	6	3	12	3	3	3

		Year 6											
Main Cable	West side			1						12	12	4	
External	East side												
Main Cable	West side									4			
Internal	East side												
Tower Sicily	Internal												
	External												
Tower Calabria	Internal							6	6				
	External						12						
Deck Boxes	Internal - GI and PI spread over 6 yr cycle.			5	4								
Deck Boxes	External - GI and PI spread over 6 yr cycle.	5	4										
Deck Boxes	Special areas - GI and PI spread over 6 yr cycle.					4	3						
Special Inspect	Structural - allow 1 man week per month Avge					3						3	3
	i.e. allow average of 3 man weeks per quarter												
Special Inspect	Derived from Reliability Based Inspection analysis							2	2				
	Allow 4 man weeks in year 6.for paint												
	Man weeks per month Inspectors	5	4	6	4	7	15	8	8	16	12	7	3

STRUCTURAL STEELWORK INSPECTIONS						
6 YEAR CYCLE					Assume 4 days inspecting plus one writing per week.	
RESOURCE ESTIMATION					Assume 40 effective working weeks per year per inspector.	
					Inspection times include for inspection of fixed access stairs, ladders and platforms.	
					Internal Steel surfaces are painted.	
Main Cable	West side and	Routine Superficial - 3 months		2 men 2 days for both sides		
External	East side	Routine General - 2 years		4 men for 2 weeks for one side	say 166 clamps on one side with 2 men doing 12 perday. 4 man gang take say 7 days.	
		Principal Inspection - 6 years		4 men for 7 weeks	4 men for 6 weeks for one side plus 1 week for tower top saddles etc.	
Main Cable	West Side and	Routine General - 2 years		4 men for 1 week for one side		
Internal	East Side	Principal Inspection - 6 years		4 men for 1 week for one side		
Tower Sicily	Internal	Routine General - 2 years		2 men 3 weeks	20 sections per leg, each c 20m - 1 man 2 section per day plus 1 manday per c/b.	10+10+3 man days = say 6 man weeks
		Principal Inspection - 6 years		2 men 6 weeks	Assume PI takes twice time.	
	External	Routine General - 2 years		2 Men 1/2 week		
		Principal Inspection - 6 years		4 men 3 weeks	Allow 1 gang week per leg plus 1 gang week for three crossbeams.	
Tower Calabria	Internal	Routine General - 2 years		2 men 3 weeks	20 sections per leg, each c 20m - 1 man 2 section per day plus 1 manday per c/b.	10+10+3 man days = say 6 man weeks
		Principal Inspection - 6 years		2 men 6 weeks	Assume PI takes twice time.	
	External	Routine General - 2 years		2 Men 1/2 week		
		Principal Inspection - 6 years		4 men 3 weeks	Allow 1 gang week per leg plus 1 gang week for three crossbeams.	
Deck Boxes	Internal	Routine General - 2 years		4 men 2½ weeks	Say 120 crossbeams - gang of 4 do 12 per day plus boxes.	10 gang days @ 4 days per week.
General		Principal Inspection - 6 years		4 men 5 weeks	Assume PI takes twice time.	
					Average per annum = 5 man weeks GI and 4 man weeks on PI.	
Deck Boxes	External	Routine General - 2 years		4 men 2½ weeks	Say 120 crossbeams - gang of 4 do 12 per day.	10 gang days @ 4 days per week.
General		Principal Inspection - 6 years		4 men 5 weeks	Assume PI takes twice time.	
					Average per annum = 5 man weeks GI and 4 man weeks on PI.	
Deck Boxes	All	Routine General - 2 years		4 men 2 weeks	Allow 4 man gang 2 weeks for special areas, e.g. crossovers, expansion boxes, bearings.	
Special areas		Principal Inspection - 6 years		4 men 4 weeks	Assume PI takes twice time.	
					Average per annum = 4 man weeks GI and 3 man weeks on PI.	
Special Inspections	All	Ad hoc inspections as required.			Structural - allow 1 man week per month Avge	
					i.e. allow average of 3 man weeks per quarter	
Special Inspections	RBI	Defined scope Special Inspections		Allow 4 man weeks in year 6.	Derived from Reliability Based Inspection analysis - external paint system.	

Appendix E: Maintenance Programme

Maintenance Programme

			Years after completion of Messina Strait Bridge																																																										
Structure	**Element no.**	**Description of maintenance work**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**	**36**	**37**	**38**	**39**	**40**	**41**	**42**	**43**	**44**	**45**	**46**	**47**	**48**	**49**	**50**	**51**	**52**	**53**	**54**	**55**	**56**	**57**	**58**	**59**	**60**
Towers	1.2.1	Outer surface, total new top coat																														■																												■
Roadway Girder, direction Sicily	1.2.2.1	Outer surface, total new top coat																														■																												■
Roadway Girder, direction Calabria	1.2.2.2	Outer surface, total new top coat																														■																												■
Steel Girder, railway	1.2.2.1	Outer surface, total new top coat																														■																												■
		Upper surface, local repairs of surfacing															■										■																				■										■					
		Upper surface, replacement of surfacing																															■																											
Cross Girders	1.2.3.4	Outer surface, total new top coat																														■																												■
Expansion Joints, Roadway	1.3.2.2.1 - 2	Replacement of wearing parts																					■																				■																			
		Total replacement																																																			■									
Expansion Joints, Railway	1.3.2.2.3	Replacement of wearing parts																					■																				■																			
Hydraulic buffers	1.3.2.3	Maintenance of hydraulic sstems						■												■												■												■												■						
		Maintenance incl. oil analysis and N2 control												■																																				■												
		Maintenance incl. replacement of hoses, oil and N2 control																								■																																				
		Maintenance incl. replacement of hoses, oil, sealings and valves and N2 control																																				■															■									
Main Suspension cables	1.2.2.4	Caulking replacement																■															■															■													■
		Replacement of elastomeric wrap																															■																													■
		Opening of main cable for inspection																															■																													■
Cable Clamps	1.2.2.1	Total new top coat																■															■															■													
Carriageway surfacing	1.3.3.1	Maintenance surfacing and road marking											■					■																				■																■					■			
		Replacement of surfacing in slow lanes and local repairs																					■											■																												
		Total replacement of surfacing and road marking																																									■																			
Roadway Barriers	1.3.1.3	Replacement of galvanisation																																																	■										
Wind Screens	1.3.1.2	Replacement of galvanisation																																																	■										
Dehumidification plant	1.3.1.10	New plant for main cables																										■																								■									
Railway Track system		Ultrasonic testing		■		■		■		■		■		■		■		■		■		■			■		■		■		■		■		■		■		■		■				■		■		■		■		■		■		■		■		■	
		Rail grinding						■					■					■										■					■					■										■					■					■				
		Replacement of rails																					■																				■																			

Appendix F: Time Schedule for BMS

Establishment of Messina BMS	5 years before	4,5 years before	4 years before	3 ½ years before	3 years before	2 ½ years before	2 years before	1 ½ year before	1 year before	½ year before	
Specifications and other related tender documents											
Tendering											
Contracting, completion of specifications											
System design											
Development and installation of BMS											
Testing and remedy of failures											
User training											
Pilot BMS project											
Opening of Fixed Link											