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STUDY OF EXISTING RELIABILITY CENTERED MAINTENANCE (RCM) APPROACHES USED IN DIFFERENT INDUSTRIES

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Abstract

This document describes the state of the art in Reliability Centred Maintenance (RCM). RCM is a very useful tool in industries with strong constraints as regards users and safety, but in spite of being a standardise approach RCM can be adapted to particular constraints and requirements of the industry where it is applied. The application of RCM to several industries is discussed here.

The RCM database is a key part of any RCM toolkit. The information to improve maintenance can only be extracted from the database using statistic techniques, data mining, etc.…

While surveying the RCM state of the art, we have found numerous RCM software tools. Importance of these computerised tools is highlighted to make easier and more reproductive the RCM approach.

This study also proves that analysis models of risk, simulations, etc. can be used when carrying out the computerised tools of implementation of the RCM. This point leads to the conclusion that risk studies complementary in the RCM analysis must also be considered when defining the methodology.

Resumen

Este documento describe el estado actual de la metodología “Reliability Centred Maintenance” (RCM). RCM es de gran utilidad en industrias con fuertes restricciones de seguridad y fiabilidad. Aunque está estandarizado, el enfoque RCM puede adaptarse a las restricciones y requisitos de la industria donde se aplica. En este documento se presentará la aplicación de RCM a varias industrias.

La base de datos RCM es una parte clave del proceso RCM. La información para mejorar el rendimiento solamente puede se extraída de la base de datos utilizando técnicas estadísticas, minería de datos, etc....

Durante la investigación en el estado actual de RCM, se han encontrado numerosas herramientas para aplicar RCM mediante software. Estas herramientas tienen una gran importancia a la hora de hacer más sencillo y productivo el enfoque RCM.

Este estudio también presenta modelos de riesgos, simulaciones, etc. que pueden ser utilizados cuando se lleva a cabo la implementación de una herramienta RCM. Esto lleva a la conclusión de que los estudios de riesgo complementarios a RCM deben ser considerados en una metodología de mantenimiento.

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1. INTRODUCTION

The RAIL project will efficiently develop and use a Reliability centred maintenance (RCM) Approach for Infrastructure and Logistics of railway operation. In the RAIL project the technical task will consist in studying the RCM state-of-the-art, safety, railway regulations and the currently level of the machines used in the railway infrastructure of 4 European countries (the partners of the project). In this phase of the project we start studying the existing RCM approaches used in different industries.

This research is made from the bibliography, publications and internet information. This study is developed in four parts. The first part presents the history of the development of the RCM. This approach started at the end of the sixties when the work groups in charge of the civil aeroplanes maintenance (Maintenance Steering Group) were proposed a maintenance approach : MSG [MSG93]. Three successive versions were developed and they were used to define the maintenance plans of the Boeing 747, DC10, CONCORDE et Airbus A340. The slow evolutions between these planned revisions were replaced by a conditional maintenance [MAI00].

The third chapter of this part develop the RCM Usage in various industries. It presents the up-dated utilisation of the RCM in the industrial world with the adaptation to the specific problems and constraints of each main industrial sector. This part is broken-down in the RCM applied to aeronautical industries, nuclear industries, the chemical industries, Small and Medium Industries and others sectors. In fact the methods such as MSG, OMF, … gave birth to the RCM whose general definition could be "a global maintenance strategy of a technical system which uses a structured analysis method to give the system an inherent reliability" [HAR94]. In this part we show that the RCM can be applied to different industrial sectors and, depending on their problems and specificities, it can be adapted to more particular objectives. SMEs have constraints and reliability objectives different from those of the US Navy, the nuclear industry, hospitals or water treatment facilities.

The fourth chapter of this part deals with standards relating to the RCM problematic and constraints of safe operation imposed on the Railway sector. A synthesis of the standards relating to the problematic dealt with in the RAIL project – RCM and RAMS constraints – is made. A brief summary of the "Reliability and availability maintenance systems (RAMS)", the Cenelec standard EN50126 recently approved, is presented in this chapter.

The fifth and sixth chapters of this part deal with existing tools with a view to applying the RCM method and reliability databases generated by means of these tools. A survey of available tools and a comparative of their functionalities and possible contributions to the RAIL project are carried out. There is also a survey of some existing databases used to support maintenance activities and RCM toolkits. OREDA, SHIPNET, and the database work developed in REMAIN projects are outstanding references.

The former chapters are completed with a bibliography chapter, addresses of organisations related to the project and the railway industry; a glossary of the most frequently used technical terms of the maintenance, reliability and quality domains completes this work; the definitions of all these terms come from international standards.

To complete this part of the report, an appendix including many Internet references to companies, organisations, research centres, and documents relating to RCM techniques is shown.

2. RELIABILITY-CENTRED MAINTENANCE HISTORY

Over the past twenty years, maintenance has changed, perhaps more than any other management discipline. The changes are due to a huge increase in the number and variety of physical assets (plant, equipment and buildings) which must be maintained throughout the world, much more complex designs, new maintenance techniques and changing views on maintenance organisation and responsibilities. Maintenance is also responding to changing expectations. These include a rapidly growing awareness of the extent to which equipment failure affects safety and the environment, a growing awareness of the connection between maintenance and product quality, and increasing pressure to achieve high plant availability and to contain costs. Maintenance people have to adopt completely new ways of thinking and acting, as engineers and as managers. At the same time the limitations of maintenance systems are becoming increasingly apparent, no matter how much they are computerised.

Apart from civil and military aeronautic sectors, the application of the RCM (Reliability Centred Maintenance) methodology is not a statutory obligation. For this reason, a great number of methods for the development of maintenance programmes based on reliability are currently available. Some of these methods are the subject of books and specialised softwares. The selection of the level analysis depends of the objectives fixed by the company (availability, economic aspect, constraints, etc.) As in the nuclear domain, the "ALARA" concept (As Low As Reasonable and Achievable) can be applied in others industrial sectors.

This chapter provides a brief introduction to the state of the art of RCM, including approaches in different industries, existing RCM standards, RCM tools and databases used nowadays to implement a RCM environment. This state of the art will summarize all the aspects of the RCM methodology.

Before starting, we take a brief look at how maintenance has evolved over the past fifty years.

According to Moubray [MOU97], since the 1930's, the evolution of maintenance can be traced through three generations :

- The First Generation. It covers the period up to World War II. In those days industry was not very highly mechanised, so downtime did not matter much. This meant that the prevention of equipment failure was not a very high priority in the minds of most managers. At the same time, most equipment was simple and much of it was over-designed. This made it reliable and easy to repair. As a result, there was no need for systematic maintenance of any sort beyond simple cleaning, servicing and lubrication routines. The need for skills was also lower than it is today.

- The Second Generation. As this dependence grew, downtime came into sharper focus. This led to the idea that equipment failures could and should be prevented, which led in turn to the concept of preventive maintenance. In the 1960's, this consisted mainly of equipment overhauls done at fixed intervals. The cost of maintenance also started to rise sharply comparatively to other operating costs. This led to the growth of maintenance planning and control systems. These have helped greatly to bring maintenance under control, and are now an established part of the practice of maintenance. Finally, the amount of capital tied up in fixed assets together with a sharp increase in the cost of that capital led people to start seeking ways in which they could maximise the life of the assets.

- The Third Generation. Since the mid-seventies, the process of change in industry has gathered even greater momentum. The changes can be classified under the headings of new expectations, new research and new techniques. Figure 1 shows how expectations of maintenance have evolved. Downtime has always affected the productive capability of physical assets by reducing output, increasing operating costs and interfering with customer service. By the 1960's and 1970's, this was already a major concern in the mining, manufacturing and transport sectors. In manufacturing, the effects of downtime are being aggravated by the world wide move towards just-in-time systems, where reduced stocks of work-in-progress mean that quite small breakdowns are now much more likely to stop a whole plant. In recent times, the growth of mechanisation and automation has meant that reliability and availability have now also become key issues in sectors as diverse as health care, data processing, telecommunications and building management. Greater automation also means that more and more failures affect our ability to sustain satisfactory quality standards. This applies as much to standards of service as it does to product quality. For instance, equipment failures can affect air conditioning control in buildings and the punctuality of transport networks as much as they can interfere with the consistent achievement of specified tolerances in manufacturing. More and more failures have serious safety or environmental consequences, at a time when standards in these areas are rising rapidly. In some parts of the world, the point is approaching where organisations either conform to society's safety and environmental expectations, or they cease to operate. This adds an order of magnitude to our dependence on the integrity of our physical assets - one which goes beyond cost and which becomes a simple matter of organisational survival. At the same time as our dependence on physical assets is growing, so too is their cost to operate and to own. To secure the maximum return on the investment which they represent, they must be kept working efficiently for as long as we want them to. Finally, the cost of maintenance itself is still rising, in absolute terms and as a proportion of total expenditure. In some industries, it is now the second highest or even the highest element of operating costs. As a result, in only thirty years it has moved from almost nowhere to the top of the league as a cost control priority.

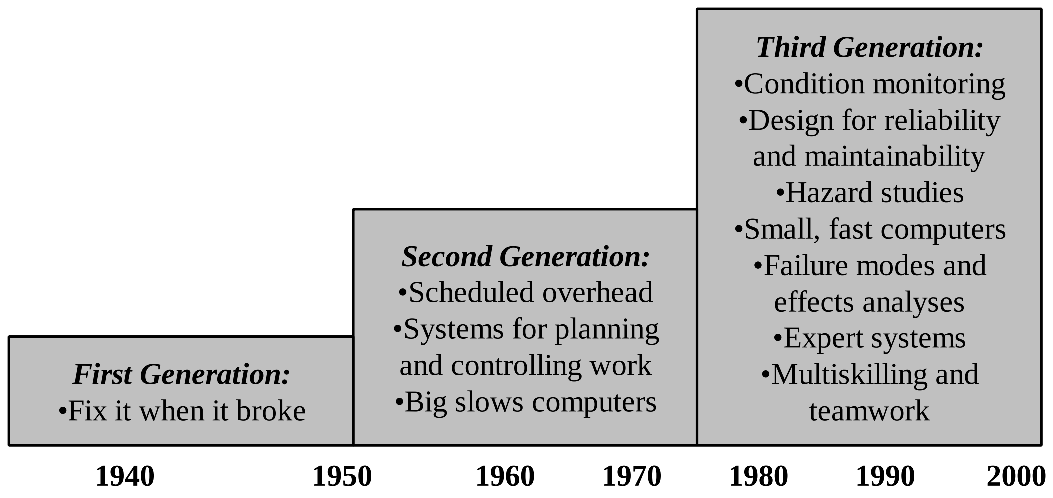


Figure 2-1 : Evolution of RCM

3. RCM USAGE IN THE DIFFERENTS INDUSTRIES

RCM is now used in other industrial sectors than the aircraft maintenance sector. In this section, the state of the art of RCM techniques in different industries is shown, to demonstrate that RCM has been successfully applied to most of them. For each kind of industry, a brief introduction, followed by a link to an extended document, has been made.

3.1 AIRCRAFT AND AEROSPACE INDUSTRY

The RCM methodology was developed for the first time by United Airlines company for the Defence American Department and was published in 1978. In this part, different RCM (MSG-3) applications will be presented in order to show the work already done in this sector.

RCM has been used extensively in the military and commercial aerospace sector, together with AR&M, MSG-3 [MSG93] and LCC services. Examples of industries in this field are airline operators, manufacturers, air traffic management systems and baggage handling systems. We have made an extended study of the :

- US NAVY RCM [MIL96, NAV90, NAV00] approach, to show the RCM military approach,
- AIR CANADA to show civil usage of RCM tools in airline operators.

3.1.1 Reliability-Centred Maintenance in the Naval Air Systems Commands (NAVAIR) Programs

Aviation maintenance philosophy has changed over the past twenty years. In the past, the Navy operated on the premise that the resources for performing maintenance tasks were unlimited. However, today the fact is that most resources are not only limited, but in most cases are lacking. This has driven to look for new initiatives designed to improve maintenance techniques and equipment availability. The **NAVAIR Affordable Readiness effort** is one such initiative. It recognises Reliability-Centred Maintenance as the main tool in developing and implementing its integrated maintenance concept.

Currently, RCM is being applied to all new NAVAIR acquisitions and major system modifications. The Navy uses several documents that provide guidance for the RCM program. These documents are:

- **NAVARINST 4790.20**, Reliability-Centred Maintenance Program. This outlines the policy guidance and assignment of responsibilities required of successfully plan, implement, and execute effective RCM analyses on NAVAIR aircraft, systems, and support equipment.
- **NAVAIR 00-25-403**, Guidelines for the Naval Aviation Reliability-Centred Maintenance Process. This manual covers planning for RCM, RCM theory and specific guidance, documenting the analysis, and implementing analysis results.
- **MIL-STD-2173 (AS)**, Reliability-Centred Maintenance Requirements for Naval Aircraft, Weapons Systems and Support Equipment. This standard provides procedures for conducting RCM analyses for naval aircraft, systems, and support equipment.
- **NAVAIR RCM Website**. This site provides easy access to NAVAIR RCM information, software, and documentation.

3.1.1.1 RCM Process

In order to conduct a successful RCM analysis and sustain it through maintenance programme refinement, each NAVAIR programme (weapon system or support equipment) must have an approved RCM programme plan. The objective of the RCM program plan is to describe the processes and procedures to be used during the analysis, and to identify all resources needed to perform the analysis.

This section provides a short discussion of the primary steps that make up the RCM process. These steps include Failure Modes Effects and Criticality Analysis, Significant Function Selection, Task Evaluations, and Task Selection.

3.1.1.1.1 Failure Mode Effects and Critically Analysis (FMECA)

A failure mode and effects and critically analysis is a process that evaluates, documents, and ranks the potential impact of each functional and hardware failure has on mission success, personnel safety, system performance, maintainability, and maintenance requirements. The information provided by a FMECA is one of the primary inputs for the RCM process.

The FMECA is an analytical tool used to determine functions, function failures, failure modes, and failure effects for a given item of hardware. The standard used to develop a FMECA is included in the MIL-STD-1629A, *Procedure for Performing a Failure Mode, effects and Criticality Analysis*. This analysis can determinate: function, functional Failure A, Failure mode 0i, failure effect and consequences, ..

3.1.1.1.2 Significant Function selection

The Significant Function (SF) Selection Logic provides a method for selecting only those functions that are worthy of analysis. Selection of functions at the proper level of detail will improve not only the effectiveness of the RCM analysis in the short-team, but also the effectiveness of the resulting preventive maintenance program in the long-term.

Next figure shows the Selection Logic diagram used to determinate significant functions and non-significant functions. The significant functions are worthily of analysis, and are the functions whose failures will have an adverse effect on the end item with regard to safety, the environment, operations, or economics.

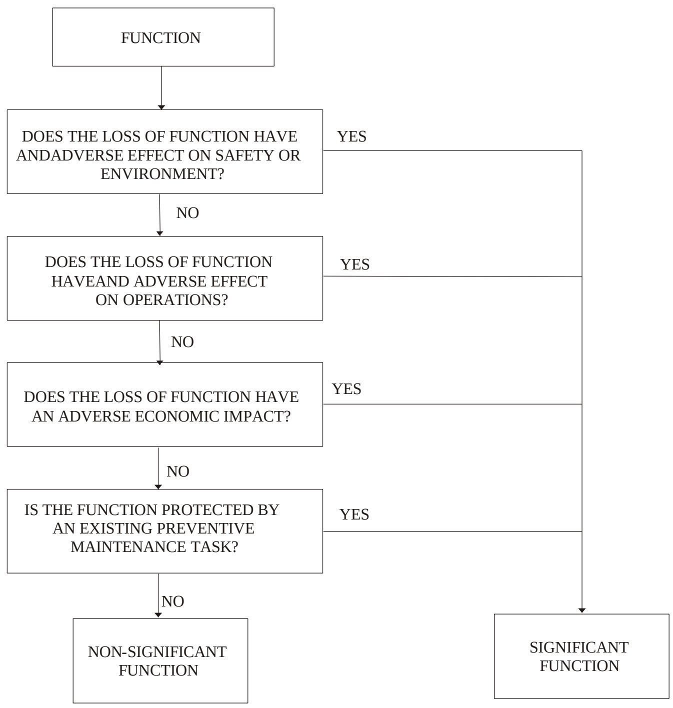


Figure 3-1 : Selection Logic diagram in NAVAIR

3.1.1.1.3 RCM Decision Logic, Task Evaluation, and Task Selection

The significant functions that were identified by the SF Selection Logic undergo further analysis as they are subjected to the RCM Decision Logic. The RCM Decision Logic is used to determine what type of action would be appropriate to either eliminate or lessen the consequences of functional failures. Every function has one or more failure modes. Each of these failure modes must be processed through the Decision Logic to determinate if a preventive maintenance task can be developed to mitigate the consequences of their occurrence.

The Decision Logic requires that the following elements be considered for each failure mode being analysed:

- Consequences of failure (safety, environmental, operational, economical).
- Visibility of a functional failure to the operating crews.
- Visibility of reduced resistance to failure.
- Age-reliability characteristics of each item.
- Economic trade-off decision based on a comparison of the cost of performing a preventive maintenance task to the cost of not performing the task.

The RCM Decision Logic Diagram is show in this figure :

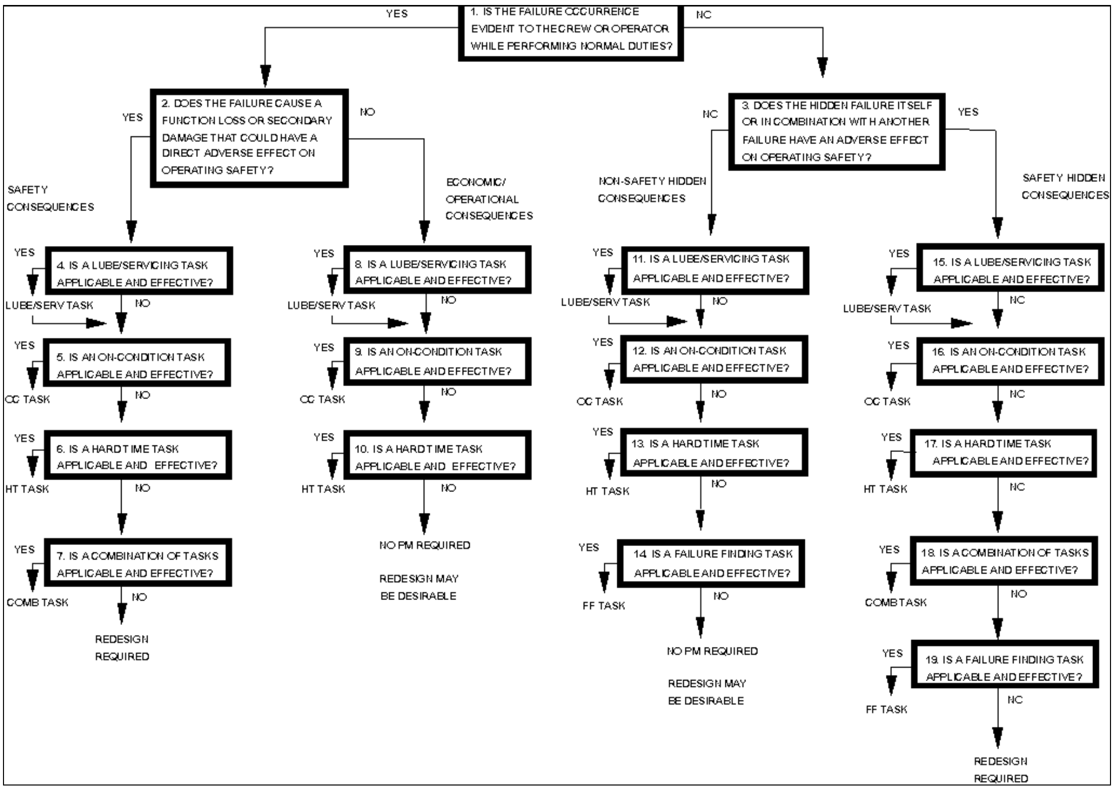


Figure 3-1 : RCM Decision logic

The Decision Logic consists of the four branches listed below :

- Evident Safety/Environmental consequences.
- Evident Economic/Operational Consequences.
- Hidden Economic/Operational Consequences.
- Hidden Safety/Environmental Consequences.

All four branches of the Decision Logic tree propose the following four types of preventive maintenance tasks: service tasks, lubrication tasks, on condition tasks, and hard time tasks. Two branches, the Hidden Safety/Environmental Consequences and the Hidden Economic/Operational Consequences, also contain proposal for failure finding tasks.

If safety is not involved, and none of the proposed tasks prevent the functional failure from occurring, then "No PM" may be desirable. When safety is involved, the functional failure must be prevented either by a PM task or some other action. If it is determined that an appropriate PM task is not available to reduce the consequences of failure to an acceptable level, some other action must be taken to deal with them. Several options, such as an item redesign, the introduction of flight restrictions, changing maintenance procedures, etc, can be applied to mitigate the problem.

3.1.1.1.4 Integrated Reliability-Centred Maintenance System (IRCMS)

The Integrated Reliability-Centred Maintenance System (IRCMS) program is a software tool used by analysts to perform and document RCM analyses to determine the applicability of and preliminary inspection intervals for potential preventive maintenance tasks. It aids the analyst in providing the justifications for and tracability of each preventive maintenance task that results from the RCM analysis. It must be emphasised that IRCMS cannot perform an RCM analysis. It requires input by an analyst who is knowledgeable in RCM theory and knows how to use the program.

The current version of the IRCMS is a Windows application, and is designed to run as an independent application or from a local area network. Multiple users can access an IRCMS project simultaneously, but access is limited to one user at a time at or below the function level. Following is a list of requirements for running the IRCMS program :

- Windows 95/98 or Windows NT,
- 486 central processing unit (minimum).

3.1.2 Air Canada

High repair and maintenance costs presented a challenge – to determine the potential benefits of better use of data and information. Studies of the problems encountered by a selected number of fleet operators in the mining, aviation and road transportation industries revealed many similarities. Considering just 10 Canadian industrial sectors, one finds that for every dollar spent on new machinery, an additional 51 cents is spent on maintaining existing equipment. This amount to repair costs of approximately CAN$15.3 billion per year. A strategic decision was made to start with the commercial aviation industry.

The Integrated Diagnostic System (IDS) is an applied Artificial Intelligence (AI) project concerned with the development of hybrid information systems to diagnose problems and help manage repair processes of commercial aircraft fleets. The project was initiated in 1992 by the National Research Council (NRC) of Canada after examining the economic importance of diagnosing complex equipment problems correctly.

Air Canada’s maintenance operations are carried out with the following characteristics: diagnosis is seen as only part of the solution, the scope of a maintenance project should extend to all aircraft systems on all fleet (Air Canada’s current fleet size is 134 aircraft and growing), the benefits were conservatively estimated to be in the vicinity of 2% of the entire maintenance budget, decision making is highly distributed, and newer generation equipment produces increasing amounts of potentially useful data. Innovative information technology was required to aid in the integration and interpretation of data.

A parallel airline market assessment was also carried out. It revealed a potential world market exceeding CAN$1B/year if similar benefits are obtained by other airlines (only fleet size >30 aircraft considered).

Decision making environment at Air Canada shows the following procedures :

- Line technicians repair aircraft at the gate or on overnight layover; their prime objective is to safety turn aircraft around with minimum disruption,
- Maintenance Operation Control staff view the entire fleet from a maintenance perspective. They act on any problems reported by the pilot or on-board systems to minimise disruption. They also monitor fleet status, identified trends, deal with persistent and foreseeable problems, and determine maintenance policy,
- Engineering looks at specific performance indicators of the equipment and will only become involved with difficult immediate concerns, on an as-required basis. They typically have the longest decision horizon,
- Manufacturers representatives are involved in certain difficult problems,
- Parts stores personnel must ensure that an adequate supply of spare parts is available from the various production stores both within and external to the airline,

- System Operations Control personnel keep the entire fleet flying on schedule. They make system-wide decisions on such a factors as disruption due weather or equipment failure and flight crew readiness.

Modern aircraft, such as the Airbus A320 or Boeing B767, have systems on board which can transmit data to ground stations. These data consist of routine performance snapshots (e.g. altitude, temperature, pressures, engine temperatures, valve positions, etc.), pilot messages, aircraft-generated fault messages, and special purpose reports generated when prescribed limits are exceeded. There are many additional databases that support maintenance. They contain descriptions of symptoms and associated maintenance actions (free form text), deferred problems, flight schedules, weather, component reliability, and parts location. There is also a wealth of useful information held at the manufacturer and by people and information systems in the engineering and maintenance operation control departments. This is not widely distributed and thus not available to the line technical in a timely manner.

3.1.2.1 IDS System

The Integrated Diagnosis System (IDS) is a maintenance tool designed to support Air Canada's control operations. IDS was designed to provide information to both line technicians and Maintenance Operation Control staff. Allowing developing their activities across two different decision making time horizon, information needs, work environment, and required skills. However, communication between them is critical to effective fleet management. Line technicians contribute to Maintenance Operation Control's understanding of fleet status and maintenance practices. Additional IDS features are :

- Complete aircraft maintenance supported (rather than particular subsystems),
- Low level diagnostic is not the main focus of the system (the trend is towards embedded diagnostics, which are best left to the equipment manufacturer),
- Existing practices and sources of knowledge are supported/exploited wherever is possible.

Operational Schema

In broad terms, IDS refines an asynchronous stream of messages of atomic symptom and repair action events into descriptions of complete fault-repair episodes. The process exploits many knowledge sources, some allowing messages to aggregate, others allowing messages (or clusters) to merge, be modified or discarded. The ideal result is clear, concise, complete descriptions of faults events, which unambiguously associate symptoms and correct repair actions.

The starting point of IDS are messages received on-line from different land stations. These stations gather the information from the aircraft when it is in range. These data is transmitted in real-time when the plane is in air, so many diagnostics may be processed before aircraft landing.

The major processing blocks, information stores (object sets, databases, case-bases, rules sets), and information flows in IDS are shown in below. Reading down from the top, centre of the diagram you see the message stream (from aircraft embedded diagnostic computers and from the maintenance databases) entering IDS:

- The first processing step classifies and cleans up these messages to produce IDS Message Objects (IMOs). Classification is performed using case-based reasoning,
- The second processing step clusters these IMOs into Fault Event Objects (FEOs). This is implemented as a small set of complex rules, which were derived through conventional knowledge acquisition sessions with engineers and maintenance staff,
- FEO management takes not only an IMO as input but also Troubleshooting Manual (TSM) objects and Minimum Equipment List (MEL) objects,
- The TSM objects represent clusters of IMOs, which are identified in the MEL manual as indicating that the operation of the aircraft is restricted in some way because of safety concerns. The MEL knowledge comprises a small set of rules and several large lookup tables,
- The third stage of refinement associates the symptoms (i.e. messages clusters in the Fault Event Objects) with appropriate repair actions. The resulting Snag (aviation term for an equipment problem) Rectification Objects (SROs) are stored. This matching process exploits a combination of rule-based and case-based reasoning,
- Finally, suggested repair actions are composed and presented to the user. These are derived from historical maintenance events similar to current FEO (using CBR) and from the Troubleshooting Manual) if the FEO contains a TSM object).

3.1.2.2 Automatic Fleet Monitoring

This process provides support for identifying abnormal situations in a fleet or user selected aircraft. The performance of the aircraft is monitored in real-time and the user is warned when there is evidence of abnormal behaviour. An abnormal behaviour is typically one that is associated with unusual trends in failures of components, subsystems, or performance degeneration.

3.1.2.3 Data Analysis Support

This feature provides support for advanced data analysis. It is particularly for cases when users, such an engineer, have received reports of some problems and are interested in investigating further. This form of data analysis can be used for both component failures and abnormal behaviour. Some of the methods available when performing this action are :

- **High-level Problem Selection**, that allows the users to define data analysis tasks gathering the data according to high-level conditions, such as engine high fuel consumption, engine #2 high vibration, or specific component failure,
- **Data Analysis Control**, that allows the users to exclude certain situations from the analysis procedure, such as a specific aircraft, includes additional features or range a variable period of time.

3.1.3 Synthesis

The RCM methodology was developed for the first time by United Airlines company for the Defence American Department and was published in 1978. RCM has been used extensively in the military and commercial aerospace sector, together with MSG-3 [MSG93] and LCC services. Examples of industries in this field are airline operators, manufacturers, air traffic management systems and baggage handling systems.

However, RCM application for RAIL techniques can be very different, because AIR industries have a lot of information relating to planes and other installations, while railway companies may not have at their disposal this information so fast. As an example, in some cases maintenance is made quickly by local teams before notifying the failure to the central maintenance department. In those situations, failure and reparation are made at the same time. However, the RCM tools used in aircraft industries are very good, as will be shown in next sections.

3.2 NUCLEAR INDUSTRY

One of the first sector to use RCM methodology was the nuclear sector because of their similarities with the aeronautic sector (safety, availability, maintenance costs). Today, more than 400 nuclear power stations producing electricity are using RCM in different ways. Safety rules are very strict, thus each nuclear power station is checked by a specialised association in order to respect these rules.

The application of Reliability Centred Maintenance (RCM) in the Nuclear Industry has been both enhanced and recommended. The failure mode analysis and effects analysis (FMEA) provides a format for identifying the dominant failure modes of component failures leading to a functional failure and the impact of each component failure locally at the component, on the system, and on the plant. It is extensively used in most nuclear plants to enhance safety and reliability.

Some examples of applications are listed below :

- **Applications in the United States of America** The **Nuclear Regulatory Commission** (NRC) of the USA. This organisation has issued a complete book of nuclear regulations, including maintenance. RCM technology is being used as the preferred maintenance technique [NRC 1991, NRC 1995],
- **OMF (**Optimisation de la Maintenance par la Fiabilité) at EDF (France),
- **Links in others countries** More information on RCM applications to the nuclear industry in other countries can be found at http://insp.pnl.gov:2080/.

3.2.1 Nuclear Industries in the USA

In an effort to improve plant safety and reliability and control or reduce maintenance costs, the nuclear utility industry has taken RCM technology gained from the commercial airlines industry and the U.S. military and applied it to nuclear power plants [NRC91, MRC95].

Since 1984, the Electric Power Research Institute (EPRI) in San Diego has pioneered a number of plant studies demonstrating the usefulness of RCM as a preventive maintenance optimisation technique.

Three initial RCM pilot studies were performed on single nuclear plant systems between 1984 and 1987 with promising results. However, the feasibility and cost-effectiveness of RCM, particularly in a large, multi-system application at an operating nuclear plant, had not been fully demonstrated. If the promising results of the RCM pilot studies were to be realised throughout the industry and encourage a wider use of the technology, the overall costs and benefits associated with the application of RCM methodology had to be demonstrated.

In 1988, EPRI initiated two large-scale demonstrations on multiple systems at Rochester Gas and Electric's Ginna Nuclear Power Station and Southern California Edison's San Onofre Nuclear Generating Station. Over a two-year period, researchers refined RCM programs, performed RCM analysis on plant systems, implemented the results, and evaluated the usefulness of the project. At Ginna, areas for improvement were identified for each of the 21 systems analysed, and approximately 1300 changes to the existing preventive maintenance program were recommended. At San Onofre, there was a total estimated saving of over 8000 maintenance man-hours on the first four systems evaluated, with comparable savings on the remaining eight systems.

In a parallel effort other utilities in the nuclear industry have initiated RCM programs. In 1991, seven utilities, Arizona Public Service Company, Commonwealth Edison, Florida Power Corporation, Pacific Gas and Electric Company, Philadelphia Electric Company, Texas Utilities Electric Company, and Union Electric Company participated in an RCM cost-benefit study. Combined, these utilities provided data from the evaluation of 72 systems. Each of the seven utilities surveyed realised a measurable benefit from the performance of RCM analysis. A saving in maintenance labour and administrative costs was quantifiable for six of the seven.

These projects led to the widespread adoption of RCM by nuclear facilities in North America and now to an increasing extent by nuclear facilities throughout the world.

Some facts that demonstrate this widespread adoption of RCM are the following :

- RCM consulting and training companies provide support to a growing number of nuclear industry clients,
- RCM tools are used extensively by nuclear facilities. The RCM turbo tool is being used by about twenty power generation industries all over the world. GasTOPS' RCM software tool was applied in Ontario Hydro ranked among the largest power generation utilities in North America in order to improve maintenance effectiveness at its nuclear generating stations,
- Expert panels for monitoring the effectiveness of maintenance at nuclear power plants include usually a Nuclear RCM Manager.

3.2.2 The OMF project (in EDF France)

3.2.2.1 Presentation of the system

This system is very important in the functioning of a nuclear power station. That is why, EDF has done a pilot application on this device. This picture shows the position of the RCV system of a nuclear power station. This OMF project in an extract of the ZWINGELSTEIN’s book [ZWI96].

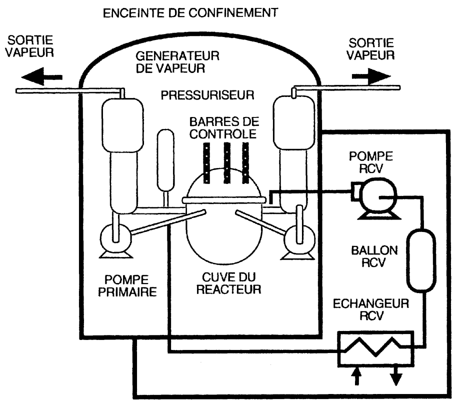


Figure 3-1: Nuclear power station

3.2.2.2 OMF objectives

The objectives of the 'OMF' methodology are :

- To maintain or improve reliability and availability,
- To control costs and optimise maintenance,
- To assure a structured and rational approach,
- To use experimental return.

3.2.2.3 Presentation of the 'OMF' methodology

The methodology used for this application is based on four main steps which are represented on the logic diagram. (Figure 3-2)

3.2.2.4 Critical equipment research

In the first step, each machine is defined as an item. The principle consists in defining the consequences of the failure modes for each item. Failures modes could have consequences on :

- Main functions for safety,
- Energy production,
- Reparation costs involved by the failure.

For the research of critical equipment in the RCV system, a functional breaking down is carried out.

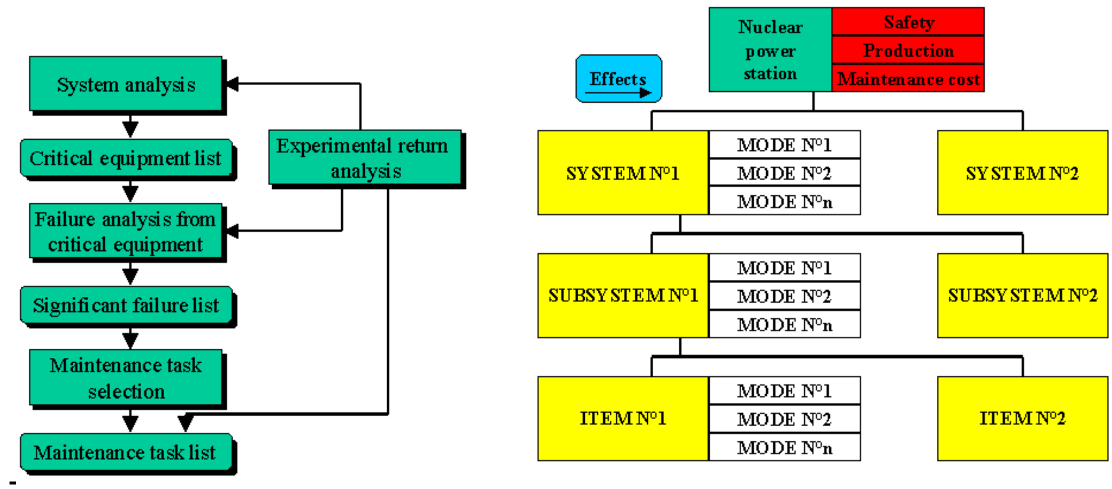


Figure 3-1 : Principle of 'OMF' methodology & Functional decomposition of a nuclear power station

The methodology to draw up the list of critical equipment is described is the Figure 2-5.

In the ultimate part of the research of the critical equipment, the list of the critical machines is as follows :

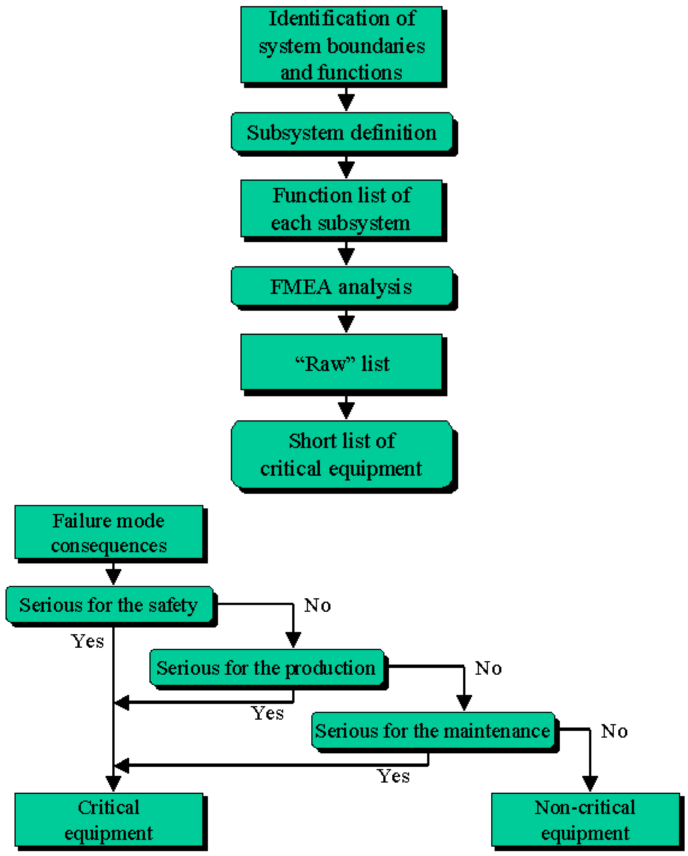


Figure 3-2 : Selection of critical machines & Decision tree for failure classification

3.2.2.5 Establishment of the significant failures list of critical equipment

Failure modes used in the research of critical machines concerning the whole machine. Each critical equipment must be decomposed into functional items.

The methodology to analyse the significant failure mode is described below :

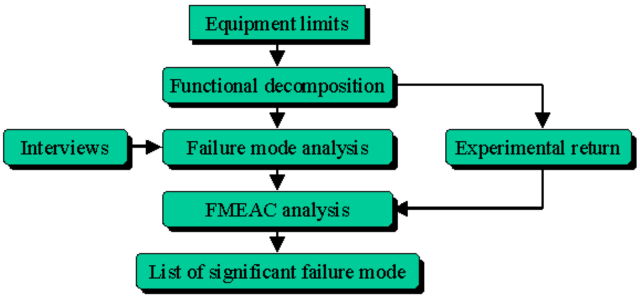


Figure 3-1 : Diagram for significant failure selection

3.2.2.6 Maintenance task selection

In this step, for each failure cause one or several maintenance tasks are selected.

The final tasks must be correct : effective, applicable and economic.

The method used is a logic decision tree to define the most adequate task.

3.2.2.7 Generalisation of the 'OMF' methodology

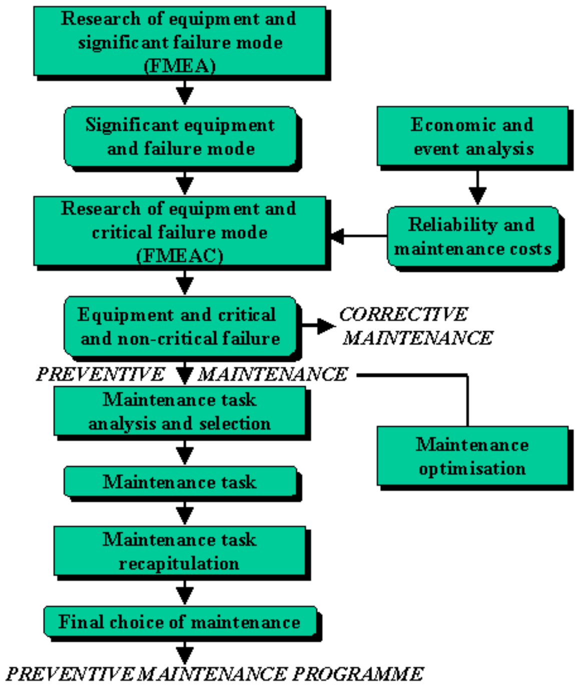


Figure 3-1 : Generalisation of the 'OMF' methodology

3.2.3 Synthesis

The nuclear industry has stringent requirement on safety and reliability because of potential catastrophic failures. This feature is very similar to the RAIL project, because in the railway infrastructure, some failures may lead to catastrophes. What it is more interesting in the nuclear industry of the USA is the existence of a Nuclear Regulatory Commission, which is in charge of regulating and controlling the safety processes. There are safety inspectors all along the USA, that apply the same rules to every nuclear power plant. RCM is a leading technique to satisfy such inspections.

3.3 SHIPPING

RCM has been recently applied successfully to a sea going vessel. During the last six years, progressive maritime organisations around the world have been co-operating to form a world wide information network, called RAM/SHIPNET, to support the optimisation of these three key factors throughout all stages of a vessel's life cycle. Consisting of layered Reliability, Availability and Maintainability (RAM) databases, RAM/SHIPNET has been developed through a co-operative effort of owner/operators, government organisations and regulatory agencies.

More information is provided in the RCM databases section.

3.4 RCM IN CHEMICAL INDUSTRIES

The chemical process industries (CPI) are extremely diverse, producing hundreds of chemicals that are used in the manufacturing of consumer goods. The materials created and used in chemical process plants range from the relatively innocuous to those that pose significant risks to people and the environment. Industry is constantly being challenged to manage the risks associated with the production and use of these materials, while remaining competitive in the global marketplace.

For years, companies have concentrated on making their equipment more reliable, and on correcting perceived problems with technology. But while use of better technology has usually resulted in tremendous increases in productivity, there may not have been commensurate improvements in the prevention of major accidents. In fact, recent reviews show that human error and the lack of adequate management systems are the most significant contributors to major plant accidents.

Reliability Centred Maintenance (RCM) is being extensively used into this industrial area, existing strong regulations and development criteria. The **state of the art of its regulations and applications** is shown below.

3.4.1 State of the art of the RCM regulations approach

From the CPI's early days, it has been apparent that facilities need to be reliable and safe. Indeed, strategies to increase workplace safety have become a normal part of plant design, operating and maintenance philosophies.

For years, companies have concentrated on making their equipment more reliable, and on correcting perceived problems with technology. But while use of better technology has usually resulted in tremendous increases in productivity, there may not have been commensurate improvements in the prevention of major accidents. In fact, recent reviews show that human error and the lack of adequate management systems are the most significant contributors to major plant accidents.

3.4.1.1 LAW

A variety of safety laws and regulations dealing specifically with catastrophic chemical accidents have come about recently. Among the first attempts to deal with chemical disasters were those in Europe, following the Flixborough, U.K., vapour-cloud explosion in 1974 and the release of toxic materials in Seveso, Italy, two years later. The bulk of U.S. efforts for prevention of major chemical plant accidents began in the aftermath of the Bhopal tragedy in 1984. A more recent U.S. regulation that addresses accidental releases stems from the passing of the Clean Air Act Amendments (CAAA) in November 1990. This legislation mandates that EPA create regulations to require facilities possessing listed chemicals above a threshold amount to develop and to implement extensive risk-management plans (RMPs).

These RMPs must contain three specific components: a hazard assessment of potential worst-case accidents, an accident-prevention programme, an emergency-response programme.

Meanwhile, in Bhopal's aftermath, the U.S. Dept. of Labour’s Occupational Safety and Health Administration (OSHA) began performing wall-to-wall inspections of chemical plants. One conclusion that OSHA drew from these inspections was that it could not consistently address the safety concerns associated with catastrophic accidents without a new regulatory standard. OSHA's efforts culminated in a new rule, Process Safety Management of Highly Hazardous Chemicals. The rule requires that companies possessing a hazardous substance in excess of a specified threshold amount must develop and implement a process safety management (PSM) system.

OSHA's ``performance based'' regulation is a significant departure from previous safety legislation that prescribes specific equipment requirements or actions to be taken. OSHA's PSM rule establishes goals, describes the basic elements of a program designed to fulfil these goals, and outlines important activities associated with each element.

3.4.2 Techniques

The methods approved by OSHA include, but are not limited to: What-If Analysis, Checklist Analysis, What-If/Checklist Analysis, Hazard and Operability (Hazop) Analysis, Failure Modes and Effects Analysis (FMEA), FTA, or Fault Tree Analysis. All of them are included into the RCM process used in chemical companies.

3.4.2.1 What-If Analysis

This technique systematically examines the responses of process systems to equipment failures, human errors and abnormal process conditions. It requires participation by team members who know and understand the basic hazards associated with the process and its operation. The team leader helps a team develop ``what if'' questions about the process, such as “What if the pressure regulator failed to close?”. By answering these questions, the team identifies potential hazards and suggests ways to improve safety.

The results of a What-If Analysis are generally documented by listing the specific questions, responses, and recommendations generated in the meetings. One of the strengths of this method is that it can be applied to any system at any stage of its design or development. However, the results of the analysis are highly dependent upon the experience of the leader and the team, and the completeness of the list of questions.

Because it is not as systematic as other techniques, What-If Analysis is not generally used as a stand-alone PHA technique. However, it is an excellent supplement to more-structured techniques, such as Hazop, Checklist and FMEA.

3.4.2.2 Checklist Analysis

Checklists are commonly used for identifying known types of hazards associated with a process and for helping ensure compliance with standard industry practices. This technique compares aspects of a system against a list of items to discover and document possible deficiencies.

The items included in a checklist should be based on features of similar systems, on company standards, and on common industry practice or experience.

Checklist Analysis is an experience-based technique that strengthens any PHA effort; however, the method alone does not generate the brainstorming of potential process problems that more-creative hazard evaluation techniques, such as What-If, Hazop and FMEA, offer. A checklist review of one specific piece of equipment for which an appropriate checklist exists, such as a safety checklist that was developed by experts for evaluating new-compressor installations, may be adequate. However, conducting a PHA using only a checklist is not generally recommended.

3.4.2.3 What-If/Checklist Analysis

As the name suggests, this technique combines the brainstorming of What-If Analysis with the systematic nature of Checklist Analysis. It is an improvement over either of the two. The checklists used in these analyses usually include more-general items intended to inspire creative thinking about known types of hazards and potential incidents. Because such checklists are inherently based on experience, and because applicable checklist items may differ from site to site, a team may choose to ``What-If'' potential events that are beyond the experience base of a checklist.

3.4.2.4 Hazop Analysis

The Hazard and Operability Analysis technique provides an efficient, detailed and audible study of process variables. It systematically identifies ways the process equipment can malfunction or be improperly operated, thus leading to undesirable conditions. To apply Hazop Analysis, the team analyses each process section or procedural step to identify consequences of deviations from the design or procedural intention. For each deviation, the team :

- Decides whether any consequences of interest would result from credible causes of the deviation,
- Identifies the engineering and administrative control features that guard against the deviation,
- Recommends ways to reduce the likelihood of the deviations or severity of the consequences.

Results of a Hazop Analysis are usually recorded in a table listing item numbers, descriptions of the deviations, possible causes identified by the team, potential consequences of the deviations, existing safeguards (control features), and recommendations of the team. Because it is thorough and easy to use, Hazop Analysis is the most popular technique for PHAs.

3.4.2.5 Failure Mode and Effects Analysis (FMEA)

The FMEA technique involves the methodical study of component failures. Here, all the failure modes for each component in a system are identified, and the effect of each component failure on the system is evaluated. As in Hazop Analysis, existing safeguards are identified, and recommendations for further improvements are documented. Because the FMEA technique focuses on component failures, problems related to process chemistry, such as autocatalytic decomposition, may be overlooked. For this reason, FMEA is most appropriately used for processes that do not involve reactive chemistry. These include crushing, blending, mixing, conveying, transferring, distilling, coating and packaging. Complex control systems, such as emergency shutdown or interlock systems, are also often analysed by FMEA.

3.4.2.6 Fault Tree Analysis (FTA)

FTA is a deductive reasoning method for determining the logical relationships of component failures and human errors that result in a specific failure of a system. The fault tree portrays the combination of failure events that cause a specific undesired system failure, commonly referred to as the ``Top'' event. The technique can be used to quantify the frequency or likelihood of a system failure; however, quantification is often not needed to identify the most important contributors to system failures. This method is generally too detailed and too specific for frequent use in PHAs. It is best used when the PHA team needs to evaluate specific system failures that result from multiple equipment failures or human errors, or both.

The documentation of an FTA usually includes the graphical fault-tree model, the combinations of failures that cause the Top event, and numerical evaluations of the Top event. This technique is most often used to complement a Hazop, FMEA or What-If/Checklist Analysis to model specific system failures, such as a furnace explosion.

3.4.2.7 Techniques combination

Rarely is there a single best hazard-evaluation technique for a PHA. In fact, the selection often involves choosing not just one technique, but rather several complementary ones for analysing different parts of a process or different types of hazards associated with a process. When selecting hazard evaluation techniques, one must consider the severity of the hazards of the process, such as the inherent dangers of the chemicals and the process conditions, the complexity of the process, such as the nature of the control systems, and the efficiency of the techniques for addressing the hazards of the process.

Most often, a detailed, well-structured hazard evaluation technique, such as Hazop Analysis or FMEA, is used as the basic technique for the PHA of a process. In sections of the process where the hazards are less severe or the process is less complex, a less-detailed -but more efficient -technique, such as What-If/Checklist Analysis, is used.

Conversely, sections of the process with more-severe hazards or more-complex control logic may warrant the use of a more-detailed technique, such as Fault Tree Analysis.

3.4.3 Reliability Databases in Chemical Industries

The Centre for Chemical Process Safety (CCPS) of the American Institute of Chemical Engineers (AIChE) has developed and operated an equipment reliability database used to :

- Determine process integrity, reliability and availability of equipment components, process units and plants,
- Develop risk-based maintenance planning and continuous improvement of key equipment.

The CCPS Equipment Reliability Database provides: conversion of existing system to provide valid and useful data, and availability of high quality CPI and HPI specific data.

The engineering process consists in :

- Facilitating reliability/availability assessment,

- Making decisions on the need for redundant systems,
- Improving equipment designs with greater confidence,
- Selecting the best equipment for specific services.

On the other hand, the maintenance must include the next tasks: estimating required work force, benchmarking current efforts, both frequency and time, integrating predictive and preventive maintenance efforts.

CPPS deals the safety and loss prevention through the next topics: quantifying risks, minimising human reliability issues.

Participants are the members of the steering Committee which guides the project and can discuss the concepts and taxonomies, share analytical techniques, and swap experiences with peers in industry. Participants have access to their own data and the generic data developed from the experience of all participants.

Project participants are: Air Products & Chemicals Inc., Amoco Corporation, ARCO, BP Oil International, Caltex Services, Celanese Limited, Chevron Research and Technology Corp., Dow, DuPont, Eastman Chemical Co., Exxon, Factory Mutual Res. Corp., Flour Daniel Inc., GE Plastics, The Hartford Steam Boiler Inspection and Insurance Co., Hercules Inc., ICI-UK, Intevep S.A. (Venezuela), Mitsubishi Chemical Corp., Phillips Petroleum Co., Rohm and Haas Co., Shell, Syncrude Canada, Ltd., Texaco, Westinghouse Savannah River Operations.

3.4.4 Synthesis

Due to tragedies, chemical companies must follow a well established set of laws and rules to enforce security and reliability. The methods approved by OSHA include, but are not limited to: What-If Analysis, Checklist Analysis, What-If/Checklist Analysis, Hazard and Operability (Hazop) Analysis, Failure Modes and Effects Analysis (FMEA), FTA, or Fault Tree Analysis. All of them are included into the RCM process used in chemical companies.

The Centre for Chemical Process Safety (CCPS) of the American Institute of Chemical Engineers (AIChE) has developed and operated an equipment reliability database used to determine process integrity, reliability and availability of equipment components, process units and plants. It also helps to develop risk-based maintenance planning and continuous improvement of key equipment. The CCPS Equipment Reliability Database provides conversion of existing system to provide valid and useful data, and availability of high quality CPI and HPI specific data.

The experience in safety and reliability regulation in chemical companies should be applied to railway industries. It would be desirable to have a set of rules and techniques to be used, as a minimum, to enforce security and reliability in every kind of operation, including maintenance.

3.5 PROCESS/OIL & GAS

RCM is used in many oil companies, such as Shell, BP, Amoco, or OREDA, to enhance maintenance and reliability. In this section, the maintenance state of the art is shown for two companies: **Amoco Oil Maintenance, Oreda consortium.**

3.5.1 Amoco Oil Maintenance

Maintain Assets Network (MAN) [JON93, JON93b] has served in Amoco as a vehicle to substantially strengthen the culture of maintenance and reliability in Amoco's* chemical businesses over the past two years. It is one of five "networks of excellence" established by the Amoco Chemicals Manufacturing Council in 1996 to drive improvement in 20 manufacturing metrics established to measure performance of the company's chemical sector and chemical plants.

MAN met for the first time in late 1996 and consisted of representatives from nine U.S. chemical plants, three non-U.S. chemical plants, and one representative for eight fabrics and fibber plants. The group met bimonthly and began to set priorities, with initial activities centred on improving three metrics: maintenance costs, as a percent of estimated replacement value (ERV), availability ratio (reliability), and sustaining capital Baseline costs were established and a goal set for 1999 to reduce maintenance costs by 50 percent. Maintain Assets Network (MAN) is one of five "networks of excellence" established by the Amoco Chemicals Manufacturing Council in 1996 to drive improvement in 20 manufacturing metrics established to measure performance of the company's chemical sector and chemical plants.

3.5.1.1 Networking activities

The Reliability Subcommittee explored reliability best practices inside and outside the chemical sector and the company and reported to the network in December 1997. It recommended the use of 12 reliability practices and six reliability tools:

- **Reliability practices:** elements of preventive maintenance, equipment repair history, corrosion monitoring, portable vibration monitoring, on-line vibration monitoring, infrared thermography, positive material identification, rotating equipment alignment, steam trap monitoring, use oil analysis, rotating equipment balancing, critical equipment monitoring,
- **Reliability tools: r**eliability in engineering, reliability modelling, equipment maintenance plans, root cause failure analysis, reliability centred maintenance, data recording and analysis,
- **Benchmarking practices**: leadership, planning & scheduling, preventive & predictive maintenance, reliability improvement, spare parts management, contract maintenance management, human resource development and training.

All documents were placed on the Amoco Web page and updated as needed.

3.5.1.2 Total Productive Maintenance (TPM)

After a TPM presentation to the Manufacturing Council in July 1998, the TPM Steering Committee (TPMSC) started to develop details around the essential TPM elements Amoco planned to pursue. These elements included: equipment improvement teams (EIT), asset ownership (autonomous maintenance), asset reliability, maintenance effectiveness, early equipment management, training.

The TPMSC then selected four areas of TPM as good places to start. They were autonomous maintenance/clean to inspect; process recording and data entry (PRIDE), an operator-based data gathering process using a combination bar code reader and data entry tool; equipment improvement teams; and work order priority.

These "places to start" provided a means to quickly immerse the plant in a TPM culture using best practices that had proven successful within Amoco. Plants could quickly link up with other plants that had implemented a given process, learn from their experience, and generate early success while developing their longer-range plans.

PRIDE is an Amoco data-gathering tool that also can transform the operator into an equipment reliability resource. Using the Equipment Specific Maintenance Plans (ESMP), employees can select the equipment reliability data to monitor the equipment condition, predict impending failures, and help troubleshoot the root cause of breakdowns. This information can then be trended and used by the equipment improvement teams.

Equipment Improvement Teams (EIT) exist in some form at most of the plants. They are cross-functional teams that are given the time, training, and resources to address the root cause of poor equipment performance or breakdowns. Several plants have well-established EIT programs that serve as the cornerstone of their TPM effort. Other plants use them sporadically to solve major problems. The intent of TPMSC is to upgrade plants' use of EIT.

Work order prioritisation, misuse, and abuse were barriers to plants being able to plan and schedule their work. The Texas City plant recognised this in 1996 and learned a process called the Ranking Index of Maintenance Expenditures (RIME) at a planning and scheduling workshop at the Marshall Institute. It is a process where criticality of the equipment and the importance of the different types of work determine priority with minimum interference from people. Its use dramatically reduced the number of urgent work orders and it was cited as a pocket-of-excellence during benchmarking. It was thought that by using RIME, all plants could do more and better planning and scheduling to reduce costs and take a first step away from reactive unplanned maintenance.

The TPMSC also researched job postings for TPM co-ordinators, external TPM consultants, and Amoco technical experts for specific elements and tools, as well as suggested training and training material. All of this was assembled into a TPM Manual to assist the plants with developing their implementation plans.

3.5.1.2.1 Metrics and measurements

Because the plants used different computer systems and accounting practices, getting consistent un-manipulated data for measurements has been a major problem for MAN. With the impending start up a new company-wide system, MAN commissioned the Measurements Steering Committee (MSC) to develop standard measures. Its objectives are :

- Establish standard CMMS cost reports for all U.S. chemical plants,
- Consolidate MAN best practice scorecards for the purpose of measuring progress,
- Select and define key CMMS metrics to be used and recommend targets,
- Investigate reporting for non-CMMS and non-U.S. plants.

3.5.1.2.2 Effects of strategy

The most dramatic effect of MAN has been the downward trend in maintenance costs. Cost performance has closely followed the goals set forth in the three-tiered strategy and was reduced by 30 percent in two years. However, the improvements in reliability measures did not materialise as quickly as expected but their goals are still expected to be met. Several of the activities sponsored by MAN should deliver additional benefits in 1999 and 2000. The Maintenance and Reliability Strategic Plans at each of the plants were completed in 1998 and should have a substantial impact as they are fully implemented.

Taxonomy no 1.1.1.1.1		Item Machinery Compressors Centrifugal Electric Motor Driven (100-1000)kW									
Population	Installations	Aggregated time in service (10^6 hours)						No of demands			
5	2	Calendar time * 0.1248			Operational time [1] 0.0832						
Failure mode	No of	Failure rate (per 10^6 hours).					Active	Repair (manhours)			
	fail.	Lower	Mean	Upper	SD	MLE	rep hrs	Min	Mean	Max	
Critical	**23*** **23[1]**	**1.31** **2.02**	**217.71** **471.18**	**827.93** **1806.90**	**304.49** **665.33**	**184.33** **276.36**	**10.0**	**0.5**	**24.3**	**186.3**	
Failed to start	1* 1[1]	0.94 0.29	8.42 17.10	22.20 61.58	7.02 22.41	8.01 12.02	-	13.0	13.0	13.0	
Fail while running	14* 14[1]	0.97 1.28	132.09 285.42	499.13 1093.54	183.39 402.61	112.20 168.22	10.0	0.5	24.0	186.3	
Unknown	1* 1[1]	0.94 0.29	8.42 17.10	22.20 61.58	7.02 22.41	8.01 12.02	-	11.4	11.4	11.4	
Vibration	7* 7[1]	0.71 0.70	65.50 140.94	243.34 538.64	89.14 198.24	56.10 84.11	-	0.5	28.5	117.5	

Figure 3-1 : Example of data sheet

3.5.2 Oreda consortium

For many years Norwegian and foreign oil companies have been collaborating in the collection of data on maintenance, reliability and safety of offshore installations. Used in conjunction with specially developed software, these data provide a basis for the preparation of reliability analyses. Such analyses simplify the job of selecting the "best" technical solutions and have led to significant savings in the development and operation of platforms.

In the early 80s a number of oil companies operating in the North Sea and the Adriatic started a collaborative project. The idea was to survey the reliability of important equipment under 'real life' operational conditions. The project, which was given the acronym OREDA (Offshore REliability DAta), has been carried out in five phases until the end of 1999, and is continued in a sixth phase until end of 2001. SINTEF Industrial Management, Dept. of Safety and Reliability has been a member of the project since it began, and has been project manager since 1992.

3.5.2.1 Application

OREDA is a unique data source on failure rates, failure mode distribution and repair times for equipment used in the offshore industry. Such data are necessary for reliability as well as risk analyses. Possible applications are: Reliability, Availability and Maintainability (RAM) analyses, Regularity studies, Risk analyses, Planning and scheduling of maintenance, inspection and testing, Cost benefit studies, Selection of alternative system designs.

The system covers a wide range of components and systems: machinery, electric equipment, mechanical equipment, control and safety equipment, subsea equipment The data in the data base represent the North Sea (Norwegian and UK sector) and the Adriatic Sea. Data have been collected for altogether 7,629 equipment units. The data represent a total observation period of 22,373 years, and 11,154 failures have been recorded.

The data are presented in data sheets for various functions, applications, capacities, fluids, sizes etc. of the equipment. An example of such a data sheet is shown below:

OREDA also includes the following facilities: Maintainable Item versus Failure Mode, Failure Descriptor/Cause versus Failure Mode. This information is valuable when conducting a Failure Mode and Effect Analysis (FMEA). The FMEA analysis is further a major part of a reliability centred maintenance (RCM) analysis.

In OREDA each equipment class (e.g. compressors) is broken down in a **three-level hierarchy** :

- Level one **-** equipment unit (e.g. compressor),
- Level two **-** submit (e.g. lubrication system),
- Level three **-** maintainable item (e.g. bearing).

Maintainable item/level is defined as an item that contribute a part, or an assembly of parts, that is normally the lowest indenture level during maintenance. There are tables with the relative (percentage) contribution from each maintainable item to the total failure rate is given in total and related to the failure modes. In the OREDA database a "**failure descriptor**"**-**field is available. The information in this field describes the apparent or observed failure cause. In the Failure cause versus Failure Mode tables, the relative (percentage) contribution from each failure cause to the total failure rate is given; in sum and related to the failure modes.

3.5.2.2 Bibliography

Reliability data collected and processed in the OREDA project has been published in generic form in three Reliability Data Handbooks; 1984 (1st edition), 1992 (2nd edition) and recently in 1997 (3rd edition) [ORE84, ORE92, ORE97]. They include reliability data on offshore equipment compiled in a form that can easily be used for various safety, reliability and maintenance analyses. The '97 edition of the OREDA Handbook include data from phase III of the OREDA project, and covers the period 1990 **-** 92. The data are compiled in a similar manner as the former two Handbooks, but include also data on a more detailed level typically for use in maintenance analyses (e.g. RCM).

3.5.3 Synthesis

For many years oil companies have been collaborating in industrial management, safety and reliability and consultants in the collection of data on maintenance, reliability and safety of offshore installations. The result has been well established regulations, laws, tools, and data bases. OREDA is the best example of a successful maintenance project. They have been collecting data for ten years by now, starting with a small prototype back in the 80´s. The most dramatic effect of this effort has been the downward trend in maintenance costs. As an example, the MAN project in AMOCO reduced by 30 percent in two years.

However, the improvements in reliability measures did not materialise as quickly as expected but their goals are still expected to be met. Reliability seems to be a strong problem, only related to maintenance in some aspects. Security is also a problem producing more expectations than results. Both topics are very difficult to define with a RCM tool, as they usually depend on many components and aspects of the system (including human behaviour in many cases).The experience in oil industry is a good starting point for the RAIL project because of three main reasons: geographical distribution of the equipment, few types of equipment, safety and reliability is a major issue. The OREDA database is a very good example of how the RAIL database could be.

3.6 THE RCM EXPERIENCES IN SMALLS AND MEDIUM COMPANIES

The RCM approach was applied to define a maintenance strategy for the SMEs. In this paragraph the results of two European projects are presented; the first is related to the foundry sector (TOMAS CRAFT-project) and the second to the sawmills sector (MELISSA CRAFT-project). In both these projects the RCM was used as the main method to define maintenance policies and adaptation was necessary to meet the special constraints of each sector; these adaptations resulted in “lighter” RCM methods which can be transposed to SMEs.

3.6.1 In European SAWMILLS

3.6.1.1 Context

This part presents a development of tools to assist sawmills in optimising of maintenance policies. The work has been carried out in the BRITE EURAM III - CRAFT project : MELISSA. This project is aimed at developing decision making means to optimise sawmill maintenance strategy for maximum cost-effectiveness.

The MELISSA (Maintenance Evaluation by Linked and Integrated Simulation in SAwmills) project is funded by the Commission of the European Communities which gives SMEs an opportunity to obtain support for technological innovation through research and technological development programmes.

Organisations (Functions) :

- ADEPA (R.&D. Maintenance systems),
- FORBAIRT (R.&D. Maintenance systems),
- CRAN-IM & ENSMP (R&D Production systems),
- Sawmills (Equipment utilisation - Sector knowledge),
- Balcas Timber Ltd., (U.K.),
- Palfab Ltd. (Ireland),
- Murray Timber Products Ltd. (Ireland),
- Scieries Réunies d'Abreschviller (SRA) (France),
- S.A. Escourçoise des Bois (ESCOBOIS)(France),
- Société Forestière Oriel (SFO) (France),
- S.A. JEAN MATHIEU (SAJM) (France),
- J&L SIAT S.A. (SIAT) (France),
- RAUNION SAHA OY (RAUNIO) (Finland).

The project applies Reliability Centred Maintenance (RCM) principles to improve the reliability and availability of machinery in sawmills. This approach uses the knowledge of machine component failures to assess, predict, measure and cope with machine breakdowns. Initially the RCM analysis was used to form the basis of improved preventive maintenance planning and to increase the dependability of the critical machines .

3.6.1.2 The MELISSA approach

3.6.1.2.1 Approach requiring the participation of several people

Implementation of the approach implies the setting up of a project group whose all members are involved in the implementation of the RCM method.

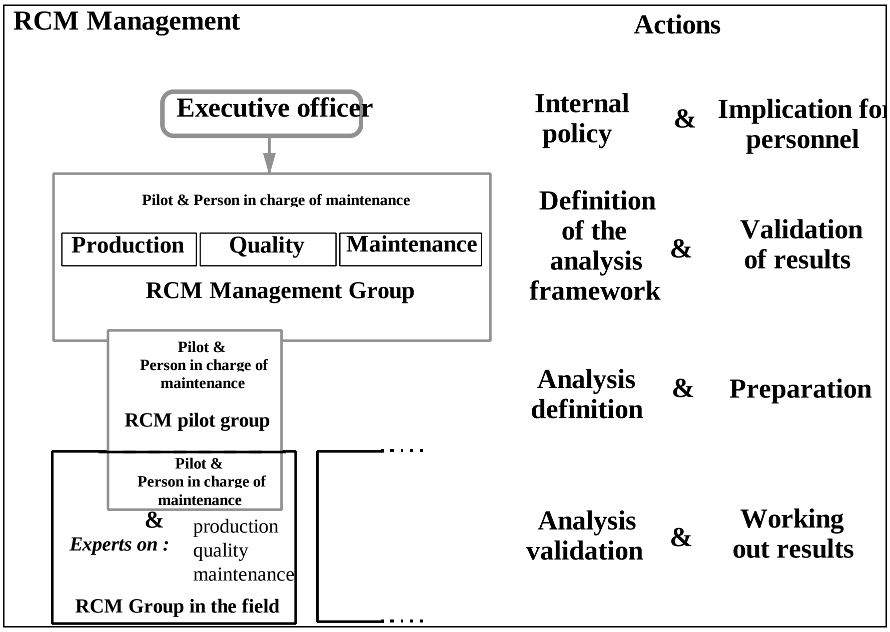


Figure 3-1 : Actors in a RCM approach

3.6.1.2.2 Steps of the method

The implementation of a simplified maintenance plan comprises 4 steps. These steps call on many data and supports relating to production, quality, and maintenance. All along these steps, involved groups must determine objectives having priority and validate results of each phase in order to continue without over diversifying their work.

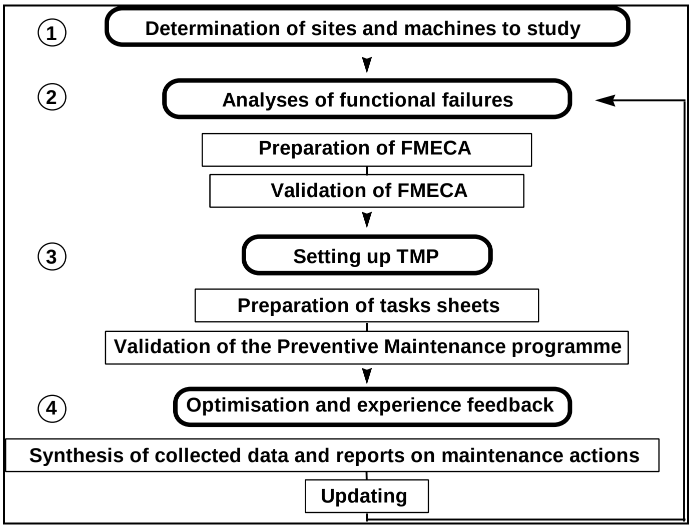


Figure 3-1 : The four main steps of the RCM approach

One of the principle of RCM analyses is limited to the study of the main critical components. The expertise of the sawmill staff, and tools like Pareto studies, critical matrix (with the FMECA principles), feedback data records... are used. The preventive maintenance will be improved for the most important machines and their most important failures .

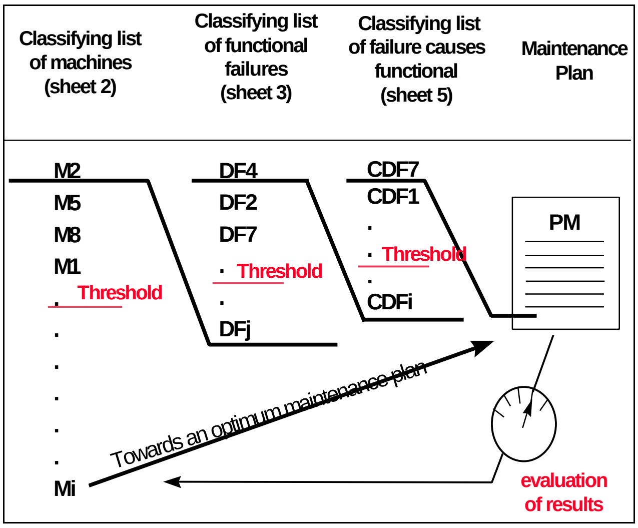


Figure 3-2 : Principle of the study limited to critical components

3.6.1.2.3 Preventive maintenance plans

They are established for the fitters, the operators and all the potential actors in the maintenance for each machine.

For example :

- The operators are assigned 1st level maintenance tasks such as : checking, lubrication ,cleaning...,
- The fitters are assigned more technical tasks such as : replacements, fixings...

3.6.1.2.4 RCM results

Before implementing the RCM approach, the reorganisation of the maintenance department starts by requesting the production manager(s) to assign to each operator responsibility for a machine, so that he is the only person in charge of the maintenance of this machine [MOU97].

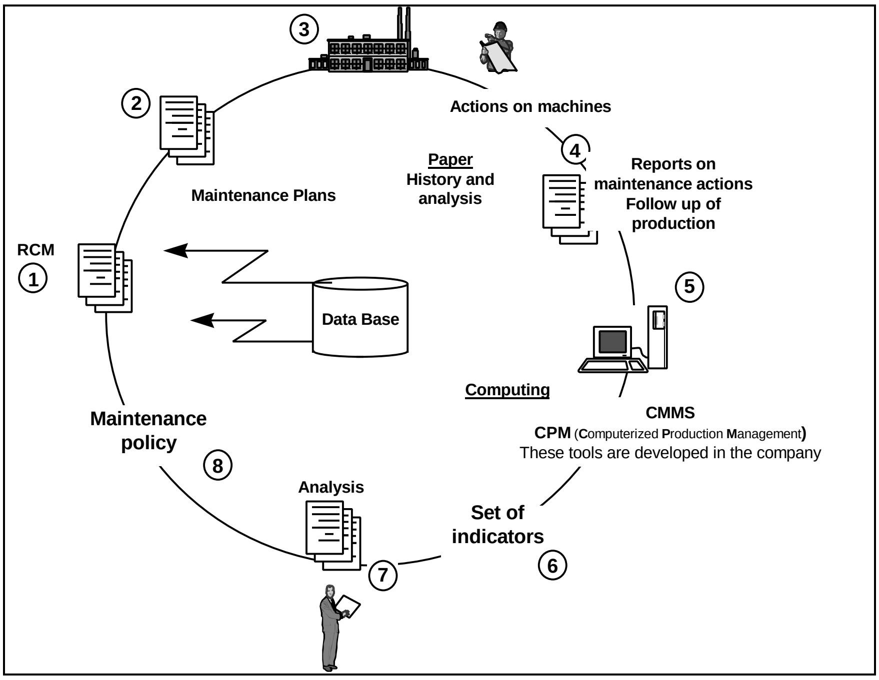


Figure 3-1 : Setting up an improving loop and an experience feedback

RCM ends when optimised preventive maintenance plans are handed over to the production and maintenance people. The staff needs tools to assist them in modifying and optimising the maintenance plans. At the same time is set up the maintenance costs management to make possible the optimisation of the maintenance budget. CMMS can be inserted to computerise the preventive tasks and maintenance costs.

This new organisation permits the implementation of the TPM that has already been set off by the person in charge of each machine and of the preventive tasks.

3.6.1.3 Availability indicator

The best and simplest way to keep the operators involved and motivated is to show them the progress of the percentage of downtimes. Do not use the progress of up-time because numbers like 99 % will appear, and they may look good whereas there are still efforts to make on. The MTBF, MTTR... indicators must be set up but are of no interest to the operators. The most important synthetic indicator is a OEE (Overall Efficiency Effectiveness ratio). The OEE calculation must be adapted to the sawmill specificity.

3.6.1.4 The simulation in the approach

The sawmills involved in the MELISSA project have brought to their the maintenance departments efficiency and a structure which permit to adapt the new technology.

System Simulation is a computerised methodology used to predict the effects of various industrial policies in order that they can be assessed prior to their implementation in a company.

The results of the simulations were used in the first step of the RCM analysis to assist "the management group" in choosing the major machines. The second aspect is to use the results of the RCM analysis in the System Simulation to examine the effects of different maintenance policies on sawmill production output. Special simulation results including economical aspects and benefits expected will be developed at the date of the Conference.

The first step of a simulation research was to create a model of production flow in sawmills. The main result of the simulation research task was a MS-LS (Machine Stop/Line Stop) limit time, an important parameter intended to improve the economical evaluation of the maintenance policies of sawmill equipment...

The final goals and deliverables of the MELISSA project will be 3 software modules for sawmills. These deliverables will be a part of a general decision making means to optimise sawmill maintenance strategy for maximum cost-effectiveness.

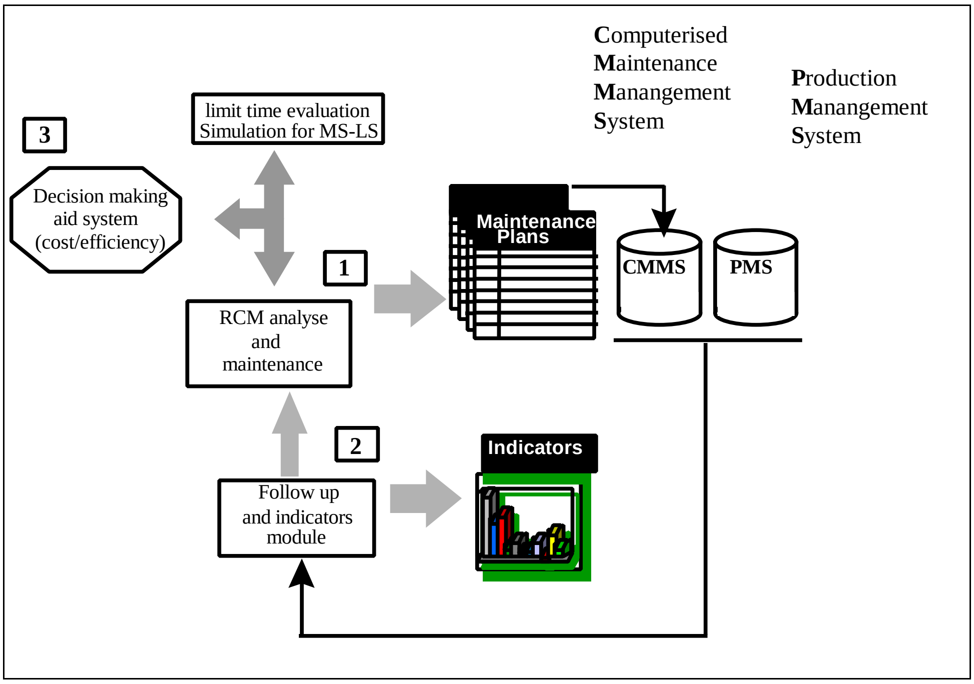


Figure 3-1 : Schema of linking the three main softwares of MELISSA

3.6.2 In European Foundries

3.6.2.1 RCM applied in a medium sized foundry

This example is an extract of the European CRAFT TOMAS project; it enables a company to implement a motivation and dialogue system while working out a new strategy and maintenance plans adapted to the constraints of this type of company.

3.6.2.2 PRESENTATION OF THE FOUNDRY

The main activity of this SME is the casting of non-ferrous metals. Its yearly yield is 12000 tons of raw and machined parts and its facilities are located in the following plants :

- A steel foundry equipped with 4 induction furnaces : 2 of 15 tons capacity and a 15 tons converter ; this plant produce every type of low-carbon steel and high-carbon steel. It includes a mechanised section and a moulding section with a lifting capacity of 100 tons,
- A cast iron foundry of a monthly production capacity of 400 tons ; it produces every grade of MEHANITE cast iron ; its equipment includes :

  -Two mechanised section dedicated to small series of parts whose weight is equal or greater than 50 kg,

  -Two sections of hand-moulding of parts whose weight is up to 40 tons.
- A special alloys foundry of steel worked out by induction furnace ; its yields stainless steels, refractory steels, manganese steels,
- A continuous casting department which produces cast iron MEETHANE bars,
- A heat treatment department which can perform all the treatments necessary for the manufactured products; the furnaces can treat parts of 8 metres diameters and 7 metres height ; besides special treatments performed in air, oil and water, surface hardening are also carried out,
- A machinery workshop of 10 machine-tools.

3.6.2.3 CONTEXT OF THE STUDY

Customers of this company belong to the iron and steel industry, mechanical engineering, electrical and related industries such as chemical and hydraulic industries and dredging equipment manufacturers. Very often foundry products must meet very severe constraints of quality, accuracy and delivery deadlines; the quality function is essential and very exacting.

The maintenance objectives are :

- An improved permanent command of the availability of the production tool,
- A art of the maintenance costs.

3.6.2.4 OBJECTIVES AND HOW TO USE THE RCM METHOD

When making the decision to implement the method, two main objectives are aimed at :

- Improving and preserving the safety and dependability of the strategy machines,
- Controling the costs and optimisation of the preventive maintenance plan.

This latter point must optimise the technico-economical point of view. With this in mind, effort must be made on the right to eliminate the improductive preventive maintenance tasks.

3.6.2.5 START OF THE STUDY : THE GLOBAL ANALYSIS OF THE INDUSTRIAL SITE

The decomposition of the production site will allows a global analysis of the factory

The use of criticality matrices will allow to classify each site for the RCM methodology.

I. Vue d'ensemble des équipements.						
			limites (ce qu'il faut étudier)			
Z1	Receptionde matières prem.		energies, manut.			
Z2	Fusion + Pont x t.		charg. four,fours,contrôle fusion,AOD + énerg., & al.			
Z3	Récuperation + transport sable		silos ext. int.,convoy. méc et pneu. + recup. sable			
Z4	Energies		transp. M.T. et groupe électro.			
Z5	Noyautage		tout pour la mise à dispo. noyaux pour moulage			
Z6	Modelage		atel. bois,plastique, ploistirène et M.O. métal			
Z7	Moulage		moule fermé et ident. et circul. chassis			
Z8	Coulée		ponts manut., préchaufage et prépa. poches			
Z9	Décochage		décocheuse, manut. chassis & pièces,netoy.			
Z10	T. Thermique		manut. fours, mpyens de refroid.			
Z11	Parachevèment		découpe grains, pièces dans le parc			
Matrice de criticité.			*(Priorité à la qualité)*			
		Equipements de production.				
Sécurité						
oui	non			**Qualité**		
			Très important	Important	Peu important	
		Très important	9	8	5	
10		Important	7	6	3	
		Peu important	4	2	1	
Bilan	**Priorités:**					
	n° 1	**Z7**				
	n° 2	**Z4**				
	n° 3	**Z8**				
	n° 4	**Z5**				
	n° 5	**Z10**				
	n° 6	**Z2**				
	n° 7	**Z3**	limite de l'étude			
	n° 8	**Z6**				
	n° 9	**Z11**				
	n° 10	**Z9**				
	n° 11	**Z1**				
Remarque:	*Le poste coulée vient après le poste moulage et il est impératif*					
	de réussir la coulée					
II. Analyse du secteur Moulage. Z7						
	1	Site moulage acier				
	2	Site moulage fonte				
III. Analyse du "Moulage Acier"						
M1	Malaxeur (MA1)					
M2	pont(s) roulants					
M3	sauterelle					
M4	charriot de transfert					
M5	engin de manutention					
M6	Pulseur					

Figure 3-1 : Breaking down of the production site

3.6.2.6 RCM ANALYSIS OF CRITICAL COMPONENT

The following diagram shows the different steps of the RCM application on an industrial site :

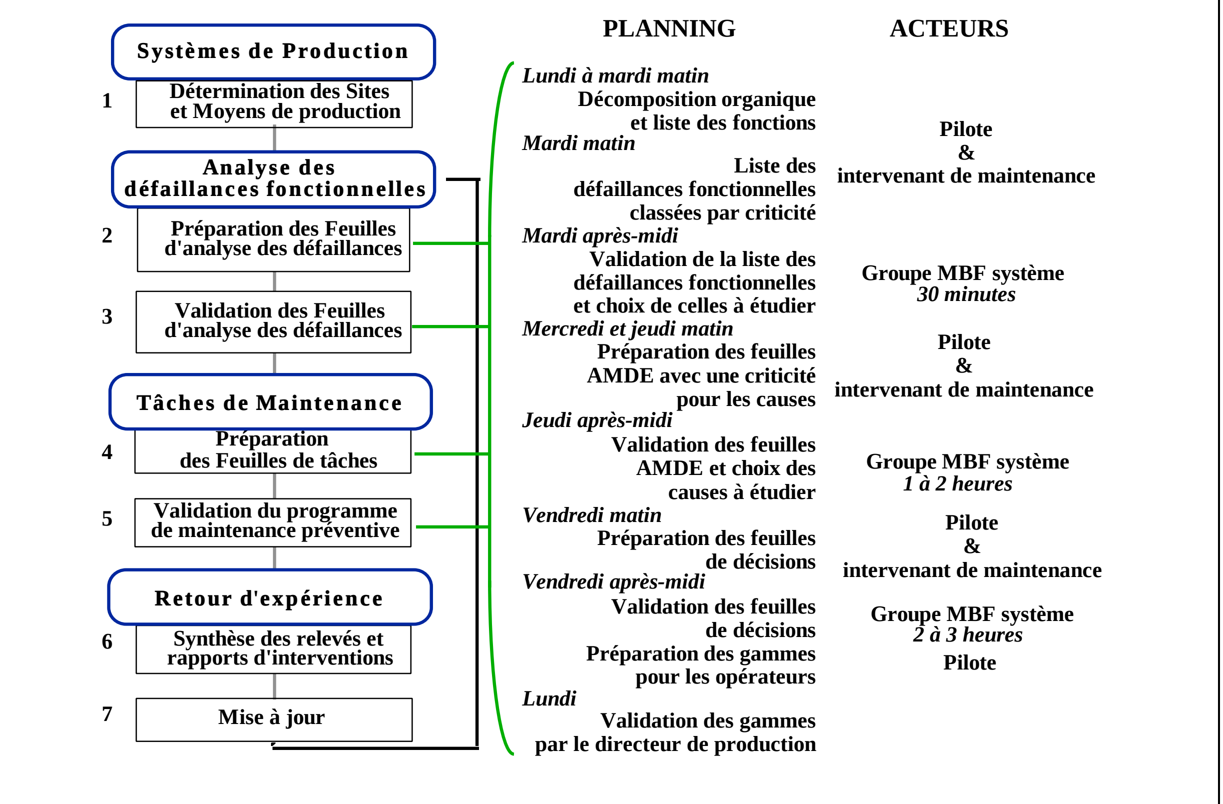


Figure 3-1 : Main steps in the RCM application

3.6.2.7 FAILURE ANALYSIS AND DECISION ON MAINTENANCE TASKS

After the FMECA analysis, the maintenance group defined at the beginning of the study gives information about failure analysis in the table. Then, for each failure cause, a maintenance task is defined and the table which follows is an example of the different tasks determined from the previous analysis.

Feuille de décision				Malaxeur MA1 / Site: Usine Acier Crit					Réf.: RCM Groupe Pilote: GP1 / Pilotes: COTAINA/ PIAULT		Date: 28/09/94
Référence				Criti.		RCM Arbre de décision			Tâche proposée	Interval du prév.	Fait par
F	DF	MD	CD	D F	FCT	évi	séc	pro			
1	A	1	A			N	N	O	à chaque remplacement de vis -> vérifier et réaligner	X tonnes	Maint.
1	A	2	A			O	N	O	prévoir rondelles autoserrantes par mateaux		Maint.
1	A	2	B			O	N	O	néant		
1	A	2	C			O	N	NO	néant		

Figure 3-1 : Table of maintenance tasks

The strong point of this application is the integration of the production in the definition of the maintenance tasks. Thus, the transfer of some fist level tasks- E.I. lubrication - is facilitated.

3.6.2.7.1 Effects on the organisation

In order to control the good development of the action plans, the company installed some control tools. This system allows the evaluation of the action plan results. Its principle is based on :

- Reports on the actions by the maintenance technicians,
- Periodic analysis of the production.

Consequently, a CMMS software is implemented to store this data.

The technical indicators of the production parameters (availability, quality rate, …) of each major machine such as they were defined by the responsible for maintenance, are regularly checked.

3.6.2.7.2 Effects on maintenance and method actions availability obtained

When implementing the methodology, one of the very significant result is the new repartition of the maintenance tasks.

The purpose of implementing preventive actions is to reduce the corrective maintenance.

Cleaning actions could be the beginning of a TPM implementation.

3.6.2.7.3 Obtained results

The RCM methodology indicators allow very quickly to supervise failures and their costs of each production machine.

But a production management must be carried out to facilitate this supervision.

In this case, the implementation of the RCM and CMMS software at the same time involved a best knowledge of the production site and an improved management of the spare part stock.

An optimisation of the maintenance programs can be rapidly considered because of the experience feedback. Thus, maintenance tasks are modified. This methodology is an efficient way for improving quality.

3.6.3 Synthesis

When applying the RCM to SMEs its definition must be modified. In SMEs of the manufacturing sector, availability of the equipment is a more important feature than their intrinsic reliability. Dependability must be provided for a low price. We have to deal with almost unique-of-their-kind systems which have to meet a wide ranges of production needs. The approach must be participative : maintenance operators and production operators have to co-operate to bring their complementary expertise. Then we tend towards a non-exhaustive but essential analysis whose objective is an optimised maintenance plan. The budget of the maintenance department would not be sufficient to achieve all the technically desirable actions if an exhaustive analysis was carried out. The responsible for the maintenance department feels a greater need for a decision making aid tool which will help him organise into a hierarchy and decide which actions to take within the frame of his budget.

3.7 OTHERS INDUSTRIES AREAS

RCM was used in other industrial and non-industrial sectors. In this paragraph we present RCM applied to the design of underground train lines, the definition of the maintenance policy of hospital technical equipment and also to a new definition of maintenance strategy of drinkable water treatment and supply.

3.7.1 RCM APPLIED IN A HOSPITAL

3.7.1.1 Context of the study

The law (July 1991) governing the hospital organisation resulted in a general reorganisation, involving a lot of people concerned by :

- the management,
- the structure evolution,
- the evaluation.

This hospital rule defines a largest autonomy concerning the management of each hospital. The economic aspect is very important because of the colossal budget which must be used efficiently.

The reduction of hospital costs is a problem. The maintenance optimisation is a way to reduce these costs. The development of the risk control becomes a necessary for avoiding the failures which involve big costs.

The improvement of the maintenance function is the guarantee of the durability of the infrastructures and equipment. The purpose consists in :

- giving security to exploitation,
- increasing equipment availability,
- improving service quality,
- decreasing exploitation charges.

3.7.1.2 MAINTENANCE IN THE HOSPITAL

The maintenance function is located at the level of technical department.

The principal functions of the maintenance department are :

- Financial planning and budgetary programme,
- Budgetary management and indicators,
- Technical knowledge of equipment,
- Technical management of equipment,
- Maintenance follow up,
- Administrative management.

The effectiveness of a system is measured as follows :

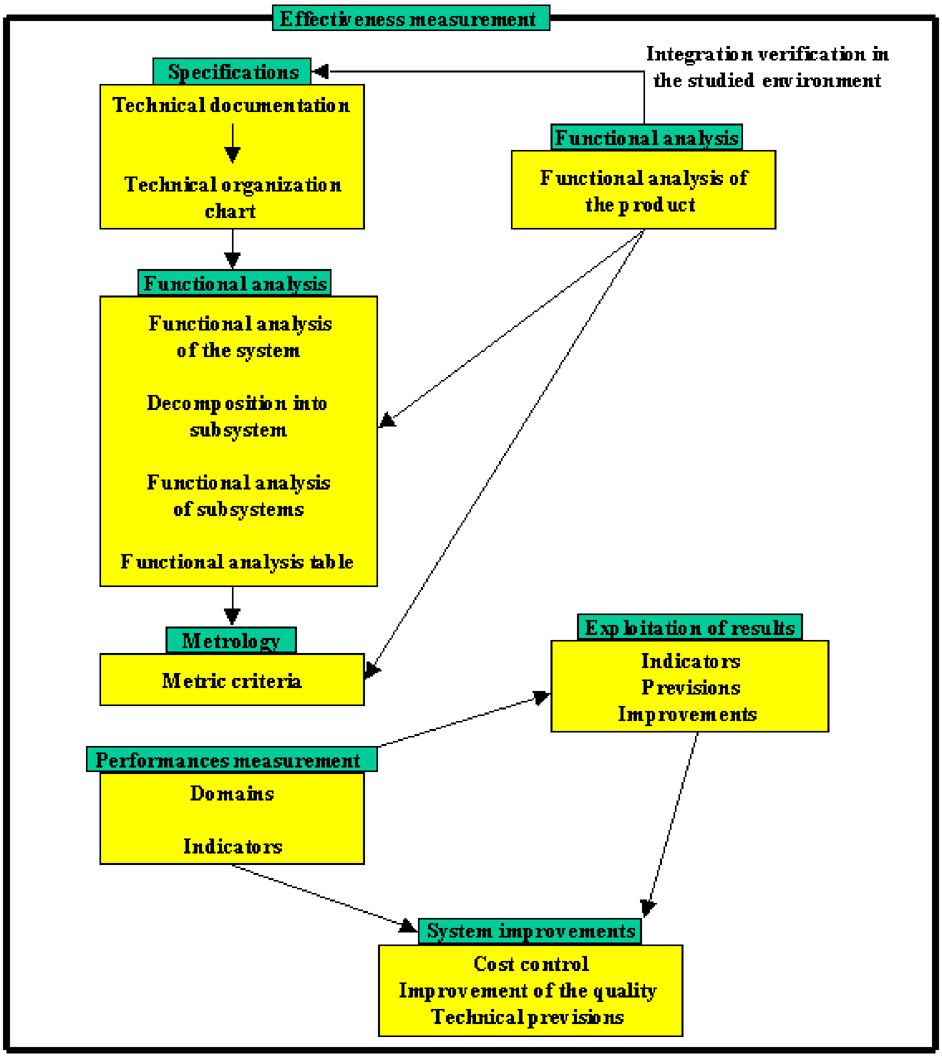


Figure 3-1 : Effectiveness measurement

3.7.1.3 REQUIRED PROCEDURE FOR OPMTIMISATION OF MAINTENANCE

The methodology has two objectives :

- Installing a structure improving the system knowledge,
- Installing indicators.

The two principal parts of the procedures are :

- A forward-looking procedure,
- An operational procedure.

This first step consists in :

- Establishing an architecture of the studied system,

- Verifying the reliability objectives,
- Determining the allocation of maintenance programmes,
- Determining major machines.

3.7.1.4 RESULTS

The different activities linked with the technical control of a process and its dependability, require providing a certain maintenance level.

The optimisation of the maintenance consists in :

- Defining exactly the maintenance tasks,
- Implementing effective tests,
- Managing seriously spare part stocks,
- Making sure that human resources are available and competent.

The research for the optimum is a continuous task. Indeed, it is essential that all information is correctly exchanged.

Each person must have maintenance indicators to evaluate the maintenance efficiency. In the biomedical industry, gains are considerable (more than 30%). Nevertheless, the risk notion is not sufficiently taken into account. Consequently, the appropriateness of the equipment maintenance and the risk level due to a failure entails an increase of the maintenance costs.

3.7.2 RCM APPLIED IN A COMPANY OF WATER DISTRIBUTION

3.7.2.1 PRESENTATION OF THE COMPANY

The “Canal de Provence”(SCP) company deals with hydraulic development in 5 French departments in the South of France.

Structures setting up started in 1960 and is still progressing.

Today’s, the workforce is of 400 people :

- 150 allotted to build new structures,
- 150 allotted to the technical management,
- 100 allotted to the financial management.

Structure designation	Number
Galleries, aqueducts, siphon	147,6 km
Conduits	413 km
Pipes (Diameter 500 mm)	554 km
Pipes (Diameter < 500 mm)	3851 km
Large structures	14
Reserves (> 1 million m^3)	4
Reserves (between 1 million and 10000 m^3)	9
Reserves (< 10000 m^3)	56
Automatic filters	35
Pumping station and superpressure	69

Water treatment station	3
Little station for drinkable water	12
Micro station and Mini station	8
Exploitation local	67
Telecontrol centres	10
Teletransmission station	162
Cable of Teletransmission	455 km

The technical management is performed by two departments :

- The exploitation department,
- The maintenance department.

3.7.2.2 CONTEXT OF THE STUDY

The number of the structure is very large. Their maintenance requires different knowledge.

Thus, the maintenance is divided into workshops :

- Civil engineering,
- Building,
- Pipes,
- Mechanics,
- Electricity,
- Electronics.

Sharing out the budget between corrective maintenance and preventive maintenance is a bit delicate but the RCM methodology can resolve this problem.

3.7.2.3 PRESENTATION OF THE STUDY

The workgroups for this study are :

- The management group,
- The pilot group.

3.7.2.4 APPLICATION OF THE RCM METHODOLOGY

3.7.2.4.1 General

When making the decision to implement the method, there are two main objectives :

- Improvment and preservation of the safety and dependability of the strategic machines,
- Command of costs and optimisation of the preventive maintenance plan.

This latter point must optimise the technico-economical point of view. With this in mind, effort must be made to eliminate the improductive preventive maintenance tasks.

3.7.2.4.2 Identification of critical structures

It was decided to implement the RCM on the structures because of their large number. The identification was facilitated because of existing CMMS software.

26 categories of structures were identified. Their classification is the first step in the RCM methodology

For the continuation of the study the structure called “pumping station” will be used.

3.7.2.4.3 The failure analysis

3.7.2.4.3.1 Breaking down the structure

RCM as well as FMECA are used to find out failures.

The analysis consists in breaking down the structure into items or secondary functions with a view to identifying easily the failures.

The different levels are listed just below :

Level	Designation	Information domain
1	Production structure	Organic
2	Function inside the structure	Functional
3	Workshop in charge of the item	Functional
4	Item	Organic

In FMECA, level 2 identifies the principal functions. Then level 3 lists the different items concerning level 4.

The first step of the study consists in finding and classifying the functional failures (level 2).

3.7.2.4.3.2 Grid of quotation

Two grids are used in order to :

- select functional failures,
- to select the failure modes of each item.

GRAVITY		FREQUENCY			
		1	2	3	4
		Less than one time every 3 years	Less than one time a year	Less than one time a semester	More than one time a semester
	Stoppage time < 12 h and / or maintenance costs < 10 kf				
	Stoppage time < 24 h and / or maintenance costs < 50 kf				
	Stoppage time < 1 week and / or maintenance costs < 100 kf				
	Stoppage time < 1 week and / or maintenance costs > 100 kf				

3.7.2.4.4 Proposed improvements

They were analysed through a logic decision tree.

The decision of improvement is made by taking account of the economic aspect. It consists in a comparison in two cases (before and after improvement) of the annual maintenance cost.

3.7.2.4.5 Operation improvements

A lot of sensors were bought.

Modification of maintenance tasks.

More inspections.

Some discards.

3.7.2.5 STUDY ASSESSMENT

The RCM methodology was very interesting for the SCP. Different rules were set and some improvements were very significant. The consequences of the RCM application were measured thanks to the CMMS software.

3.7.3 AN RCM APPLICATION TO RATP (METEOR)

3.7.3.1 RATP

RATP : Régie Autonome des Transports Parisiens is company which exploits all the Parisian transport net.

This company is divided into 4 main sectors :

- Finance, management and development,
- Service rendered to passagers,
- Social and international relations,
- Maintenance, Works and Industrial Policy (Infrastructure, information system, equipment, logistic, rolling stock, …)

3.7.3.2 METEOR

Figure 3-1 : METEOR picture

In October 1991, RATP started the METEOR project. METEOR is a new generation underground railway whose main feature is its fully automated operation. The length of the line is 19,6 km with 20 stations and will transport 40 000 passengers/hour.

The initial version trains (length : 90 m) were made of 6 carriages and the second generation trains are made of 8 carriages. Trains run at a 40 km/h speed.

3.7.3.3 MSG-3 context

3.7.3.3.1 Objectives

For further information see the summary of the **MSG-3**

3.7.3.3.2 The new maintenance policy of future rolling stock

The maintenance must contribute to the safety and the quality of exploitation.(Costs and availability) .

Before, three levels were defined :

- First level : Concerning the trains, in a specialised workshop for train maintenance,
- Second level : Concerning the carriages, and notably the components which were maintained in an overhaul workshop,
- Third level : Concerning the breaking down of the component whose each item was revised in the overhaul workshop.

The new maintenance policy must comply with the main 5 rules:

- Breaking down into maintenance levels linked to standard X60.010 [AFN88],
- Appropriateness between man, system and environment,
- Use of techniques to maintain safety,
- Development of the quality system,
- Research for the direct and indirect costs optimisation.

Levels	Application	Missions	Activities
1 and 2	Train	Availability and quality of the service	Short duration repairs (<3h) without exploitation stoppage
3	Train + Component	Availability and quality of the service and material durability	Long duration repairs on trains or components involving technical and human resources
4	Component + Item	Material durability	General review for each component
5	Component + Item	Material updating	Modernisation and technological updating

3.7.3.4 METEOR maintenance policy based on safety

The safety practice involved a high level of safety.

Class	Severity level	Consequences for people	Consequences to operation
4	Catastrophic	Fatalities and/or multiples severe injuries	
3	Critical	Single fatality and/or severe injury	Loss of a major system
2	Marginal	Minor injury	Severe system(s) damage
1	Insignificant	Possible minor injury	Minor system damage

Class	Category	Description
F	Frequent	Likely to occur frequently
E	Probable	Will occur several times
D	Occasional	Likely to occur several times
C	Remote	Likely to occur sometime in the system life cycle
B	Improbable	Unlikely to occur but possible
A	Incredible	Extremely unlikely to occur

3.7.3.4.1 The risk classification

This step will classify all the events that could affect safety and it will use the grids of Severity and Frequency .

The criticality of each event will be calculated and a list of critical component is the result of this operation.

3.7.3.4.2 Realisation practice

It consists in :

- Collecting documents,
- Defining the environment,
- Defining the category of the task (Manual, Automatic, …),
- …

3.7.3.4.3 Guarantee to maintain correct safety levels

This guarantee is not only based on global or partial tests of the train but also is based on double control of actions carried out by the maintenance operators.

For each action, a report is done by the person who performed it. Then , this report is checked verified by an another person.

3.7.3.4.4 Complementary obligations to guaranty safety

Technical verification are conducted by the responsible for the maintenance department.

3.7.3.4.5 Results and conclusion

Using the MSG-3 methodology was a real success at all levels.

The profit involved varies between 1% and 25%.

MSG-3 can justify maintenance tasks and guarantees a high level of safety and availability.

RATP has generalised this methodology to improve the whole maintenance activity.

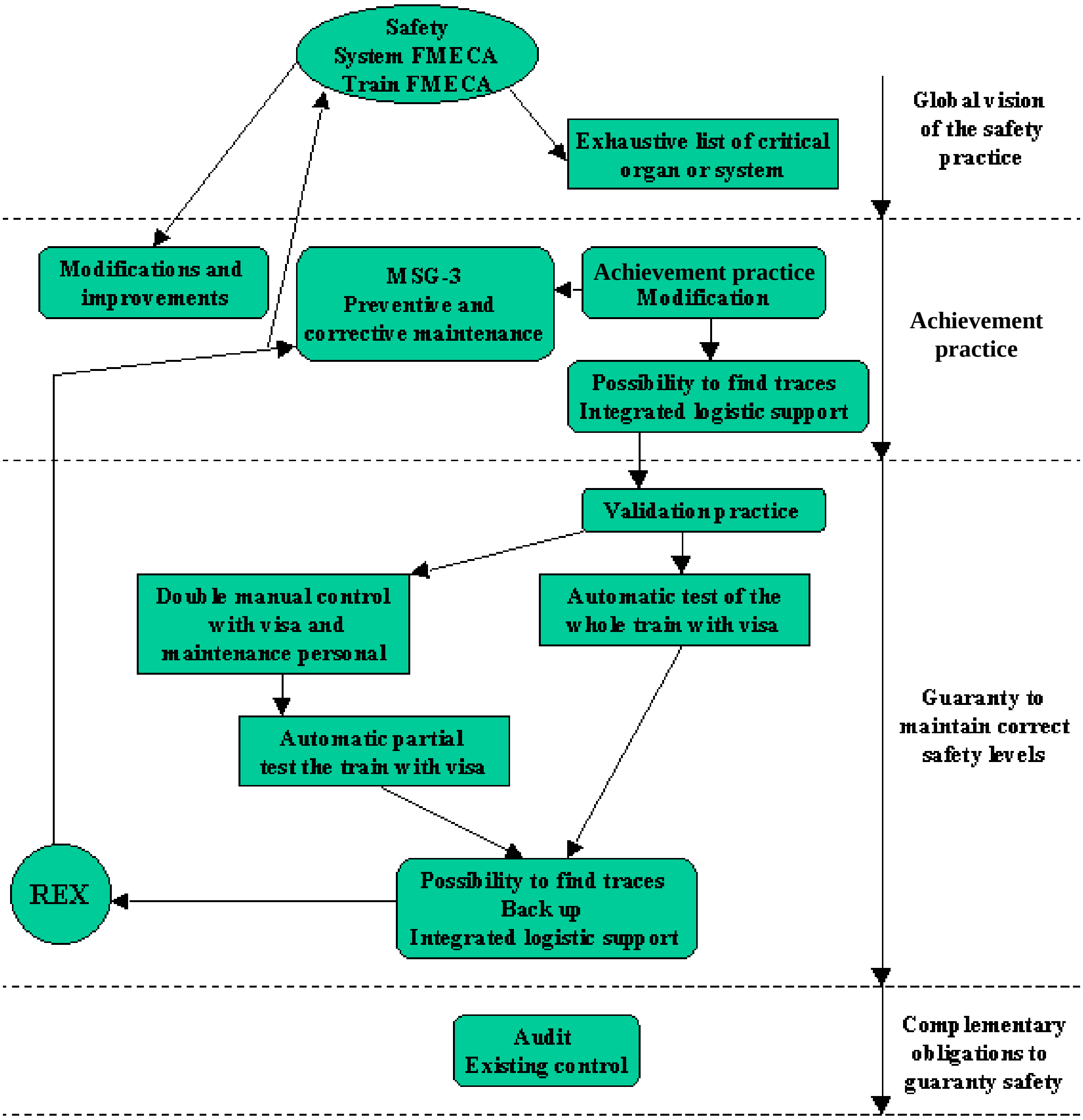


Figure 3-1 : Main steps of the method

4. RCM AND THE STANDARS

Today, an international standard describes the RCM method and offers forms to be used when applying it. This standard should be used as a basis of the approach that will be developed in the RAIL project. This paragraph briefly presents the main aspects of this standard.

In the study of the aspects relating to Reliability, Availability, Maintainability and Safety (RAMS) of all the railway transport related equipment an international standard frames the evaluation of the above characteristics. A short summary of the main parts of this standard, that must be taken into account in the study, is presented.

In the aircraft industry and exploitation the MSG method is currently an internationally recognised standard that must be taken into account in this study. Its last version is briefly presented below.

There are also other standards more particularly relating to maintenance and its management : they will have to be taken into account in the RAIL studies.

4.1 RCM INTERNATIONAL STANDARD

In this part, the references and a summary of the standard is done.

4.1.1 REFERENCES

INTERNATIONAL STANDARD

Dependability management

IEC 60300-3-11

Part 3-11 : Reliability Centred Maintenance (RCM)

4.1.2 INTRODUCTION

Reliability Centred Maintenance (RCM) was initially developed for the commercial aviation industry in the late 1960s, ultimately resulting in the publication of the document, MSG-3, upon which the modern usage of RCM is based. It is now a proven and accepted methodology used in wide range of industries.

The methodology described in this standard is based largely on the tried and tested procedures in MSG-3, but is equally applicable to a variety of equipment other than aircraft.

Reliability Centred Maintenance (RCM) is a method for establishing a preventive maintenance programme which will efficiently and effectively allow the achievement of the required safety and availability levels of equipment and structures, which is intended to result in improved overall safety, availability and economy of operation.

RCM provides the use of a decision logic tree to identify applicable and effective preventive maintenance requirements.

The basic steps in undertaking an RCM analysis are as follows :

- Defining the system and/or subsystem boundaries,
- Defining the functions of each system or subsystem,
- Identifying functionally significant items (FSI),
- Identifying the pertinent FSI functional failure causes,
- Predicting the effects and probability of these failures,
- Using a decision logic tree to categorise the effects of the FSI failures,
- Identifying applicable and effective maintenance tasks which comprise the initial maintenance programme,

- Redesign of the equipment or process, if no applicable tasks can be identified,
- Establishing a dynamic maintenance programme, which results from the routine and systematic update of the initial maintenance programme and its revisions, assisted by the monitoring, collection and analysis of in-service data.

The application of RCM requires detailed analyses of the product and its functions, which can be labour intensive and therefore comparatively expensive.

4.1.3 MAINTENANCE PROGRAMME APPROACH

4.1.3.1 General

The maintenance programme is the set of tasks which result from the RCM analysis. Maintenance programmes are generally composed of an initial programme and on-going, “dynamic” programme.

4.1.3.2 Maintenance programme objectives

As part of maintenance philosophy, the objectives of an effective maintenance programme are :

- To maintain the function in terms of the required safety,
- To maintain the inherent safety and reliability levels,
- To optimise the availability,
- To obtain the information necessary for design improvement of those items,
- To accomplish these goals at a minimum total life cycle cost (LCC), including maintenance costs and costs of residual failures,
- Monitoring the condition of specific safety, critical or costly components is very an important action in a dynamic programme.

4.1.3.3 Maintenance programme content

The content of the maintenance programme itself consists of two groups of tasks :

- A group of preventive maintenance tasks (lubrication, inspection,….),
- A group of non-scheduled maintenance tasks.

4.1.4 RCM BASED PREVENTIVE MAINTENANCE PROGRAMME

4.1.4.1 General

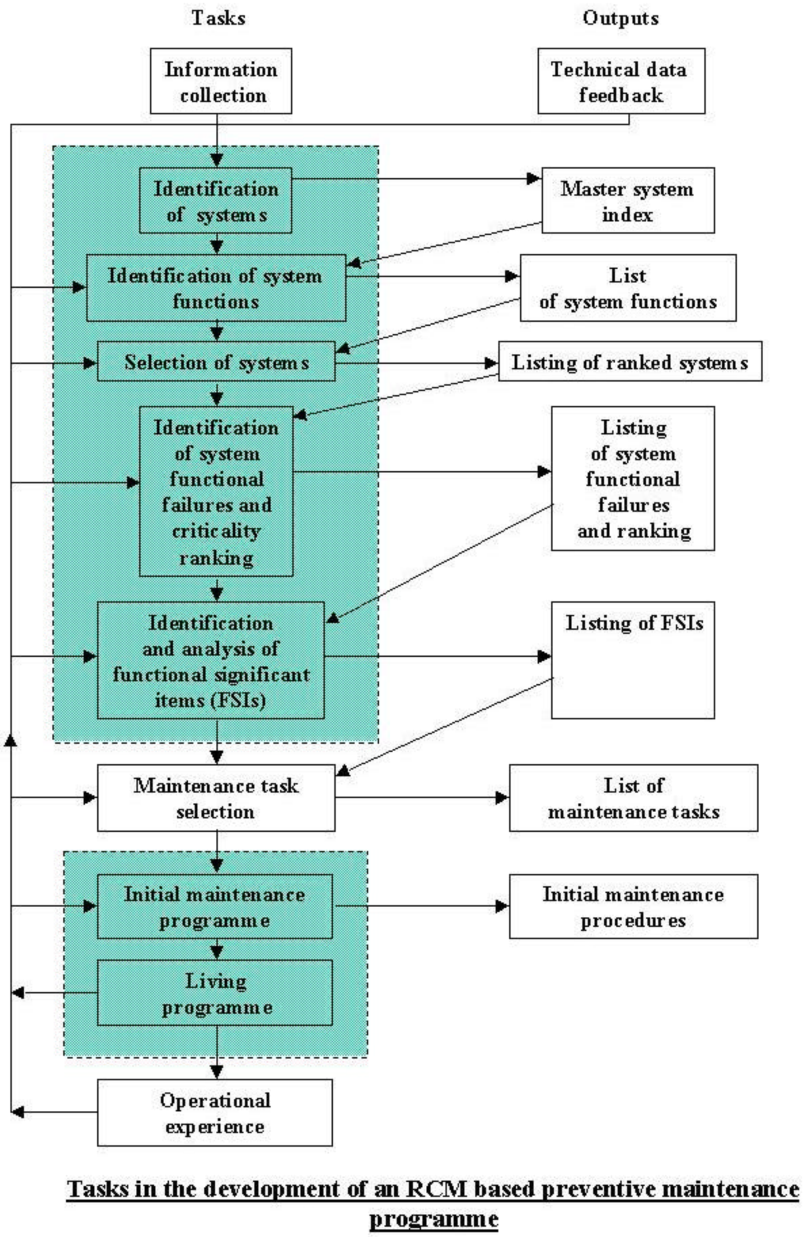


Figure 4-1 : Preventive maintenance programme

4.1.4.2 Maintenance task selection (decision logic tree analysis)

The approach used for identifying applicable and effective preventive maintenance tasks is one which provides a logic path for addressing each FSI functional failure. The decision logic tree uses a group of sequential YES/NO questions to classify or characterise each functional failure.

Two levels are apparent in the decision logic :

- The first level requires an evaluation of each functional degradation/failure for determination of the ultimate effect category, i.e. evident safety, evident operational, evident direct cost, hidden safety, hidden non-safety or none.
- The second level takes the failure causes for each functional degradation/failure into account in order to select the specific type of tasks.

4.2 MSG 3 STANDARD

In this part, the references and a summary of the standard is done.

4.2.1 REFERENCES

Airline /Manufacturer, September 1993

MAINTENANCE PROGRAM DEVELOPMENT DOCUMENT

Originally Issued September 30, 1980 Revision 1: March 31, 1988 Revision 2: September 12, 1993

Maintenance Steering Group - 3 Task Force ; Air Transport Association of America

4.2.2 OBJECTIVE

It is the objective of this document to present a means for developing a maintenance programme which will be acceptable to the regulatory authorities, the operators, and the manufacturers. The maintenance programme details will be developed by co-ordination with specialists from the operators, manufacturers, and the Regulatory Authority of the country of manufacture. Specifically, this document outlines the general organisation and decision processes for determining scheduled maintenance requirements initially projected for the life of the aircraft and/or powerplant.

Historically, the initial scheduled maintenance programme has been specified in Maintenance Review Board (MRB) Reports. MSG-3 is intended to facilitate the development of initial scheduled maintenance programs. The remaining maintenance, that is, non-scheduled or non-routine maintenance, consists of maintenance actions to correct discrepancies noted during scheduled maintenance tasks, other non-scheduled maintenance, normal operation, or data analysis.

This document addresses the development of a maintenance program using the MSG-3 analysis procedure. Any additional requirements developed, using different ground rules and procedures from MSG-3, must be submitted with selection criteria to the Industry Steering Committee for consideration and inclusion in the MRB Report recommendation.

4.2.3 SCOPE

For the purpose of developing an MRB report, MSG-3 is to be used to determine initial scheduled maintenance requirements. The analysis process identifies all scheduled tasks and intervals based on the aircraft's certificates of operating capabilities.

4.2.4 ORGANISATION

The organisation to carry out the maintenance programme development for a specific type aircraft shall be staffed by representatives of the airline operators purchasing the equipment, the prime manufacturers of the airframe and powerplant, and the Regulatory Authority :

- Industry Steering Committee
- Working Groups

4.2.5 PROGRAMME REQUIREMENTS

It is necessary to develop a maintenance program for each new type of aircraft prior to its introduction into airline service.

4.2.5.1 Purpose

The primary purpose of this document is to develop a proposal to assist the Regulatory Authority in establishing an initial scheduled maintenance program for new types of aircraft and/or powerplant. The intent of this programme is to maintain the inherent safety and reliability levels of the equipment. This programme becomes the basis for the first issue of each airline's maintenance requirements to govern its initial maintenance policy. Initial adjustments may be necessary to address operational and/or environmental conditions unique to the operator. As operating experience is accumulated, additional adjustments may be made by the operator to maintain an efficient maintenance program.

4.2.5.2 Approach

It is desirable, therefore, to define in some details :

- The objectives of an efficient maintenance programme,
- The content of an efficient maintenance programme,
- The method by which an efficient maintenance programme can be developed.

4.2.5.3 Maintenance Programme Objectives

The objectives of an efficient airline maintenance programme are:

- To ensure realisation of the inherent safety and reliability levels of the equipment,
- To restore safety and reliability to their inherent levels when deterioration has occurred,
- To obtain the information necessary for design improvement of those items whose inherent reliability proves inadequate,
- To accomplish these goals at a minimum total cost, including maintenance costs and the costs of resulting failures.

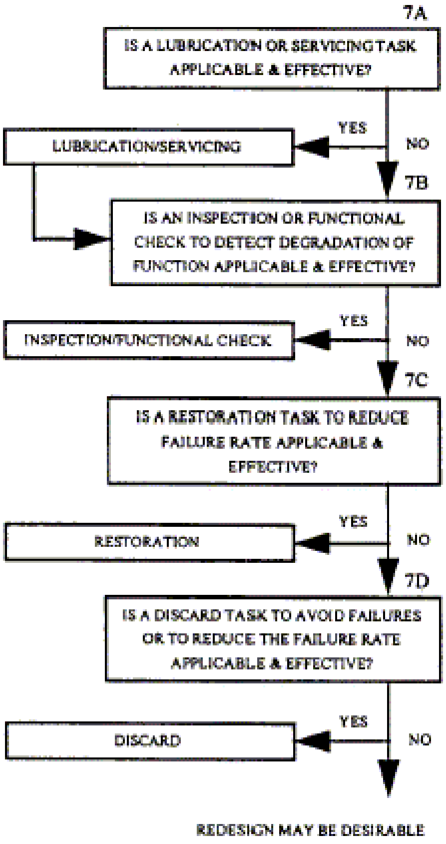


Figure 4-1 : Example of system/powerplant logic diagram

4.3 RAMS RAILWAY APPLICATIONS STANDARD

In this part, the references and a summary of the standard is done.

4.3.1 REFERENCES

EUROPEAN STANDARD EN 50126

Railway applications – The specification and demonstration of Reliability, Availability, Maintainability and Safety (RAMS)

4.3.2 INTRODUCTION

This European Standard provides Railway Authorities and the railway support industry, throughout the European Union, with a process which will enable the implementation of a consistent approach to the management of reliability, availability, maintainability and safety, denoted by the acronym RAMS.

This European Standard can be applied systematically by a railway authority and railway support industry, throughout all phases of the lifecycle of a railway application, to develop railway specific RAMS requirements.

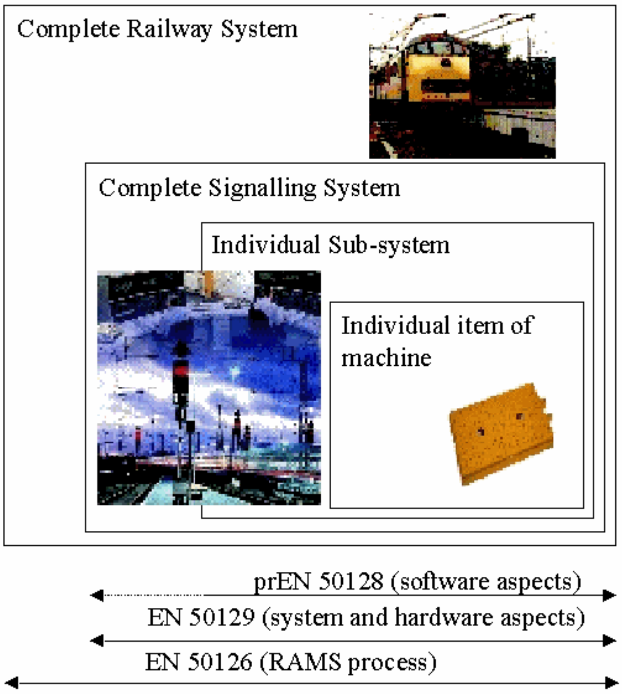
The approach defined in this standard is consistent with the application of quality management requirements contained within the ISO 9000 series of International standards.

4.3.3 SCOPE

This European Standard :

- Defines RAMS,
- Defines a process, based on the system lifecycle and tasks within it, for managing RAMS,
- Enables conflicts between RAMS elements to be controlled and managed efficiently,
- Defines a systematic process for specifying requirements for RAMS,
- Addresses railway specifics.

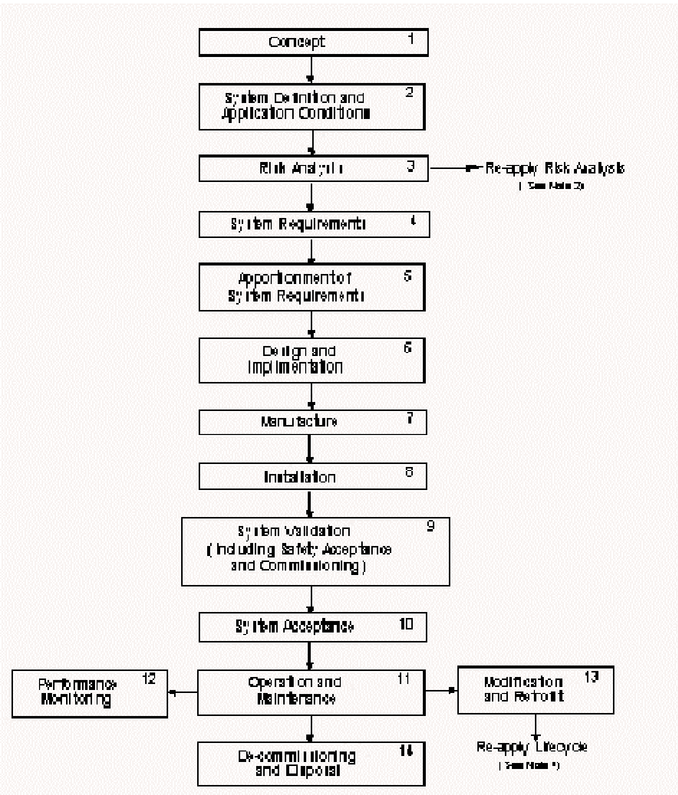
Safety Assessment Criteria



- •EN 50126 : Specifications and demonstration of reliability, availability, maintainability and safety (RAMS)
- •prEN 50128 : Software for railway control and protection systems
- •ENV 50129 : Safety related electronic signalling systems

From : Transportation Systems SiemensAG presentation

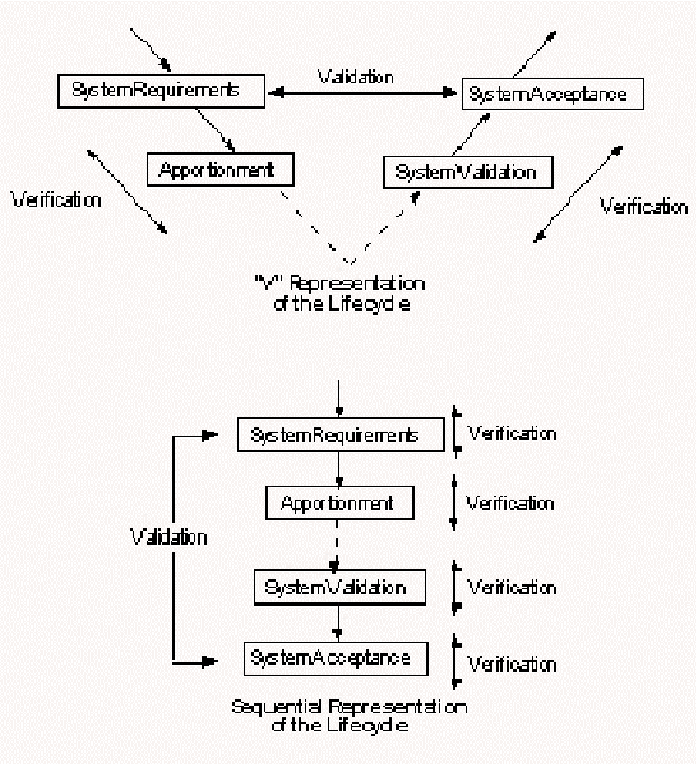
EN 50126 : Specification and demonstration of RAMS (I)



- •Addresses all rail way applications and stakeholders (operators, suppliers, authorities)
- •RAMS lifecycle similar to IEC 61508 standard
- •Defines a systematic, risk-oriented process toward specification and verification of RAMS requirements
- •Integrates RAM and safety activities (establishment and implementation of a RAM Programme and Safety Plan)
- •Clearly defined responsibilities for all RAMS tasks within each phase of lifecycle

From : Transportation Systems SiemensAG presentation

EN 50126 : Specification and demonstration of RAMS (II)



•Does not require or prescribe any particular RAMS targets

•Does not address security issues

•Requires verification activities in each phase and validation of the requirements but does not define the methods to be used

•Requires a Quality Management System (QMS) compliant with the requirements of EN ISO 9000.

•Requires an adequate and affective configuration management system

From : Transportation Systems SiemensAG presentation

4.4 OTHERS STANDARDS

Further to the RCM, others standards were developed in well defined domains such as the U.S.Navy, Naval Engineering, Oil companies, etc…

These standards are the following :

- Mil-Std-2173(AS), US Navy (Air), NAVAIR, NAS Patuxunt River,
- NES 45, Naval Engineering Standard for Ships & Submarines,
- Maintenance Strategy Review (MSR), Shell Expro, Aberdeen,
- …

To complete the RCM standard, there are also other standards which define specific terms relating to maintenance and quality. Among them there are the following :

- IEC 60-050 (191) for reliability terms,
- NFX 60-010 for maintenance terms,
- ISO 9000 for quality model,
- ISO 8402 for quality terms,
- …

5. RCM TOOLS EXISTING

Most RCM tools are provided through Software Toolkits. Usually, those tools offer a range of software packages which include: Reliability Prediction methods (such as MIL-HDBK-217, Bellcore, Mechanical, NPRD), Failure Modes & Effects Analyses (FMEA/FMECA), Maintainability, Reliability Block Diagram (RBD), and Life Cycle Cost tools. The main goal of those tools is to help maintenance people analyse and improve the system to produce a more reliable product.

In this section we introduce some RCM tools which are currently used by maintenance teams. Shorts descriptions, and links, to those tools are shown below :

5.1 MAIN TOOLS

Web Link	Name of the tool	Company	Software kind	Restrictions	Interesting?
Demo FMECA Manager	**FMECA Manager**	Baas&Roost	RCM	CD demo	****
DemoWINMBF	**WinMBF**	Corim Solutions	RCM	CDdemo	****
Http://www.nalda.navy.mil	**IRCMS 6.0**	*US Navy*	RCM+LCC	Software	****
Http://www.powertechnic.com.au	**Analyst**	*Powertechnic Pty Ltd*	LCC	demo	**
Http://www.itemsoft.com	**AvSim**	*Item Software*	LCC+Reliability	CDdemo	*
Http://www.itemsoft.com	**LCC Ware**	*Item Software*	LCC	CDdemo	***
Http://www.itemsoft.com	**Reliability Workbench**	*Item Software*	RCM	CDdemo	**
Http://www.itemsoft.com	**RCMcost**	*Item Software*	RCM+LCC	CDdemo	****
Http://www.itemsoft.com	**Hazop Plus**	*Item Software*	RCM	CDdemo	**
Http://www.itemsoft.com	**Failmode**	*Item Software*	RCM	CDdemo	**
Http://www.itemsoft.com	**TelStress**	*Item Software*	Reliability	CDdemo	**
Http://www.bqr.com	**CARE**	*BQR Reliability Engineering Ltd.*	RCM	demo	**
Http://www.udc.net	**Gtrack**	*United Dynamics "AT"*	RCM	demo	***
Http://www.barringer1.com	**LCC Modelling**	*Barringer and Associates*	LCC	freeware	**
Http://www.pragma.co.za	**ON KEY Analyser**	*PRAGMA*	RCM	demo	**
Http://www.relexsoftware.com	**Relex**	*Relex Software Corp.*	RCM+LCC	demo	**
Http://www.ozemail.com.au	**TDBU**	*Maint. Management Sol.*	RCM	demo	**
Http://www.zip.com.au	**RCM Turbo**	*Strategic*	RCM	X	
Http://www.fractalsoln.com	**Software in Reliability**	*Fractal Solutions*	RCM	X	
Http://www.aladon.co.uk	**Aladon Limited**	*Aladon*	RCM	X	
Http://www.jmssoft.com	**Some Products**	*Jmsoft*	RCM	X	
Http://www.fmeca.com	**FMEA tools**	*Haviland Consulting*	RCM	demo	**
Http://www.lincolntechnology.co	**Reliability Imp. Software**	Lincoln technologies	RCM	X	
Http://www.logistic.com.au	**Omega PS RCM**	*Logistic*	RCM	X	
Http://manufacturing.software-directory.com	Ivara.EXP	*Ivara corporation*	RCM	X	

5.2 THEIR FONCTIONNALITIES

All these maintenance software tools have many efficient functionalities. For the RAIL project, most of these tools are very interesting because of their possibility to support risk or/and cost analyses. The results can directly be used to set up a maintenance programme based on the risks and the costs involved.

Furthermore, the results of these analyses can be backed up in libraries to be used again when similar studies have to be carried out. These data could be inserted in the database developed for the RAIL project.

The following table summarizes all the functionalities of each software and the main functionalities are :

- F1 : Study of the criticality of the “equipment” in its context.
- F2 : Study of the LCC aspect of the “equipment” in its context.
- F3 : A FMECA analysis is proposed.
- F4 : Study of the task with a logic decision tree.
- F5 : Study of the maintenance programme with a cost aspect (benefits)
- Fi : Others functionalities

Name of the tool	F1	F2	F3	F4	F5	Fi
FMECA Manager	*High*	*	*High*	*Lower*	*	*
WinMBF	*High*	*Lower*	*High*	*Lower*	*Medium*	*
IRCMS 6.0	*Medium*	*	*High*	*Medium*	*	*
Analyst	*	*High*	*	*	*	*
AvSim	*	*	*	*	*	*MonteCarlo Sim*
LCC Ware	*	*High*	*	*	*	*
Reliability Workbench	*	*	*High*	*	*	*Failure Tree*
RCMcost	*Lower*	*Lower*	*High*	*Medium*	*Medium*	*
Hazop Plus	*Medium*	*Lower*	*High*	*	*	*
Failmode	*Medium*	*	*High*	*	*	*
TelStress	*	*	*	*	*	*Reliability pred.*
CARE	*High*	*Lower*	*Medium*	*Medium*	*High*	*MTTR MTBF*
Gtrack	*	*	*Medium*	*	*	*
Life Cycle Cost Modelling	*	*High*	*	*	*	*
ON KEY Analyser	*Medium*	*Medium*	*High*	*Medium*	*Medium*	*
Relex	*High*	*Lower*	*High*	*Lower*	*High*	*Failure Tree*
TDBU	*High*	*Medium*	*High*	*High*	*Medium*	*
RCM Turbo	*Lower*	*	*High*	*High*	*Medium*	*
Software in Reliability	*	*	*Medium*	*	*	*
Aladon Limited	*High*	*	*High*	*Lower*	*	*
FMEA tools	*Lower*	*	*High*	*	*	*
Reliability Improvement Software	*Medium*	*Medium*	*High*	*High*	*High*	*
Omega PS RCM	*High*	*	*High*	*	*	*
Ivara.EXP	*Medium*	*Medium*	*High*	*High*	*Medium*	*

5.3 SYNTHESIS

Most of these applications are very efficient. But the RAIL software tool, which must be developed, need have a powerful library of equipment and failure characteristics. It should enable a quick and efficient preparation of better preventive maintenance plans for fixed assets and facilities. Furthermore, we did not have found applications where we can limit the study to a threshold of criticality. The criticality must be evaluated against fixed criteria. The different data must be integrated in a database, this is the reason why the software tool to develop must me able to transmit these data.

In next paragraph, the use of tools such as DataBase Management System (DBMS) will be developed with a view to increasing dependability in the maintenance management.

6. RCM DATABASE

The storage and analysis of data are the key process in maintenance, but when the number of data and components grow it could be a difficult task if we do not have a database with the component characteristics, failure modes, and other issues. Without a database, analysis of the number of incidents would have been more difficult if not impossible.

Databases help manage large amounts of information, and they can become powerful risk management tools when used to study safety process trends and their underlying causes. The incident data revealed process safety trends and pointed to opportunities for improvement. That allowed corporate process safety to eliminate non value-added work and focus on efforts with the greatest impact.

Below we examine the following databases which store information about components and failures :

- RAC (Reliability Analysis Centre) /DSC (Data Sharing Consortium),
- INSC (International Nuclear Safety Centre),
- RAM/SHIPNET (Reliability, Availability, and Maintainability Information Management for the New Millennium),
- OREDA (Off-Shore Reliability Data Base),
- REMAIN Data Base,
- Navy Maintenance Data Base.

6.1 RAC (RELIABILITY ANALYSIS CENTRE) /DSC (DATA SHARING CONSORTIUM)

The RAC Data Sharing Consortium (DSC) compiles and disseminates data on parts and systems. The consortium is open to all commercial, U.S. government, and foreign organisations and is maintained by the Reliability Analysis Centre (RAC). The RAC is a DoD sponsored Information Analysis Centre (IAC) whose purpose is to collect, analyse, and disseminate data and information pertaining to the reliability and quality of components and systems.

The purpose of the DSC is to accumulate data from various sources and assemble this data into a repository accessible to members of the DSC. There are currently many commercial organisations performing component testing to insure that the parts selected for their products or systems are robust enough to operate reliably in the field.

Advantages of data sharing include cost savings from the reduction and/or elimination of redundant testing and the accumulation of a greater base of data with which to evaluate the quality and reliability of parts and systems.

The Data Sharing Consortium database includes the following types of data :

- Part Failure Data : Component screening, qualification, test and field performance data.
- Failure Analysis : Failure analyses and reports which document the actual cause of failure/failure mode and mechanism of failed devices. Failure analysis data will be used to separate part technology factors from application, testing, and repair factors (i.e., electrical overstress, fault isolation ambiguity, and difficulty of repair, and part robustness to repair processes).
- System Failure Data : Manufacturing, test and field data for systems and assemblies.
- Diminishing Sources/Obsolete Devices : Data which addresses life cycle management issues of systems, components and assemblies.
- Common Parts : This data provides members of the DSC with insight which will enable the use of common components among members. This approach can help reduce obsolescence by maximising the use of common parts and thus improve their marketability. It will also aid members who are interested in working together to procure components in common buys between multiple companies.

Data from original equipment manufacturers and component vendors are contained in the DSC. Test and field data are based on the results of component and system testing, or the field usage, or subsequent analysis of each consortium member's systems, assemblies and components including vendor components contained in these systems and assemblies.

6.2 INSC: INTERNATIONAL NUCLEAR SAFETY CENTRE

The International Nuclear Safety Centre (INSC), which operates under the guidance of the Director of International Nuclear Safety and Co-operation (NN-30) in the U.S. Department of Energy (DOE), has the mission of improving nuclear power reactor safety world-wide. The INSC is dedicated to the goals of developing enhanced nuclear safety technology and promoting the open exchange of nuclear safety information among nations. The INSC sponsors scientific research activities as collaborations between the U.S. and its international partners, who have also established safety Centres in their countries. INSC activities are currently focused on Soviet-designed nuclear power plants in Russia and Eastern Europe.

The INSC Database provides an interactively-accessible information resource and communications medium for researchers and scientists engaged in projects sponsored by the INSC. Major portions of the INSC Database are devoted to nuclear plant-specific information, material properties for safety and risk analyses, INSC project documentation, and project-specific reactor safety bibliographies.

Material properties that are to be included in the database are intended to meet the needs of analysts using computer codes and doing experiments for safety evaluation of the world's commercial nuclear reactors. The focus is on the materials used in light water reactors (LWRs) with initial emphasis on high-priority properties of materials unique to Soviet nuclear reactor designs and reactors in eastern-Europe and developing countries.

A list of properties for each material and the phases to be considered are determined based on a *needs assessment*. The longer-term goal is to include data that will meet future needs such as materials used in evolutionary reactor designs, properties of extended burn up fuel, and possibly properties of mixed oxide fuels.

In accord with a proposed database by the IAEA, the properties are organised according to material type in the following categories: fuel, cladding, absorber materials, structural materials, coolants, concrete, and mixtures relevant to last stages of severe accidents. The database user may select one of these categories to obtain a list of materials for which there are properties. The categories for the properties to be assessed are: thermodynamic properties, transport properties, and mechanical properties.

The INSC Database has been implemented by the Reactor Analysis Division at Argonne National Laboratory. Information cataloguing and database maintenance is performed with automated database management systems.

6.3 RAM/SHIPNET (RELIABILITY, AVAILABILITY, AND MAINTAINABILITY INFORMATION MANAGEMENT FOR THE NEW MILLENIUM

During the last six years, progressive maritime organisations around the world have been co-operating to form a world wide information network, called RAM/SHIPNET, to support the optimisation of these three key factors throughout all stages of a vessel's life cycle. Consisting of layered Reliability, Availability and Maintainability (RAM) databases, RAM/SHIPNET has been developed through a co-operative effort of owner/operators, government organisations and regulatory agencies.

The overall objective of RAM/SHIPNET is to provide a sound basis for improving the safety, reliability, and cost effectiveness of marine machinery used onboard vessels. The general objective of RAM/SHIPNET Roll out is to demonstrate and validate the system developed for supporting the optimisation of safety, reliability and cost effectiveness throughout all stages of a vessel's life-cycle. Specific objectives of RAM/SHIPNET are summarised as follows :

- **Capturing RAM Data for continuous improvement:** To provide additional decision support tools and information on equipment and system RAM by capturing key data mainly on corrective maintenance activities. Also, to process this failure legacy data with other maintenance, cost, and safety related data to evaluate performance and identify potential areas for improvement.

- **Sharing RAM data:** To provide software tools and infrastructure for sharing lessons learned at different levels by linking chief engineers, ship operators-managers, regulatory agencies, equipment manufacturers, and shipyards/designers,
- **Providing RAM data for risk based classification:** To provide assistance to migrate from prescriptive class survey rules to risk based/reliability Centred survey rules by providing RAM data on marine machinery,
- **Technology Demonstration:** To demonstrate the added value of using proven RAM and risk management methodologies with pilot studies.

The different databases of RAM/SHIPNET are as follows :

6.3.1.1 LEVEL 1 - DATE & SHIPPER : RAM Database for a single ship

A shipboard equipment Data Entry Program called DATE (DATa Entry Program) for use by vessel Chief Engineers to efficiently collect equipment failure information and compile it in a standard format.

DATE can also be used by a Chief Engineer to view equipment nameplate, machinery history and failure data for his vessel.

A shipboard Equipment Performance Program called SHIPPER (SHIP PERformance Review) for use by vessel Chief Engineers to track and evaluate the reliability of equipment on their vessel based on the failure data compiled by DATE.

6.3.1.2 LEVEL 2 – SPIN : RAM Database for a shipping company for all of its fleet(s)

A Fleet Performance Indicator Program called SPIN (Ships' Performance INdicator) for use by shore side superintendents to track and evaluate equipment reliability for one class of ship or for an entire fleet. This program allows a flexible comparison of reliability data in a multi-level environment, i.e. single equipment, equipment class, single ship, ship group, fleet with each comparative group defined by the software user.

6.3.1.3 LEVEL 3 - SHIPS' RAM : RAM Database for the rest of the maritime industry

A SHIPS' RAM program is currently being developed to merge the data from the fleets of all project participants and to process and disseminate this data upon request. Steps will be taken during the data merging process to maintain the confidentiality of the data source.

6.4 OREDA (OFFSHORE RELIABILITY DATA)

OREDA is a project organisation currently sponsored by nine major oil companies operating in the North sea and Adriatic. OREDA's main purpose is to promote the use and exchange of reliability technology and data among the participating companies.

The objectives of OREDA are :

- Improve safety by providing experience and data on risk
- Improve reliability and availability by use of reliability data to select most reliable equipment and configuration, and reveal weak designs for future improvement.
- Improve maintenance effectiveness by using failure data to refine maintenance strategies.
- Enhance industry reputation by demonstrating a high degree of understanding of equipment performance and characteristics.

The OREDA project has established a comprehensive data bank with reliability data for offshore process, safety and sub sea equipment. The data bank comprises data from a wide variety of platforms, equipment types and operating conditions.

Application of data: availability studies (availability estimates, design optimisation, and equipment selection), risk analysis (estimate probabilities of critical events, estimate survival time for safety-critical items), LCC, benchmarking, maintenance planning and optimisation, condition monitoring, and trend monitoring.

6.4.1 Database structure:

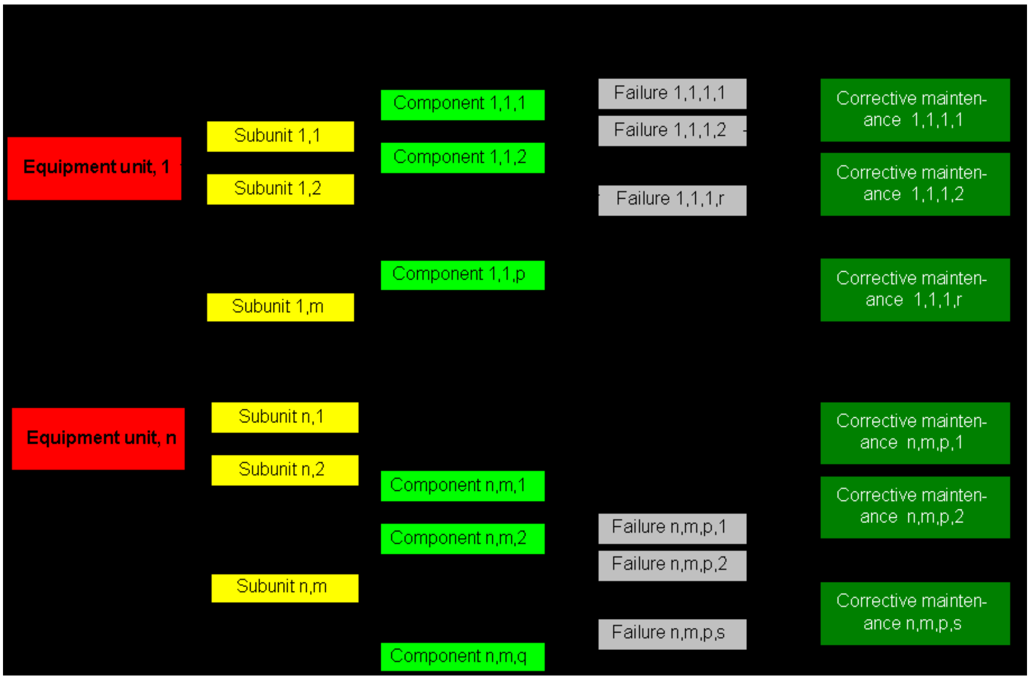


Figure 6-1 : OREDA database structure

Data collected in the various OREDA Phases stored in database:

		Phase II		Phase III		Phase IV	
System		**Inv.**	**Fail**	**Inv.**	**Fail**	**Inv.**	**Fail**
Rotating machinery:	- Gas Turbines	109	2587	54	2667	56	1986
	- Compressors	50	1557	45	1915	75	900
	- Electric generators			49	810	87	367
	- Combustion engines					39	390
	- Electric motors					56	92
	- Pumps	271	3122	103	1549	294	1395
Static equipment	- Vessels	329	411	54	356	148	632
	- Heaters and boilers					8	41
	-Turboexpanders					7	75
	- Heat exchangers	170	116	75	239	51	91
Other	- Valves	645	410	899	726	821	769
	- Control systems					11	73
	- Fire & gas detection equipment			5828	2339	79	69
	- Pipelines					16	23
	- Process sensors/control			487	507	140	47
	- Subsea systems	42	39	35	46	21	38
Total		**1616**	**8242**	**7629**	**11154**	**1909**	**6988**

Figure 6-2 : Data collected in OREDA databases

6.5 REMAIN

To support efficient rail traffic throughout Europe, the research and development project REMAIN aims at the design and promotion of an *integrated system* for the management of *reliability* and *maintainability* in European railway systems.

The project was funded by the Commission of the European Communities, Directorate-General for Transport, under contract *RA-96-SC.230*. REMAIN was launched in November 1996 and successfully completed in April 1998.

The consortium carrying out the project consists of two of the major European railway companies, a public transportation operation, a supplier of infrastructure equipment, a software house, and two of the leading applied research organisations in Europe.

Main objective of the REMAIN project is the promotion of a modular system for the management of reliability and maintainability of European railway systems.

In general the approach of the consortium is based on investigations in the following five areas: to acquire relevant data from components mainly on a sensor basis, to transmit these data into Centres for diagnosis; to diagnose and predict individual component status; to combine individual information to derive RAMS information for railway systems and to define a system architecture for the integration of the preceding areas

6.5.1 Database structure

The general purpose of a REMAIN database is to facilitate systematic storage and retrieval of data. Part of the data is needed locally (level of one railway company), but for the extension of experience also a global database (on European level) is proposed.

The proposed database structure is widely based on experience from the OREDA project. Failures and maintenance activities are linked to an inventory database. One inventory record corresponds to one physical equipment, for example one particular turnout. Inventories are classified into "classes", a "turnout" is an example of a class.

REMAIN proposed two levels of databases: local to each company and European database. The **local REMAIN databases** are implemented and maintained by each participating railway company. Each company chooses its own platform for implementation. **A global common railway database** gives each railway company access to (anonymous) data from other railway companies. The main objectives for such a database are to extend the experience base (more data), to compare the reliability of various products (installing new equipment for which one self does not have experience), to validate LCC data during life time, and to feedback to equipment vendors. This will help the manufactures to improve the reliability of their equipment.

The Reliability and Maintainability data shall be collected in an organised and structured way. The major data categories for inventory, failure, maintenance and state information data are given below. In the proposed REMAIN database structure cost data are not shown explicitly. However, the inventory, failure and maintenance database have fields (variables) describing cost data :

- ***Inventory data:*** The description of an inventory is characterised by identification data (inventory location, classification , installation data, inventory class data, etc), design data (manufacturer' s data, design characteristics, etc.), application data (operation, environment, etc.)
- ***Failure data*** are characterised by identification data, failure record and inventory location. Failure data for characterising a failure, e.g. failure date, maintainable items failed, severity class, failure mode, failure cause, method of observation.
- ***Maintenance data*** are characterised by identification data (maintenance record, inventory location, failure record, etc.) and maintenance data; parameters characterising a maintenance, e.g. date of maintenance, maintenance category, maintenance activity, items maintained, maintenance man-hours per discipline, active maintenance time, down time.

6.6 SYNTHESIS

All RCM toolkits and programs are supported by a database including components, failures, actions to repair, etc. Most of them are small databases for small companies or sections of a company. However, the examples shown in this section are large databases related to a maintenance organisation, and not a single company. The main motivation for them is to provide support, and knowledge, to large companies. However, it is important to notice that most of the former databases have been going on for several years.

The RAIL databases will be also large, and should also last several years to be loaded with data. It should support efficient rail traffic throughout Europe, and to promote an *integrated system* for the management of *reliability* and *maintainability* in European railway systems.

Main objective of the RAIL project database should be the promotion of a modular system for the management of reliability and maintainability of European railway systems. Moreover, it should be structured to allow each railway company to maintain a local database, coexisting with a global database.

OREDA is, with no doubt, the best example to follow.

7. RCM MAIN LINKS AND ORGANISATIONS

7.1 ORGANISATIONS

The European Railways included lot of organisations. These organisations are involved in the dialogue between industries, railways and others. They also monitor and influence Europeans policies and legislative proposals, support development of rail plans and strategies, develop initiatives and provide services to their members. Organisations listed below could help to obtain some pieces of information concerning the infrastructure and all the rules to abide by which a view to a successful RCM implementation.

Organisations	Description	Web / email
UNIFE "Union of European Railway Industries"	Support the development of the railway supply industries and promote rail transport initiatives. Monitor and influence EU policies and support members with products and services.	www.unife.org
UIC "International Union of Railways"	The UIC was founded in 1922, and today is the world wide organisation for co-operation among railway companies. Its activities encompass all fields related to the development of rail transport.	www.uic.asso.fr
CER "Community of European Railways"	It promotes the development of railway transport as an essential step to the creation of a transport system which is both efficient and environmentally sound. In this respect it acts as the railways'collective voice for decision-makers at EU-level.	www.cer.be
RIA "Railway Industry Association"	The trade association for UK-based railway suppliers. It is one of the oldest active trade associations in the UK, dating back to the Locomotive Manufacturers Association of 1875.	www.riagb.org.uk
UITP "International Association of Public Transport"	UITP is a world wide association of urban and regional passenger transport operators, their authorities and suppliers. UITP seeks to promote a better understanding of the potential of Public Transport.	www.uitp.com
HRI "Holland Rail Industry"	Holland trade railway industry association.	hri@fme.nl

7.2 RESEARCH CENTRES AND INTERNATIONAL RAILWAYS LINKS

7.2.1 Research centres

The purpose of these centres is to carry out research, studies and tests in the fields of interest common to the Railways. For the RAIL project, their experience in European projects could be solicited to acquire their knowledge in Railway innovations and much more.

One of them is the ERRI "the European Rail Research Institute" which is a foundation under Dutch law within the International Union of Railways (www.erri.nl).

7.2.2 International Railway

- The European railway server (links) : http://mercurio.iet.unipi.it
- Links : the railway-exchanges : http://www.eRailXchange.com
- Information about accidents : http://danger-ahead.railfan.net
- Links from railways in the world : http://www.ribbonrail.com/nmra/travelw2.html
- The Federal Railroad Administration server : international links : http://www.fra.dot.gov/o/hsgt/inthsgt.htm

7.3 PROJECTS

Today, an important number of projects concerning railway infrastructure were carried out or are still in progress. Some of these projects are very interesting for the RAIL project like :

- REMAIN : Modular system for Reliability and Maintainability Management in European rail Transport. Indeed, an inventory of SCRIC was done during this project and a lot of FMECA analysis were carried out.
- ROMAIN : This European project "RAILWAY OPEN MAINTENANCE TOOL" was developed and some of its studies could be reused.
- INFRACOST III : The Cost of Railway Infrastructure. This project gathered a lot of information concerning the LCC aspect of the maintenance and a few elements and data could be used in the RAIL project.

Some reports about railways projects are available in the UIC server for further information.

7.4 RCM MAIN LINKS

There are a lot of links available in the Web concerning the RCM methodology. Some of them are more interesting than the others. That is why the following list gives the main RCM links in various environments.

7.4.1 Nuclear applications :

This domain requires a high safety level and that is why the method used to implement the RCM is very interesting for the RAIL project :

- Ontario Hydro-Maintenance Re-Engineering : http://www.gastops.com/hydro.html
- International Nuclear Safety : http://insp.pnl.gov:2080

7.4.2 Military and aeronautic applications

These applications are the basis of the RCM method, the MSG-3 concept is implemented in all their equipment :

- AMS Centre of Maintenance technologies end their application in RCM (US Navy) http://www.amsinc.com/cmt
- National Aeronautics and Space Administration Reliability Centred Maintenance Guide : http://www.nrc.gov/NRR/mrule/mrhome.htm
- The Naval Aviation Maintenance Program (NAMP) : http://www.nalda.navy.mil/4790
- Conferences about the US Navy Maintenance Data-Base: http://po7.repair.navy.mil/CODE200/smwg/1199/MEETING/index.html
- RCM programs : http://owww.cecer.army.mil
- National Aeronautics and Space Administration Reliability Centred Maintenance Guide : http://www.nrc.gov/NRR/mrule/mrhome.htm
- Site du FAA (FEDERAL AVIATION ADMINISTRATION), we found several information about the maintenance in aircraft's : http://www.FAA.gov

8. GLOSSARY OF MAINTENANCE TOPICS

A

Accidental Damage (AD)

Physical deterioration of an item caused by contact or impact with an object or influence which is not a part of the equipment, or by human error during manufacturing, operation of the equipment, or by human error during manufacturing, operation of the equipment, or maintenance practices.

Age exploration

A systematic evaluation of an item based on analysis of collected information from in-service experience. It assesses the item's resistance to a deterioration process with respect to increasing age.

Apportionment

A process whereby the RAMS elements for a system are sub-divided between the various items which comprise the system to provide individual targets.

Assessment

The undertaking of an investigation in order to arrive at a judgement, based on evidence, of the suitability of a product.

Audit

A systematic and independent examination to determine whether the procedures specific to the requirements of a product comply with the planned arrangements, are implemented effectively and are suitable to achieve the specified objectives.

Availability

The ability of a product to be in a state to perform a required function under given conditions at a given instant of time or over a given time interval assuming that the required external resources are provided.

C

Commissioning

A collective term for the activities undertaken to prepare a system or product prior to demonstrating that it meets its specified requirements.

Common cause failure

A failure which is the result of an event(s) which causes a coincidence of failure states of two or more components leading to a system failing to perform its required function.

Compatibility

Ability of entities to be used together under specific conditions to fulfil relevant requirements.

Note :

The above definition is valid for the purposes of quality standards. The term "compatibility" is defined differently in ISO/IEC Guide 2.

Compliance

A demonstration that a characteristic or property of a product satisfies the stated requirements.

Condition monitoring

Process under which data on the whole population of specified items in service is analysed to indicate whether some allocation of technical resources is required. Not a preventive process, CM allows failures to occur, and relies upon analysis of operating experience information to indicate the need for corrective action.

Configuration management

A discipline applying technical and administrative direction and surveillance to identify and document the functional and physical characteristics of a configuration item, control change to those characteristics, record and report change processing and implementation status and verify compliance with specified requirements.

Corrective maintenance

The maintenance carried out after fault recognition and intended to put a product into a state in which it can perform a required function.

Criticality

Numerical index of the severity of an effect combined with the probability or expected frequency of its occurrence.

Customer

Recipient of a product provided by the supplier.

Notes :

1. In a contractual situation, the customer is called the "purchaser".

2. The customer may be, for example, the ultimate consumer, user, beneficiary or purchaser.

3. The customer can be either external or internal to the organisation.

D

Damage tolerant

An item is judged to be damage tolerant if it can sustain damage and the remaining structure can withstand reasonable loads without structural failure or excessive structural deformation until the damage is detected.

Dependability

Collective term used to describe the availability performance and its influencing factors : reliability performance, maintainability performance and maintenance-support performance.

Notes :

1. Dependability is used only for general descriptions in non-quantitative terms.

2. Dependability is one of the time-related aspects of quality.

3. The definition of dependability and note 1 given above are taken from IEC 50 (191), which also includes related terms and definitions.

Dependent failure

The failure of a set of events, the probability of which cannot be expressed as the simple product of the unconditional probabilities of the individual events.

Direct adverse effect on operating safety

Direct : to be direct, the functional failure or resulting secondary damage must achieve its effect by itself, not in combination with other functional failures (no redundancy exists and it is a primary item necessary for safe operation).

Adverse Effect on Safety : this implies that the consequences are extremely serious or possibly catastrophic and might cause the loss of equipment or injury to occupants or operating crew.

Operating : this is defined as the time interval during which the equipment is in operation and includes the presence of an operating crew and/or any occupants.

Discard

The removal from service of an item at a specified life limit.

Down time

The time interval during which a product is in a down state [IEC 60050 (191)].

E

Economic effects

Failure effects which do not prevent equipment operation, but are economically – undesirable due to added labour and material cost for equipment or shop repair.

Economic Life Limit

A life limit imposed on an item based on cost effectiveness to reduce the frequency of age related failure.

Engineering Failure Mode

The specific engineering mechanism of failure which leads to a particular functional failure.

Entity Item

That which can be individually described and considered.

Note :

An entity may be, for example :

- *an activity or a process,*
- *a product,*
- *an organisation, a system or a person, or*
- *any combination thereof.*

Environmental Deterioration (ED)

Physical deterioration of an item's strength or resistance to failure, as a result of chemical interaction with its climate or environment.

F

Failure

The termination of the ability of an item to perform a required function.

Note : When the term failure is used within a contract in the context of RCM, it should be defined as : "A failure is the presence of an unsatisfactory condition which is related to a specific situation and from the perspective of a particular observer". The particular observer should be defined.

Failure cause

The circumstances during design, manufacture or use which have led to failure.

Failure effect

The immediate effects of each failure mode on the Functionally Significant Item, on other FSIs and on the required functions of the Equipment.

Failure mode

One of the possible states of a failed item, for a given required function.

Failure rate

The limit, if this exists, of the ratio of the conditional probability that the instant of time, T, of a failure of a product falls within a given time interval (t, $t + \Delta t$) and the length of this interval, Δ, when Δt tends towards zero, given that the item is in an up state at the start of the time interval.

Fatigue Damage (FD)

The initiation of a crack or cracks due to cyclic loading and subsequent propagation.

Fatigue related sampling program

Inspections on specific equipment selected from those which have the highest operating age/usage in order to identify the first evidence of deterioration in their condition caused by fatigue damage.

Fault mode

One of the possible states of a faulty product for a given required function [IEC 60050 (191)].

Fault tree analysis

An analysis to determine which fault modes of the product, sub-products or external events, or combinations thereof, may result in a stated fault mode of the product, presented in the form of a fault tree.

Function

The normal characteristic actions of an item.

Functional check

Quantitative check to determine if one or more functions of an item performs within specified limits.

Functional failure

The termination of the ability of an item to perform a required function within specified limits.

Functionally Significant Item (FSI)

An item, identified during Functional Failure Analysis, whose failure : could affect safety, and/or is undetectable, or likely to be undetectable, during operations, and/or could have significant operational impact, and/or could have significant economic impact.

H

Hard Time

Scheduled removal of all units of an item before some specified maximum age limit, to prevent functional failure.

Hazard

A physical situation with a potential for human injury.

Hazard log

The document in which all safety management activities, hazards identified, decisions made and solutions adopted are recorded or referenced. Also known as a "Safety Log" [ENV 50129].

Hidden function

A function which is normally active and whose cessation will not be evident to the operating crew during performance of normal duties.

A function which is normally inactive and whose readiness to perform, prior to it being needed, will not be evident to the operating crew during performance of normal duties.

I

Inherent level of reliability and safety

That level which is built into the unit and therefore inherent in its design. This is the highest level of reliability and safety that can be expected from a unit, system or equipment if it receives effective maintenance. To achieve higher levels of reliability generally requires modification or redesign.

Inspection

An examination of an item against a specific standard.

Inspection – Special detailed

An intensive examination of a specific location similar to the detailed inspection except for the following differences. The examination requires some special techniques such as non-destructive test techniques, dye penetrate, high-powered magnification, etc., and may require disassembly procedures.

Inspection – Detailed

An intensive visual examination of a specified detail, assembly, or installation. It searches for evidence of irregularity using adequate lighting and, where necessary, inspection aids such as mirrors, hand lens, etc. Surface cleaning and elaborate access procedures may be required.

Inspection – General visual

A visual examination that will detect obvious unsatisfactory conditions/discrepancies. This type of inspection may require removal of fillets, fairing, access panels/doors, etc. Workstands, ladders, etc. may be required to gain proximity.

Interchangeability

Ability of an entity to be used in place of another, without modification, to fulfil the same requirements.

Notes :

1. A qualifier such as "functional interchangeability" or "dimensional interchangeability" should be used depending on specific circumstances.

2. The above definition is valid for the purposes of quality standards. The term "interchangeability" is defined differently in ISO/IEC Guide 2.

Item

Any level of hardware assembly (i.e. : system, sub-system, module, accessory, component, unit, part, etc).

L

Logistic support

The overall resources which are arranged and organised in order to operate and maintain the system at the specified availability level at the required lifecycle cost.

Lubrication and servicing

Any act of lubricating, replenishing consumables, fluid levels, or pressures, etc. for the purpose of maintaining inherent design capabilities.

M

Maintainability

The probability that a given active maintenance action, for an item under given conditions of use can be carried out within a stated time interval when the maintenance is performed under stated conditions and using stated procedures and resources [IEC 60050 (191)].

Maintenance

The combination of all technical and administrative actions, including supervision actions, intended to retain a product in, or restore it to, a state in which it can perform a required function [IEC 60050 (191)].

Maintenance policy

A description of the inter-relationship between the maintenance echelons, the indenture levels and the levels of maintenance to be applied for the maintenance of an item [IEC 60050 (191)].

Maintenance programme

Methods, procedures and resources required for sustaining the support of an item throughout its life cycle.

Maintenance tasks

An action or set of actions required to achieve a desired outcome which restores an item to – or maintains an item in – serviceable condition, including inspections and determination of condition.

Mission

An objective description of the fundamental task performed by a system.

Mission profile

Outline of the expected range and variation in the mission with respect to parameters such as time, loading, speed, distance, stops, tunnels, etc. in the operational phases of the lifecycle.

MSG-1

A working paper prepared by the 747 Maintenance Steering Group, published in July 1968 under the title Handbook : Maintenance Evaluation and Program Development (MSG-1) ; the first use of decision-diagram techniques to develop an initial scheduled maintenance program.

MSG-2

A refinement of the decision-diagram procedures in MSG-1, published in March 1970 under the title MSG-2 : Airline/ Manufacturer Maintenance Program Planning Document ; the immediate precursor of RCM methods.

MSG-3

Further refinement of MSG-2, developed for the 757, 767 series aircraft, published in October 1980 under the title : MSG-3 : Airline/Manufacturer Maintenance Program Planning Document. The MSG-3 was revised in March 1988.

Multiple location fatigue damage

The presence of secondary damage (cracking) dependent or independent of the primary damage (crack).

O

On-Condition

Process having repetitive inspections or tests to determine the condition of units with regard to continued serviceability (corrective action is taken when required by item condition).

Operating crew normal duties

Operating Crew : qualified personnel who are on duty.

Normal Duties : Those duties associated with the routine operation of the equipment, on a daily basis, to include the following :

a) procedures and checks performed during equipment operation ;

b) recognition of abnormalities or failures by the operating crew through the use of normal physical senses (e.g. : smell, noise, vibration, temperature, visual observation of damage or failure, changes in physical input force requirements, etc.).

Operational check

An operational check is a task to determine that an item is fulfilling its intended purpose. Does not require quantitative tolerances. This is a failure finding task.

Operational effects

Failure effects which interfere with the completion of the intended operations. These failures cause delays, cancellations of service, down time, reduced production, etc.

Other structure

Structure which is judged not to be a structurally significant item. "Other structure" is defined both externally and externally within zonal boundaries.

P

Potential Failure

A quantifiable failure symptom which indicates that a potential failure is imminent. This includes out of tolerance condition or failure to provide accurate measurement for calibration requirements analysis.

Preventive maintenance

The maintenance carried out at pre-determined intervals or according to prescribed criteria and intended to reduce the probability of failure or the degradation of the functioning of an item [IEC 60050 (191)].

Purchaser

Customer in a contractual situation.

Notes :

The purchaser is sometimes referred to as the "business second party".

Q

Quality

Totality of characteristics of an entity that bear on its ability to satisfy stated and implied needs.

Notes :

1. In a contractual environment, or in a regulated environment, such as the nuclear safety field, needs are specified, whereas in other environments, implied needs should be identified are defined.

2. In many instances, needs can change with time ; this implies a periodic review of requirements for quality.

3. Needs are usually translated into characteristics with specified criteria. Needs may include, for example, aspects of performance, usability, dependability (availability, reliability, maintainability), safety, environment, economics and aesthetics.

4. The term "quality" should not be used as a single term to express a degree of excellence in a comparative sense, nor should it be used in a quantitative sense for technical evaluations. To express these meanings, a qualifying adjective should be used. For example, use can be made of the following terms :

"relative quality" where entities are ranked on a relative basis in the degree of excellence or comparative sense ;

"quality level" in a quantitative sense (as used in acceptance sampling) and "quality measure" where precise technical evaluations are carried out.

5. The achievement of satisfactory quality involves all stages of the quality loop as a whole. The contributions to quality of these various stages are sometimes identified separately for emphasis ; for example, quality due to definition of needs, quality due to product design, quality due to conformance, quality due to product support throughout its lifetime.

6. In some references, quality is referred to as "fitness for use" or "fitness for purpose" or "customer satisfaction" or "conformance to the requirements". These represent only certain facets of quality, as defined above.

R

Railway authority

The body with the overall accountability to a regulator for operating a railway system.

Note : Railway authority accountabilities for the overall system or its parts and lifecycle activities are sometimes split between one or more bodies or entities. For example :

- *the owner(s) of one or more parts of the system assets and their purchasing agents ;*
- *the operator of the system ;*
- *the maintainer(s) of one or more parts of the system ; etc.*

Such splits are based on either statutory instruments or contractual agreements. Such responsibilities should therefore be clearly stated at the earliest stages of a system lifecycle.

Railway support industry

Generic term denoting supplier(s) of complete railway systems, their sub-systems or components parts.

RAM programme

A documented set of time scheduled activities, resources and events serving to implement the organisational structure, responsibilities, procedures, activities, capabilities and resources that together ensure that an item will satisfy given RAM requirements relevant to a given contract or project [IEC 60050 (191)].

Reliability

The probability that an item can perform a required function under given conditions for a given time interval (t1, t2) [IEC 60050 (191)].

Reliability Centred Maintenance

A systematic approach for identifying effective and efficient preventative maintenance tasks for equipment and items in accordance with a specific set of procedures and for establishing intervals between maintenance tasks.

Reliability growth

A condition characterised by a progressive improvement of a reliability performance measure of an item with time [IEC 600500 (191)].

Repair

That part of a corrective maintenance in which manual actions are performed on a item [IEC 60050 (191)].

Residual strength

The strength of a damaged structure.

Restoration

That work necessary to return the item to a specific standard. Restoration may vary from cleaning or replacement of single parts up to a complete overhaul.

That event when an item regains the ability to perform a required function after a fault [IEC 60050 (191)].

Risk

The probable rate of occurrence of a hazard causing harm and the degree of severity of the harm.

S

Safe Life Limit

A life limit imposed on an item that is subject to a critical failure established as some fraction of the average age which test data show that failure will occur.

Safe Life structure

Structure which is not practical to design or qualify as damage tolerant. Its reliability is protected by discard limits which remove items from service before fatigue cracking is expected.

Safety

Freedom from unacceptable risk of harm.

Safety case

The documented demonstration that the product complies with the specified safety requirements.

Safety integrity

The likelihood of a system satisfactorily performing the required safety functions under all the sated conditions within a stated period of time.

Safety integrity level (SIL)

One of a number of defined discrete levels for specifying the safety integrity requirements of the safety functions to be allocated to the safety related systems. Safety Integrity Level with the highest figure has the highest level of safety integrity.

Safety plan

A documented set of time scheduled activities, resources and events serving to implement the organisational structure, responsibilities, procedures, activities, capabilities and resources that together ensure that an item will satisfy given safety requirements relevant to a given contract or project.

Safety regulator authority

Often a national government body responsible for setting or agreeing the safety requirements for a railway and ensuring that the railway complies with the requirements.

Scheduled maintenance

Any of the maintenance opportunities which are preplanned and are accomplished on a regular basis.

Secondary damage

Damage to a system or sub-system resulting from the failure of a separate system.

Structural detail

The lowest functional level in an equipment structure. A discrete region or area of a structural element, or a boundary intersection of two or more elements.

Structural element

Two or more structural details which together form an identified manufacturer's assembly part.

Structural element

One or more structural elements which together provide a basic structural function.

Structural Significant Item (SSI)

Any detail, element or assembly, which contributes significantly to carrying operating, gravity, aero-dynamic, hydrodynamic, ground, pressure or control loads and whose failure could affect the safety critical structure of the Equipment.

Supplier

Organisation that provides a product to the customer.

Notes :

1. In a contractual situation, the supplier may be called the "contractor".

2. The supplier may be, for example, the producer, distributor, importer, assembler or service organisation.

3. The supplier can be either external or internal to the organisation.

System lifecycle

The activities occurring during a period of time that starts when a system is conceived and end when the system is no longer available for use, is decommissioned and is disposed.

Systematic failures

Failures due to errors in any safety lifecycle activity, within any phase, which cause it to fail under some particular combination of inputs or under some particular environmental condition.

T

Test

An experiment carried out in order to measure, quantify or classify a characteristic or a property of an item.

Tolerable risk

The maximum level of risk of a product that is acceptable to the Railway Authority.

V

Validation

Confirmation by examination and provision of objective evidence that the particular requirements for a specific intended use have been fulfilled.

Verification

Confirmation by examination and provision of objective evidence that the specified requirements have been fulfilled.

Visual check

A visual check is an observation to determine that an item is fulfilling its intended purpose. Does not require quantitative tolerances. This is a failure finding task.

Visual/automated check

Visual check is an observation to determine that an item is fulfilling its intended purpose and is a failure finding task. It does not require quantitative tolerance. This check may also involve the downloading of failure data from a monitoring system.

W

Wearout

The process which results in an increase of the failure rate or the conditional probability of failure with increasing number of life units.

Z

Zonal inspection

A general inspection of a specific area of an aircraft at scheduled intervals. A zonal inspection is for obvious, defects, such as leaks, frayed cables, cracks, corrosion, or physical damage.

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10. CONCLUSION

In this part a survey of the state-of-the art when applying the RCM method was carried out. After a brief review of its approach and developments since its birth from MSG, we presented its own developments in several industries sectors. From these study we can note the followings :

- The RCM approach can be easily applied to different problematic,
- There are very interesting developments that will be used as a think tank to our own adaptation of the method. IRCM, Itemsoft toolkit, Relex toolkit or WINMBF provides a good starting point for WP3,
- RCM is very relevant in areas with problematic close to those of the RAIL project, such as aerospace, nuclear industry, … with strong constraints as regards users and safety,
- In spite of being a standardise approach RCM can be adapted to particular constraints and requirements. In this study we started form standardisation and took advantages of experiences in order to adapt this approach to the problematic of maintenance of the railway infrastructure,
- Besides developments of reliability databases, that originate from RCM studies (for example NAVAIR from US Navy project), prove that the RCM approach lends itself well to this kind of development,
- All along the developments of the approach it seems necessary to take into consideration the LCC (Life Cycle Cost) aspects of the equipment considered, which has to be taken into account in Work Package 3 developments,
- The RCM database is a key part of any RCM toolkit. The information to improve maintenance can only be extracted from the database using statistic techniques, data mining, etc…

In surveying the existing we found numerous software tools which permit to apply RCM surveys and deposit them to obtain RCM supporting tools until capitalisation and reliability data management. Importance of these computerised tools was highlighted to make easier and more reproductive the RCM approach. On the contrary tools can be found on the market that cannot be used on state, in our project (with the railways specific problems), and its necessary to develop a specific tool from the RAIL project. These points should be taken in consideration when defining and specifying the functionalities of the computerised database which will result from the project.

This study also proves that analysis models of risk, simulations, etc… can be used when carrying out the computerised tools of implementation of the RCM. This point leads to the conclusion that risk studies complementary in the RCM analysis must also be considered when defining the methodology. It is important to remark, that chemical and nuclear industries have defined a set of rules to evaluate and to define the risk level of a system or component. It could be very good to have something similar in railway industry, even when standard EN50126 has some criteria defined. However, because the railway companies use different computer systems and accounting practices, getting consistent un-manipulated data for measurements might be a major problem for the RCM toolkit. It will be important to :

- Establish standard RCM and CMMS cost reports for all railway companies,
- Consolidate RCM best practices for the purpose of measuring progress,
- Select and define key RCM metrics to be used and recommend targets.

All RCM toolkits use a **database** to organize its information trying to minimize any redundant effort by storing information that the users enter through formularies and tables. Specific objectives of those databases are :

- Capturing RCM Data for continuous improvement: To provide additional decision support tools and information on equipment and system RCM by capturing key data mainly on corrective maintenance activities,
- Sharing RCM data: To provide software tools and infrastructure for sharing lessons learned at different levels by linking chief engineers, operators-managers, regulatory agencies, equipment manufacturers, and shipyards/designers.

11. APPENDIX

11.1 AN EXAMPLE OF RCM TOOL : RELEX TOOLKIT FOR RCM

Relex product line provides a complete set of tools to analyse and improve product reliability. Its main features are: Reliability Prediction Engine, Reliability Prediction Analysis, Reliability Block Diagram (RBD), FMEA/FMECA. Fault Tree, Maintainability, Life Cycle Cost (LCC). Below, we briefly describe some of them.

The **Reliability Prediction Engine** support popular electronic and mechanical reliability models including MIL-HDBK-217, Telcordia/Bellcore TR-332, and Parts Count. It also provides concurrent network operation to allow multiple users to access projects simultaneously, feedback on design modifications, reliability allocation calculations, departing analysis per several popular standards, and graphical interface. Evaluating product reliability normally begins with estimating MTBF (Mean Time Between Failures), even for a system hierarchy with associated components. This tool guides the user through the entry of all data by prompting the necessary parameters, providing a list of choices when available, and validating all entries. If the information is not readily available, you may simply leave it blank.

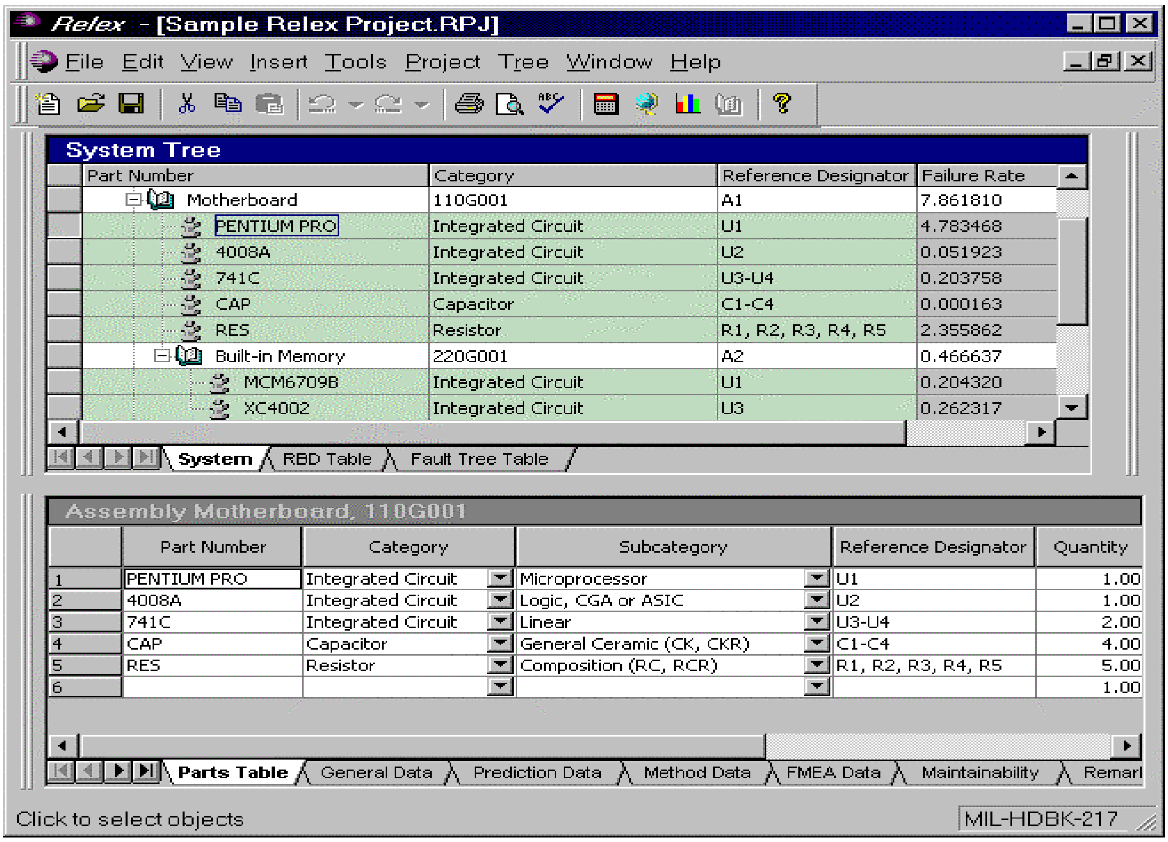

Figure 11-1 : Sample screen for RELEX tools

Reliability Prediction Analysis features include all of the Prediction Engine features, plus comprehensive parts libraries and CAD Import/Export Wizard™. It also includes support parts from many manufacturers such as AMD, Analog Devices, Cypress, Intel, etc. A major advantage of the Reliability Prediction Analysis package is access to comprehensive libraries that contain tens of thousands of parts with associated data parameters. For example, the Integrated Circuits Library consists of over 100,000 ICs including all of the 74/54 series of digital logic devices, as well as analogue/linear, microprocessors, RAMs, EEPROMs, ASICs, PALs, M38510 and SMD parts.

Relex Reliability Block Diagram features include Monte Carlo simulation engine, simple series-parallel network system, and handles various failure and repair distributions (exponential, normal, Weibull, etc.). It also performs reliability, availability, failure rate, and MTBF calculations. Using this tool, the user can diagram and analyse complex redundant systems.

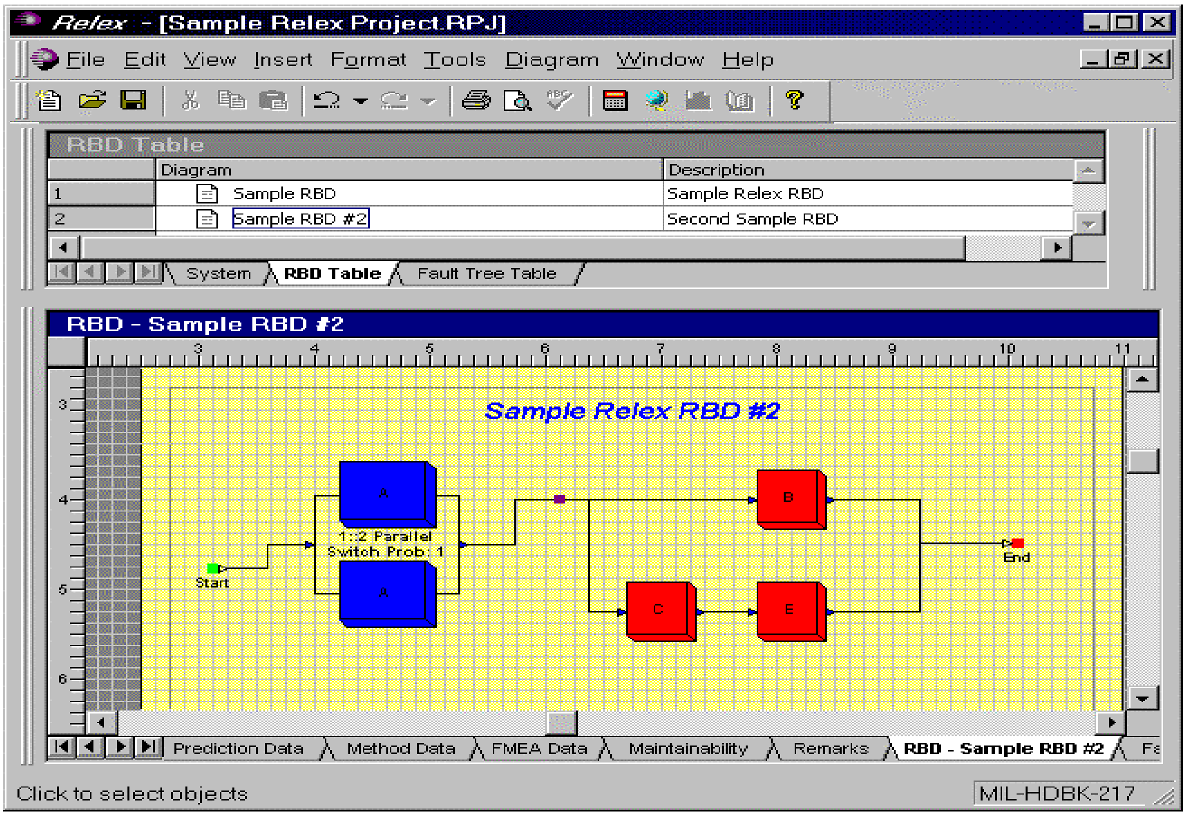

Figure 11-2 : Sample RELEX RDB project

Some **FMEA/FMECA -** Failure Mode and Effects Analysis features are that: supports automotive and SAE ARP5580 style FMEAs as well as MIL-STD-1629 FMECAs, Automatically generates initial FMEA from assembly and part information, includes a supplied set of failure mode libraries for electronic and mechanical parts. Various industries have their own FMEA standards, all supported by this toolkit. Aerospace and defence companies generally use either the MIL-STD-1629 FMECA standard (the C in FMECA represents the Criticality calculation) or the SAE ARP5580 FMEA standard. Automotive suppliers use SAE J1739, or the Automotive Industry Action Group (AIAG), Daimler-Chrysler, Ford, and GM FMEA methodologies. Other industries generally adopt one of these standards, sometimes customising them to meet their own requirements. Moreover, this toolkit supports both Design and Process FMEAs. Design FMEAs are used to analyse a system design and determine how the various failure modes affect the system operation. Process FMEAs, in contrast, are used to analyse how failures in the manufacturing or service process affect system operation.

Relex FMEA supports criticality assessment through risk priority numbers (RPN), criticality ranks, risk levels, criticality matrices, and failure mode probability calculations.

The **Fault Tree** package automatically links with cause failure modelling and time-dependent analyses reliability predictions, FMEAs, and RBDs. It also automatically creates fault trees from FMEAs, and supports event types

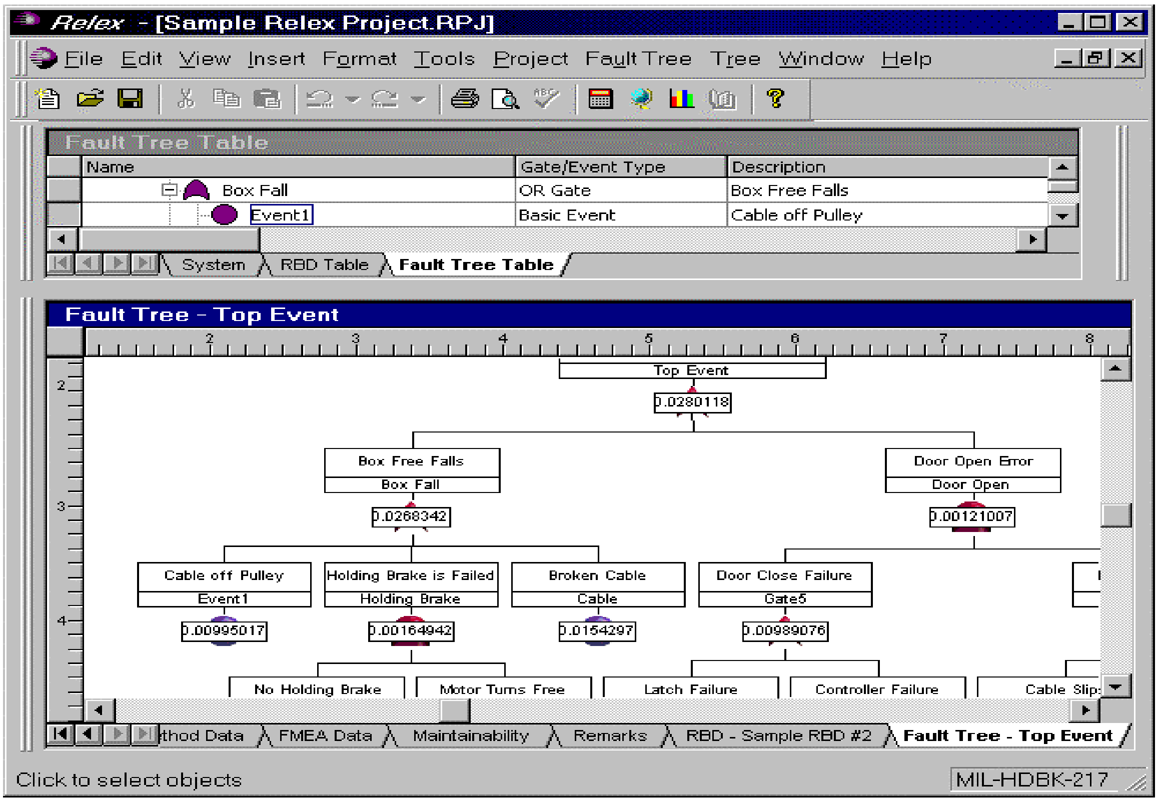

Figure 11-3 : Sample RELEX fault tree table

The Fault Tree provides both a graphical view as well as a compact table view of the fault trees. It includes calculations for both qualitative and quantitative analyses. The user can calculate the unreliability, unavailability, frequency of failures, and number of failures. You can compare the relative importance of various events using the Birnbaum, Criticality, and Fussell-Vesely methods.

The **Maintainability Prediction** features support MIL-HDBK-217 Procedures 2, 5A, and 5B, and depot, intermediate, and organised repair levels. The Maintainability Prediction provides a framework for performing maintainability analyses, calculating many maintenance parameters including the Mean Time to Repair (MTTR), Mean Maintenance Man-hours per Repair (MMH/Repair), and the Percent Isolation to a Single Replaceable Item, as well as many others. Once the user has defined your system, Maintainability Prediction can perform various calculations including Mean Time to Repair, Percent Isolation to a Single Replaceable Item, Mean Maintenance Man-hours per Repair, Mean Maintenance Man-hours per Operating Hour, Maximum Corrective Maintenance Time, and more. A task library taken directly from MIL-HDBK-472 is included with the Maintainability Prediction tool. **Life Cycle Cost** features support calculations over time intervals using inflation rate, allows comparison of various alternatives, and sensitivity analysis and Net Present Value (NPV) calculations. Life Cycle Cost (LCC) tool calculates the cost of a product over its lifetime. You may include many different types of costs such as design, production, warranty and repair, and disposal. Relex LCC provides support for parametric, analogy, bottoms-up, and direct cost analysis types.

The RELEX toolkit uses a **database** to organise its information minimising any redundant effort on your part by storing information you enter into a lookup table that is always available for use. Data fields can be up to 32,000 characters in length.