Risk-based maintenance and inspection decisions

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1. Abstract

MACRO is a multi-industry, DTI-supported joint venture (European 'EUREKA' project EU1488), that is developing guidance and tools for better cost/risk evaluation and Asset Management decision-making. It is bringing together the technical aspects of reliability and risk-based analysis with the economic factors, human issues and data uncertainty. This paper focuses on some of the resulting 'best practice' methods, analytical tools and the results that are being achieved.

The boundaries of the project have been chosen to meet the perceived priorities and a practical development timeframe. Nevertheless the range of analysis areas to be addressed is wide and includes:

- Asset Life Cycle Costing: the hands-on tools for project evaluation, equipment replacement, life extension, change control & modifications.
- Maintenance Optimization: evaluating preventive maintenance strategies, optimum intervals, legal/safety compliance, and environmental constraints.
- Inspection & Condition Monitoring: setting inspection, monitoring & test intervals, optimal condition reaction points, and cost/benefit of monitoring methods.
- Work Grouping & Shutdown Strategy: evaluating optimal task groupings, shutdown intervals and opportunities.
- Materials & Resources: cost/risk optimisation of slow-moving spares, consumables, supplier comparisons, materials pooling and alliances.

This paper concentrates on just two of these areas: Maintenance Optimization and Inspection/Condition Monitoring strategies

2. Introduction

The international MACRO project has been busily collating the experiences and best practices of collaborating organisations in many industries. In addition to the development of innovative technical methods, MACRO is generating procedural guidance and training programmes to implement risk-based management techniques.

High among these are the procedure guidance notes for reviewing or setting maintenance & inspection strategy. Of course this subject has received a lot of exposure over the last few years - mostly focussing on particular 'initiatives' such as RCM, TPM or other acronym-packaged frameworks. The following paper is a summary of the MACRO project observations and recommendations regarding best practice and the use of various tools (such as Function & Criticality Analysis, FMEA, RCM and optimisation methods).

Four major areas of work have been at the core of MACRO developments during the last 6 months. These take the form of Working Parties, discussing best practices, the specifications for any analytical tools that might be required and practical experiences of implementation. The four active Working Parties at this stage of the project are:

a) Navigator: developing a master route map for selecting appropriate analysis tools for different types of problem and decision.
b) Maintenance Strategy: combining the experiences of different tools in different circumstances to develop a robust self-help guide. This also includes the innovative developments in quantitative risk-based techniques.
c) Inspection Strategy: again, introduction of quantitative techniques to set condition monitoring or test/inspection strategy. This team is providing the hard tools for Risk-based Inspection.
d) Lifespan: the Life Cycle Costing area developed to the extent of linking specific decision requirements to the necessary tools and techniques to justify the optimum solution.

3. Maintenance strategy process

3.1 ‘Horses for courses’

The first conclusion reached by the Maintenance Strategy Working party was the need for a mixture of methods to determine what work is worth doing and when. No single formula yet on offer was found to be suited to different industries, or even to different processes, plant types or departments within the same company. The depth of analysis effort, and the value-for-money of such analysis, is clearly dependent upon the importance of arriving at the correct strategy.

Criticality filtering of the systems, equipment and failure modes is vital to avoid ‘analysis paralysis’ and loss of direction. Visible return for the effort is also essential to maintain enthusiasm and management support for any systematic initiative.

The overall flowchart that has emerged from the MACRO team is one of multi-level analysis. Dependent upon process or functional criticality, differing levels of analysis effort should be applied. At the top end, perhaps 5-10% of the most vital corporate functions, quantitative risk and performance analysis is warranted. For the next 40-60% of ‘core business’ activities, template and rule-based methods (such as RCM or RBI) are more appropriate.

At the lower levels of process criticality, not even the simple tabulated questions and FMEA work are worthwhile - a cruder but quicker ‘filter’ is required. Figure 1 shows the overall flowchart up to the point of individually identified and justified maintenance tasks.

The process of consolidation and optimization of an overall maintenance programme is the subject of a specific MACRO working party, which is developing dynamic optimisation methods for work clustering and shutdown strategies (“APT-SCHEDULE”).

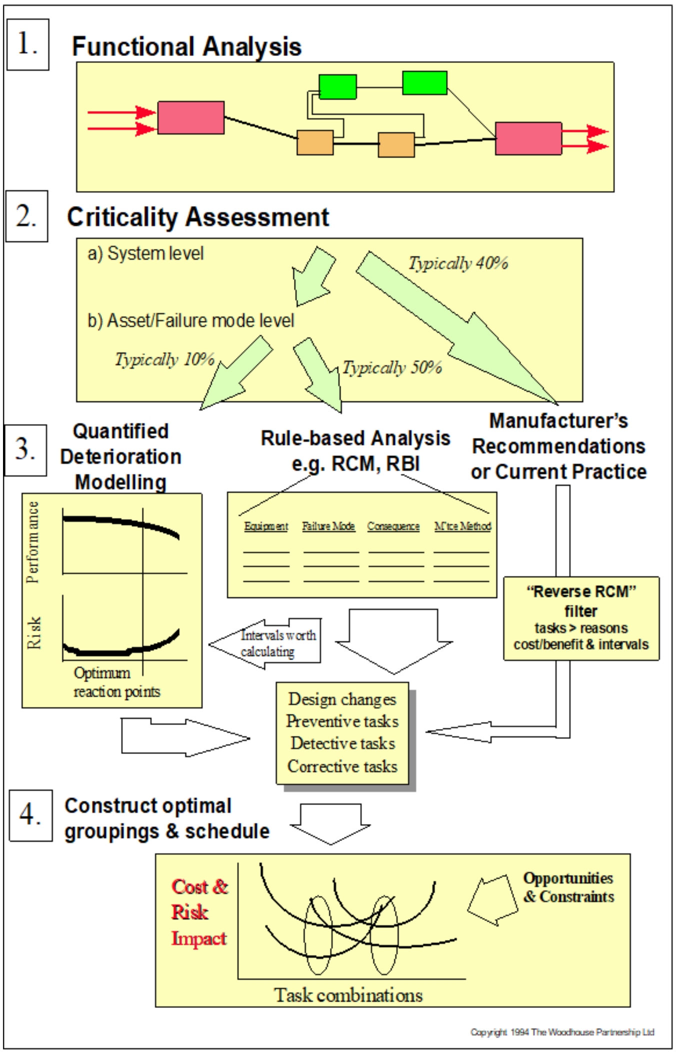

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Figure 1. Strategy methods depend upon Operational Criticality

3.2 Functional focus

In order to determine which physical assets are worth maintaining to what degree (and which are worth analysing to what level), a shift of emphasis is vital. Maintenance strategy has historically been directed at types of equipment. The same recommendations on maintenance work and intervals are issued, whatever the operational role or importance of that equipment.

The service interval and task list for a Vauxhall Cavalier is the same, whether the car is just one available from the company vehicle pool, or is a doctor's sole means of transport! Clearly the consequences of breakdown can be very different – so the importance of reliability differs and the level of maintenance should be adjusted accordingly.

Despite the common horror stories of inappropriate application, one of the big advantages of RCM logic is that it considers equipment function and loss of function as important criteria. However, in its original form, RCM only attaches these characteristics as an attribute to the equipment. The whole asset list is reviewed and, for each piece of equipment, the functional failure, operational or other consequences and the failure modes are all employed to determine the appropriate maintenance strategy.

Unfortunately, by this route, the analysis of each equipment's characteristics has to be almost complete before it becomes clear whether it was worthwhile examining in the first place. The team doing the review has to apply nearly the whole procedure to find out which items were worth reviewing at all!

To allow an earlier filter and prioritising of such analysis effort, therefore, a clear understanding is needed of which systems do what, and what happens if they do not. This process mapping or 'functional breakdown' can shift the focus dramatically. Not only does it provide a means of prioritising the maintenance strategy studies, it also achieves a wider operational awareness (it can be a revelation to maintainers and operators alike) and invariably stimulates ideas for design or procedural improvement.

The methods for mapping equipment functions are similar to those employed in 'business process re-engineering'. However, the terminology and process (or systems) viewpoint may not be familiar to the operators and maintainers who should be involved in developing the map, so guidance and facilitation is usually needed.

A summary of a simple level of Input-Process-Output diagramming was published in the Maintenance Journal in June 1997. More detailed methods (such as the ICOM format, which separates out the Inputs, Constraints, Outputs and Mechanisms) are available but the method is less important than the fact of considering operational requirements and failure likelihood/consequences first, and the necessary equipment (and its maintenance requirements) second. The underlying objective is to direct the costly analysis effort at the most important functions or core business of the organisation.

3.3 Criticality analysis

The commonly promoted versions of RCM focus firstly on equipment, and then its operational context, failure modes, consequences and maintenance requirements. The MACRO network has clearly concluded that this is wasteful and often results in duplicate consideration of identical or similar maintenance requirements, and low-value analysis of marginal equipment or failure modes.

A common feature of successful implementations is the criticality-based priority or filtering of which systems, equipment and failure modes are worth analysing in the first place. This may not be formalised 'criticality system' but, if the review of maintenance requirements is to be systematic and/or will involve a wide range of personnel from different backgrounds, then a consistent and generally agreed ranking method is necessary.

A survey of such methods, with practical applications guidance, has been prepared as one of the reference documents of the MACRO project – and was published in summary form at the Advances in Reliability Technology Symposium in April (Manchester Univ.) and in the Maintenance & Asset Management Journal last month.

The key feature of successful ranking methods is the combination of failure consequences (safety, economic, environmental or others) with the likelihood or frequency of failures. Degree of detail varies, along with the guidance and 'weighting' methods for scoring the different elements, however the combination (usually a multiplication of frequency and consequence) aims to prioritise the small-and-frequent among the big-and-rare.

Whatever method is used, the resulting process criticalities can be ranked and charted to show any natural groupings. An histogram (Pareto-style) usually reveals a few ultra critical activities, with a core group of functions beneath them, and a large number of low criticality support functions (i.e. three bands of criticality can be chosen). See figure 2 for an example.

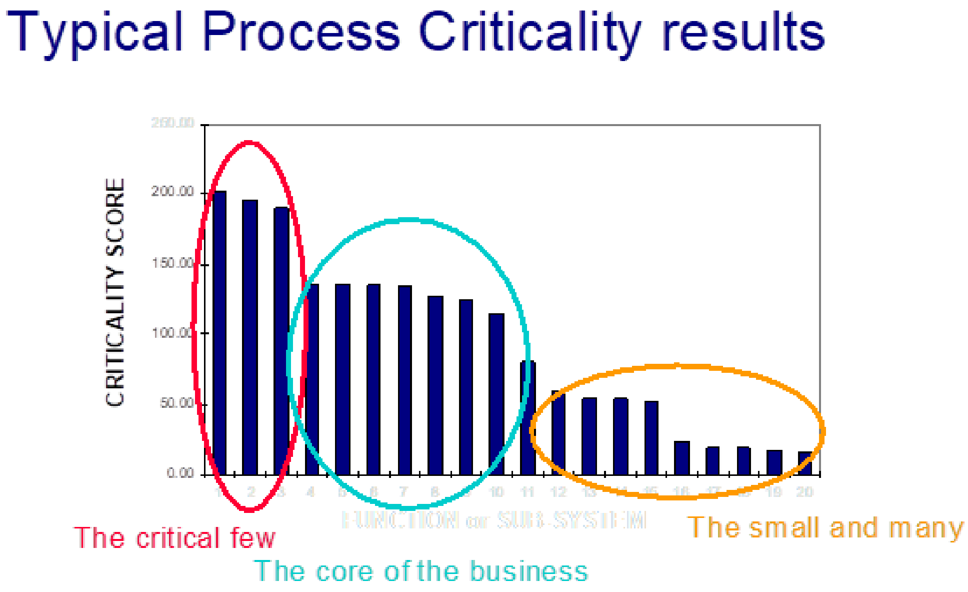


Figure 2. Criticality determines analysis method that is appropriate

4. Maintenance Strategy Selection

The MACRO project has developed structured methods to review maintenance requirements at each level of criticality. These merge existing best practices with innovative improvements and tools.

RCM and TPM logic, for example, are incorporated in their correct places, with supportive guidance on the evaluation of efficiency-oriented maintenance, lifespan-related tasks (such as painting or lubrication) and the cost/risk basis for setting inspection or maintenance intervals.

A series of articles and case studies are being prepared to cover each of these in turn, starting with the radical advances in the area of quantified (cost/risk) evaluation of maintenance options. These and related methods are also being collated into Management Mini-guides for publication next year. The corresponding analysis tools are already available and are on display in the exhibition attached to this conference.

4.1 Quantified risk-based maintenance

Once the process criticalities have been identified, the analysis of maintenance requirements splits into different levels of detail. For the few really vital processes (5-10% of all systems), the approximations and black/white assumptions of RCM or RBI ('risk-based inspection') are rarely sufficient to determine the optimal combination of operating and maintenance strategies. For example, RCM and RBI both require a clear and consistent definition of 'functional failure' - yet this is often a grey area in real life. What degree of deterioration do you choose to define as 'unacceptable'? The level of risk that is worth taking, and the quality or performance that is achieved, or the life expectancy of the asset are often trade-able commodities that can be influenced by the amount and type of maintenance. In critical areas, the additional head scratching and data collection required to quantify such risk and performance trade-offs can be very worthwhile. MACRO field-testing has shown scope for multi-million pound savings through such a quantitative approach. Examples range from painting programmes and lubrication schedules to major overhaul or shutdown strategies and inspection/test intervals. A representative case study is attached at Appendix A to this paper.

5. Risk based Inspection

The second big area of quantitative analysis is the setting of inspection and condition monitoring strategy. Much work is going on in this area in the United States, albeit mostly concentrated on the monitoring of static equipment (vessels, pipes etc) on petrochemical plants. The MACRO focus has been wider and more quantitative.

A cost/risk balancing tool has been developed to evaluate optimal strategy in the light of various uncertainties (rate of deterioration, point of failure, quality of measurement etc.) and the early results of its application are extremely encouraging. Applications already proven include the condition monitoring of wooden poles (electricity distribution), corrosion monitoring of pipes and storage vessels, function testing of safety protection and standby equipment, and instrumentation. An example of such application is illustrated in Appendix B to this paper.

Regarding the value of risk-based study (instead of simpler, rule-based approaches), the MACRO team has performed some systematic comparisons: a sample of 5 condition monitoring strategies, arrived at by RCM/RBI guidance, were checked with the APT-INSPECTION analysis. 3 of the 5 were found to be about right (+/- 20% of optimal timing) but one decision was a factor of 8x in error (the job should have been done at 1/8th of the interval, and the other was not worth doing at all. On such a 40% hit rate - generating significant improvement - the payback for the additional 'brain-strain' (in practice, about 2 hours per problem tackled) was almost instantaneous.

6. Other areas of interest

6.1 Lifespan

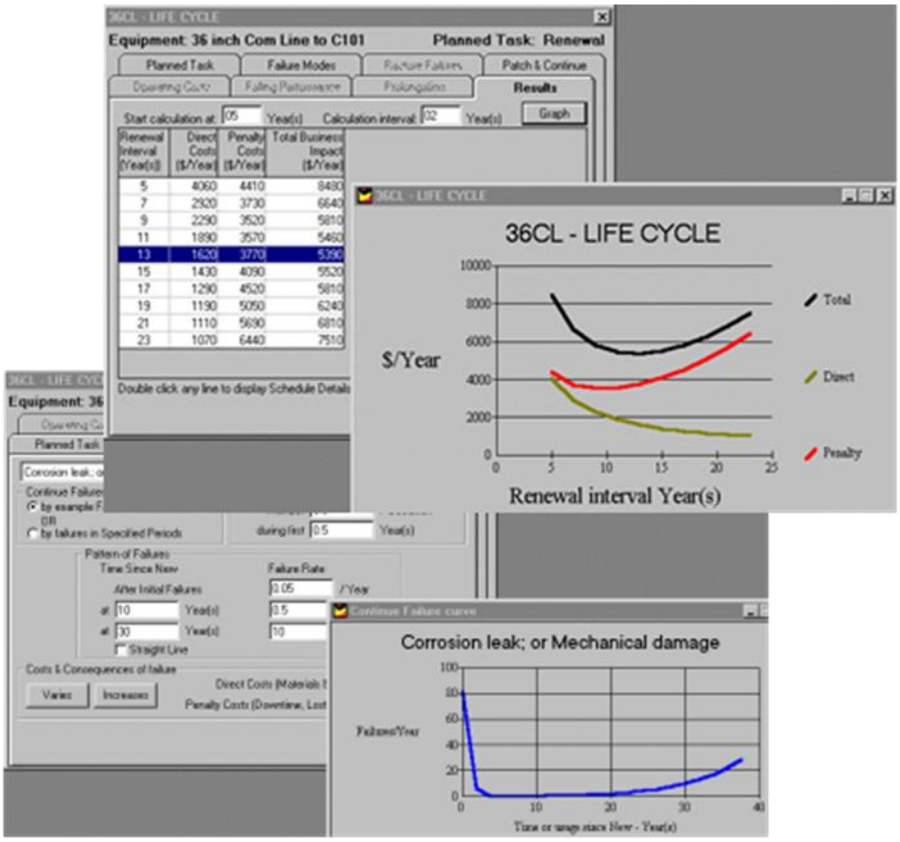
The fields of asset replacement, life extension and life cycle costing are receiving increasing attention also. A North Sea "Joint Industry Project" is embarked on developing an ISO standard for Life Cycle Costing, and the pressure for 'alliances' between contractors, vendors and operators can only increase. The MACRO work is focussing on delivering the practical tools that can aid the evaluation of specific decisions (such as the choosing repair/replacement point, evaluating a life extension proposal or comparing A vs. B equipment options). APT-LIFESPAN is due for public release toward the end of this year.

6.2 Navigator

A very big task faced the MACRO "Navigator" working party. It has been trying to map all the possible decision triggers (events or circumstances in which asset management or engineering decisions need to be made) onto the common groupings of the appropriate investigation, solutions and evaluations that have to be made. After developing a consistent mapping format and hierarchical terminology, the many decisions have been found to map quite elegantly onto a few generic templates. As a result, the key questions and investigation steps have been condensed into an easy-to-follow routemap: one for equipment-related operational problems, one for project environment or systematic studies (e.g. maintenance strategy or materials requirements) and one for mitigation and contingency options. A series of wallcharts, interactive CD-ROM and Web-site guidance is under construction.

Appendix A: Risk-based maintenance case study

Maintenance vs. Asset Replacement decision: Reliability projections are combined with failure consequences and the costs of planned maintenance/replacement. The uncertainty in most data is handled by range-estimation and sensitivity testing - showing that the decision is robust even in the light of widely varying assumptions. It can be shown, therefore, that no further data is needed.



36CL - LIFE CYCLE

Equipment: 36 inch Com Line to C101 Planned Task: Renewal

Start calculation at: 05 Year(s) Calculation interval: 02 Year(s)

Renewal Interval (Year(s))	Direct Costs ($/Year)	Penalty Costs ($/Year)	Total Business Impact ($/Year)
5	4060	4410	8430
7	2920	3730	6640
9	2290	3520	5810
11	1890	3570	5460
13	1620	3770	5390
15	1430	4090	5520
17	1290	4520	5810
19	1190	5050	6240
21	1110	5690	6810
23	1070	6440	7510

Double click any line to display Schedule Details

Corrosion leak; o

Continue Failure

● by example F

OR

○ by failures in Specified Periods

during first 0.5 Year(s)

Pattern of Failures

Time Since New		Failure Rate	
After Initial Failures		0.05	/Year
at 10	Year(s)	0.5	
at 30	Year(s)	10	

☐ Straight Line

Costs & Consequences of failure

Direct Costs (Materials

Penalty Costs (Downtime, Lost

Calculated Results, showing optimal replacement point (12 years), the conflict between planned expenditure and risk exposures, and the cost/risk penalties for replacing too early or too late:

Appendix B: Risk-based inspection case study

A typical corrosion monitoring example - with uncertainty about the deterioration rate, the onset of deterioration, the point of potential failure and the measurement quality/accuracy. Inputs include the direct and indirect costs of monitoring and different levels of failure consequence. All data can be range-estimated and tested for sensitivity. Other examples range from visual inspections of substations, ultrasonic testing, vibration monitoring to operational checks of protection equipment and functional tests of standby equipment.

Results: showing optimal inspection interval at 6-7 years (current policy was 3-yearly, so a 50% reduction in monitoring costs is available). If regulator or safety requirement limit inspection intervals to, for example, 3-yearly, the following graph shows the premium paid for such compliance – and can help to justify alternative options (such as design changes, negotiations with the authorities etc).