THE MACRO PROJECT:

COST/RISK EVALUATION OF ENGINEERING & MAINTENANCE DECISIONS

by John Woodhouse

1. Abstract

The MACRO project (reference no. EU1488 in the European 'EUREKA' collaboration agreement program) is assembling quantitative techniques for cost- and risk-based engineering/maintenance decisions, and is developing the necessary guidance for their use, particularly in circumstances of poor or patchy hard data. This paper outlines the scope of the project, the key components identified so far and the "Asset Performance Toolkit" that is emerging. Preliminary studies and feasibility trials have already showed scope for very substantial impact (improved asset availability and life cycle cost reductions). MACRO is bridging the gap between reliability engineering/asset management and the 'front line' business of industrial decision-making.

1.1 Keywords

Risk-based, Decision-making, Cost/Benefit, Optimisation, Asset Management

2. Introduction

The essence of Asset Management is getting the best value-for-money out of strategic assets over their lifespan or any specified lesser period. Inevitably, the effectiveness of any business in managing its assets is governed by the component decisions that are taken. High quality decisions will manifest themselves through value added to the business.

Assigning value to more abstract concepts (such as increased safety or public confidence) inevitably involves a degree of subjective judgement. Nevertheless, a structured approach to the task is crucial if a company wants to establish a robust and defensible decision-making policy. It is impossible to contemplate an assessment of 'value added' without considering the likelihood of success and the risks associated with each possible scenario. Nevertheless, the sophistication and analytical detail of modern reliability engineering methods are often wasted: either the methods are understood by too few, or the available data is of limited quality, inadequate volume or restrictive application.

Useful quantitative techniques for decision analysis are still rare in industry. The 'front line' environment of poor data, problem complexity and commercial pressure allows little time or even motivation to perform any depth of analysis. Yet the cost- and risk-consequences of relying on 'engineering judgement' are staggering. Wider use of even the most basic reliability engineering methods can make very substantial business impact - in one recent case, 8-figure annual savings through reduced maintenance bills and improved plant availability[1] .

This paper discusses the key drivers in an asset-centred business. It identifies the compatibility of the MACRO project with necessary practical responses to such business drivers. The practical answers bridge the current gulf between academic theory and industrial practice: this void cannot be spanned simply by hoping that asset managers can be converted magically into reliability experts. The subjects are too complex and, apart from the lucky few, the audience is not used to thinking in terms of probability or business risk. Selected elements need to be prepared and fed to the industrial front-line in pre-digested morsels

[1] Utility company 1995 study of five selected maintenance intervals (inspections, overhauls, functional tests and painting/lubrication), based on quantified but range-estimated hazard rate characteristics and failure consequences.

3. The MACRO Project

The MACRO project is a 3-year research and development programme (started in December 1995), supported by the UK Department of Trade & Industry and operating under the European EUREKA MAINE umbrella. The collaborating organisations are:

- The Woodhouse Partnership Ltd
- A/S Norske Shell
- Anglesey Aluminium Metal Ltd
- British Metalforming Trade Assoc.
- Brown & Root AOC Ltd
- Det Norske Veritas
- Institute of Asset Management
- Railtrack PLC
- The National Grid Company PLC
- Websters Mouldings Ltd.
- National Power PLC
- Yorkshire Electricity PLC

3.1 Deliverables

The terms of reference for the project identify two key deliverables:

- A decision navigation guide that helps industrial decision-makers to identify which tools, techniques and data requirements are necessary for which decision types and operational/business circumstances.
- A set of modular cost/risk evaluation and optimisation software utilities, called the "Asset Performance Toolkit". This software is to be designed for use with varying data quality and applicable to a wide range of industrial decision-support requirements. Some of the first modules to be completed (APT-MAINTENANCE and APT-SPARES) are illustrated in this paper.

Section 6 of this paper describes to range of facilities being developed.

4. Defining the need

MACRO was conceived to provide some standards and practical utilities for front line decision-makers. It includes the application of several, individually familiar, analysis techniques and will, in particular, generate guidance on which tool or technique is applicable in which circumstance. Clearly the boundaries for such a toolkit are difficult to define and the first phase of the project involved a feasibility and definition task. This first phase defined (1) the modularity of the toolkit - which groupings of facilities best fit the range of decisions faced by the same individual (or, increasingly, multi-disciplined team). This list is certainly not exhaustive but is presented as a working selection of decision types and decision makers. It provides a representative coverage of the practical requirements.

4.1 Specific Decision Responsibilities

4.1.1 Maintenance/plant/asset managers

- Justify maintenance budget: the sum of individual justifications of preventive tasks, inspections, shutdowns and housekeeping/overheads.
    - e.g. if we reduced preventive maintenance by 10%, what would be the net cost/risk impact?
- Justify specific shutdowns (work content, timing, cost/risk impact)
- Set intervals for periodic shutdowns
- Set intervals for major inspections or other planned maintenance tasks
- Set holding levels for critical spares (incl. supplier comparisons etc.)
- Compare in-house with contractor options for specific jobs or ranges of jobs.

- i.e. "what if?" considerations of differences in operating costs, overheads, work quality, downtime and response times, resulting equipment reliability etc.

4.1.2 Engineers & Technologists

The same decisions are required as for a maintenance/plant/asset manager, usually at an equipment-specific level, PLUS

- Operational problem-solving, triggered by
  - high maintenance/operating cost
  - unreliability,
  - inefficiency/bottlenecking
  - recent 'big bang' event
  - external requirement (e.g. legislation),
  - management 'concern'
  - level of general irritation
  - hunch
  - accidental discovery

Such problem-solving involves evaluation of specific design/operations changes, preventive, detective (inspection/condition-based) or corrective maintenance strategies, and contingency planning options (such as spares, bypass facilities etc.). This is likely to encompass...

- Maintenance strategy review either from an existing task list (review & filtering) or from 'first principles' of Failure Modes & Effects or Deterioration Modelling.
- Spares requirements reviews
- Individual Planned Maintenance, Inspections, Condition Monitoring and equipment replacement intervals, particularly with poor data.
- Condition reaction points for corrective maintenance or modification
- Repair versus replacement comparisons

4.1.3 Operations or Production Engineers/Managers

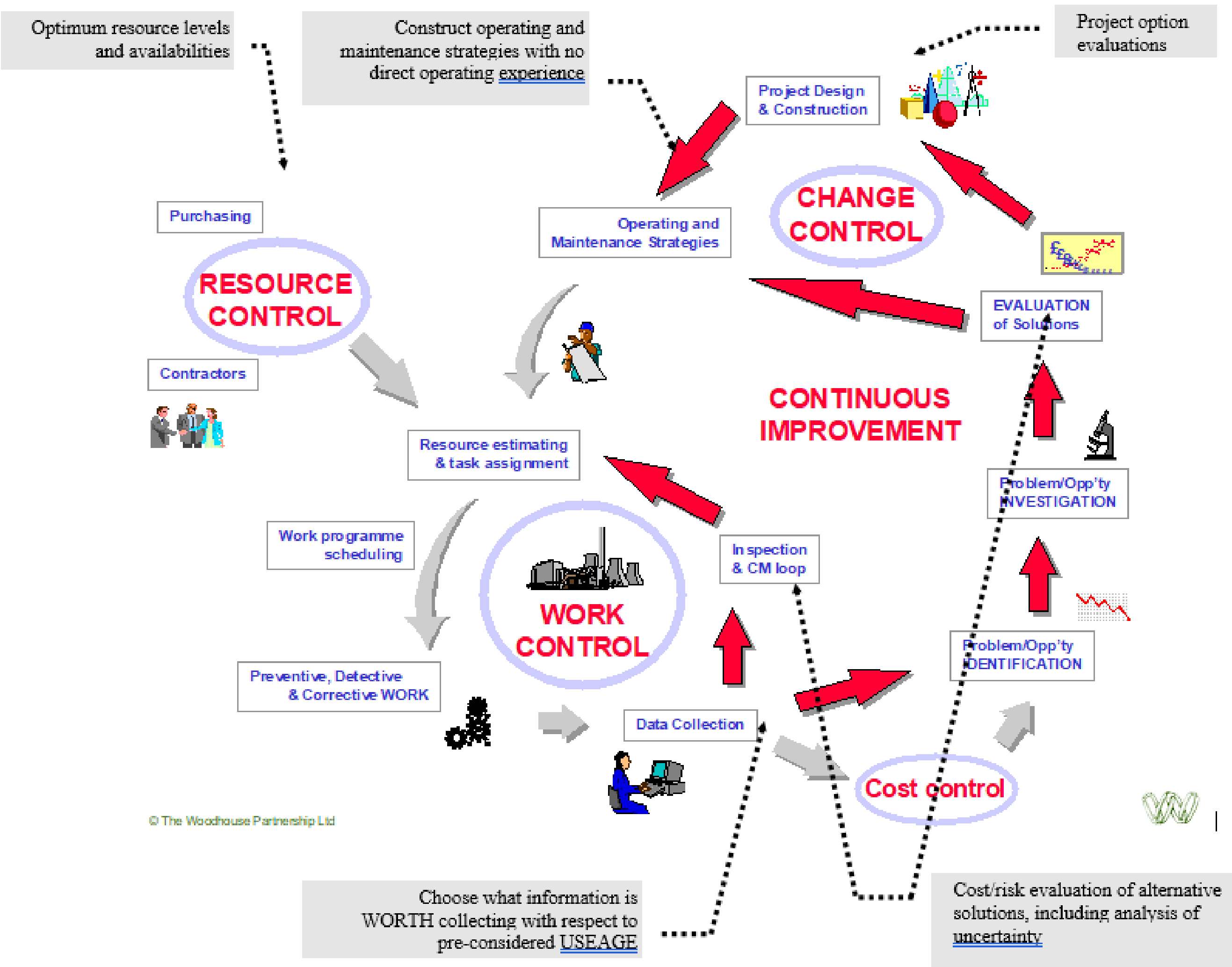
- Operational problem-solving triggered by:
  - planned & unplanned downtime
  - operating costs
  - production output levels
  - personnel productivity
  - production quality
  - operational efficiency
  - TPM/TQM metrics
  - management “concern”
  - recent 'big bang' event
  - external requirement (e.g. legislation)
  - level of general irritation
  - hunch
  - accidental discovery
- De-bottlenecking
- Batch sizes & product mix (e.g. contribution analysis)
- Project evaluations:
- Equipment modifications
- Process changes
- New technology
- Shutdown intervals
- Major asset replacement justification & timing (incl. refurbishment versus replacement comparisons).

4.2 Project Engineers/Contracting Engineers

- Project evaluations, in greenfield and brownfield circumstances
- Design option comparisons:
- Life Cycle Costing comparisons
- Pay-back analysis
- Assessment of system effects
- Initial maintenance strategy recommendations
- Initial spares requirement recommendations
- Manning and other resource levels
- Evaluation of life extension options
- Vendor & Tender evaluations/comparisons
- Life Cycle Cost quantification (including risk exposures).

The next stage in translation towards a suitable 'toolkit' involved a high level separation of potentially helpful technologies. In the following section, we present the preliminary working list of such activities and their related possible aids:

5. Decision Support Requirements



5.1 Operating Environment

5.1.1 Problem identification

Task	Appropriate Aids
Performance Indicator hierarchy and usage	Procedures
Top-10 data: reliability, maintenance cost, downtime	Procedures/tailored IT
Total Impact assessment (incl. lost opportunity costs)	Procedures/tailored IT
On-line or automatic problem diagnosis	CBM, AI & neural nets etc.
Programmed review and continuous improvement infrastructure	Procedures

5.1.2 Problem interpretation/investigation

Task	Appropriate Aids
Root Cause Analysis	SPC/Procedures
Performance Indicator 'drill-down' methods	Procedure/tailored IT
Pattern-finding (incl. SPC, Fourier techniques, RELIAN etc.)	Procedure/software

5.1.3 Evaluating possible solutions

Task	Appropriate Aids
Design or usage changes	Calculation/simulation
Preventive Maintenance tasks	Calculation
Inspection/condition-based maintenance tasks/tools	Calculation
Contingency planning options (impact reduction)	Calculation
Spares and stock holding strategy	Calculation/simulation
Manning levels and contractor requirements	Calculation/simulation
Evaluation of overall system availability effects	Simulation

5.2 PROJECT ENVIRONMENT

Task	Appropriate Aids
Project (LCC) Evaluation	Calculation
Design option comparisons	Calculation
System configuration comparisons	Simulation
Overall system performance/availability prediction	Simulation
Operating strategy- performance vs. risk trade-off	Calculation
Operating strategy - equipment loading vs. lifespan/performance	Calculation/simulation
Operating strategy - seasonality/external factors impact	Procedure/simulation
Maintenance strategy- preventive intervals	Calculation
Maintenance strategy -detective (inspect & cond. monitoring) intvls	Calculation
Maintenance strategy- corrective (contingency option evaluations)	Calculation
Spares and stock holding strategy	Calculation/simulation
Manning levels and contractor requirements	Calculation/simulation

NOTE: 'Procedures' refers to need for practical guidance or organisation rather than analytical tools, 'Tailored IT' relates to local information systems requirements, 'Calculation' includes any pure mathematical solutions and 'Simulation' covers subjects most suitable for dynamic simulation and Monte Carlo or other sampling.

Finally in the definition phase, MACRO considered a practical grouping of the underlying mathematical techniques that would support the calculation aids. At an early stage, it was considered uneconomic and of limited value to enter far into the simulation arena - there are several proprietary tools and development languages already on the market and the MACRO involvement should be limited to guidance on when and where they should be used. The MACRO utilities should, on the other hand, concentrate on the use of mathematical modelling techniques and high-speed "What-if?" analysis, particularly in the circumstance of limited or poor quality data (2). The following represents the chosen groups of analytical techniques:

6. Main modules for the Asset Performance Toolkit

6.1 ASSET LIFE & MODIFICATIONS:

Asset life cycles, life extension options, project evaluation, repair/replace decisions.

6.2 PREVENTIVE MAINTENANCE TASKS:

Optimal maintenance intervals, cost/risk evaluation of preventive maintenance, maintenance opportunities, manufacturers' recommendations & warranties, legal constraints.

6.3 INSPECTION/CONDITION-BASED TASKS:

Optimal inspection and condition monitoring intervals, failure-finding & test intervals, optimal condition reaction points.

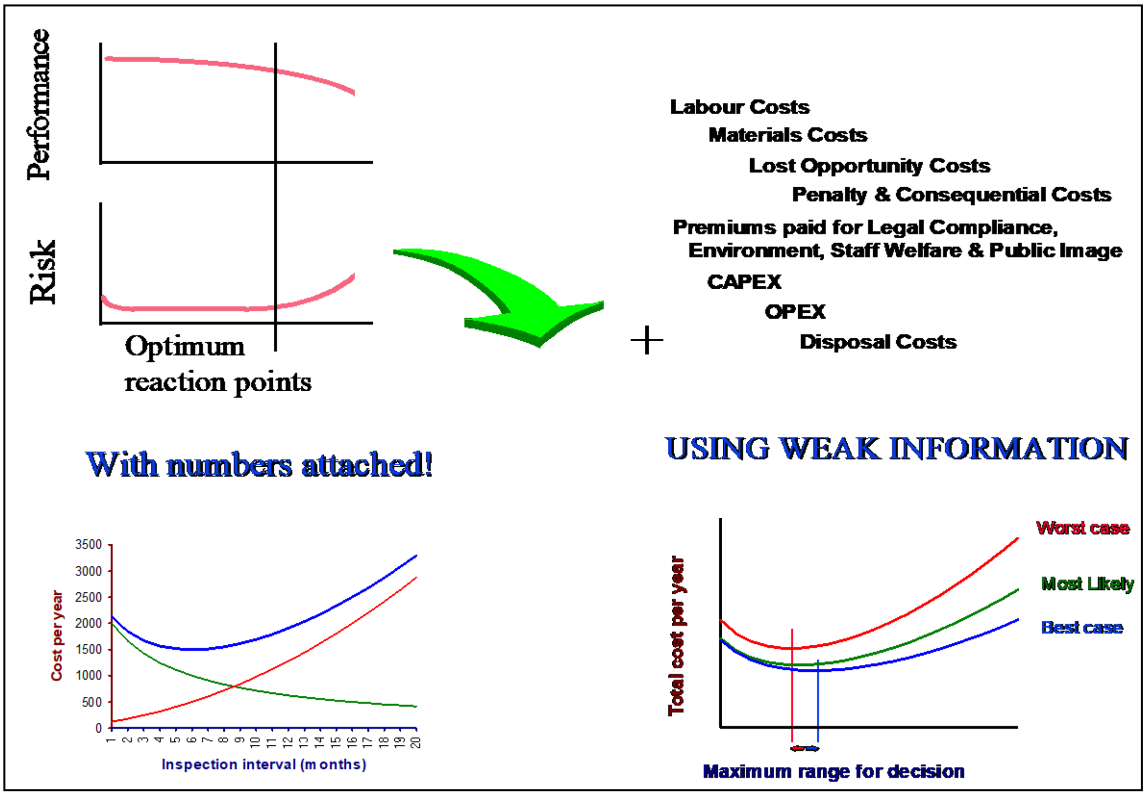
6.4 WORK GROUPING AND SHUTDOWN STRATEGY:

Optimal task grouping, shutdown intervals, age- versus block-based maintenance, opportunity evaluations.

6.5 MATERIALS & RESOURCES:

Optimal spares holding levels, evaluation of alternate locations, supply methods, pooling options.

Example process summary:



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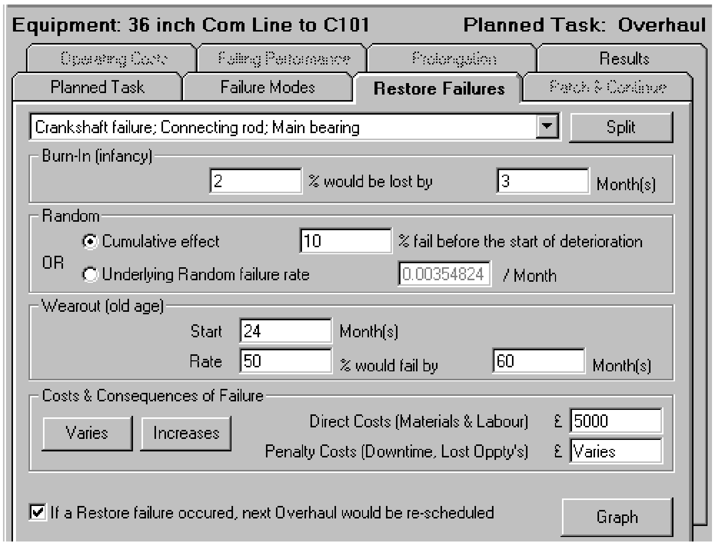
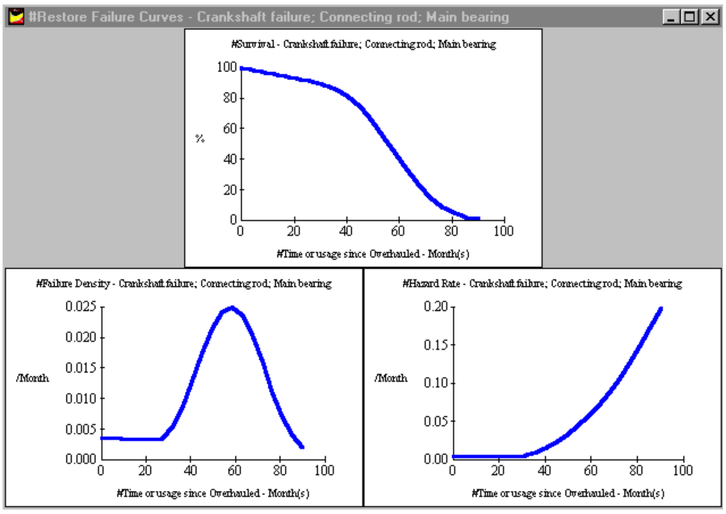
7. The Raw Material: "Hard" & "Soft" data

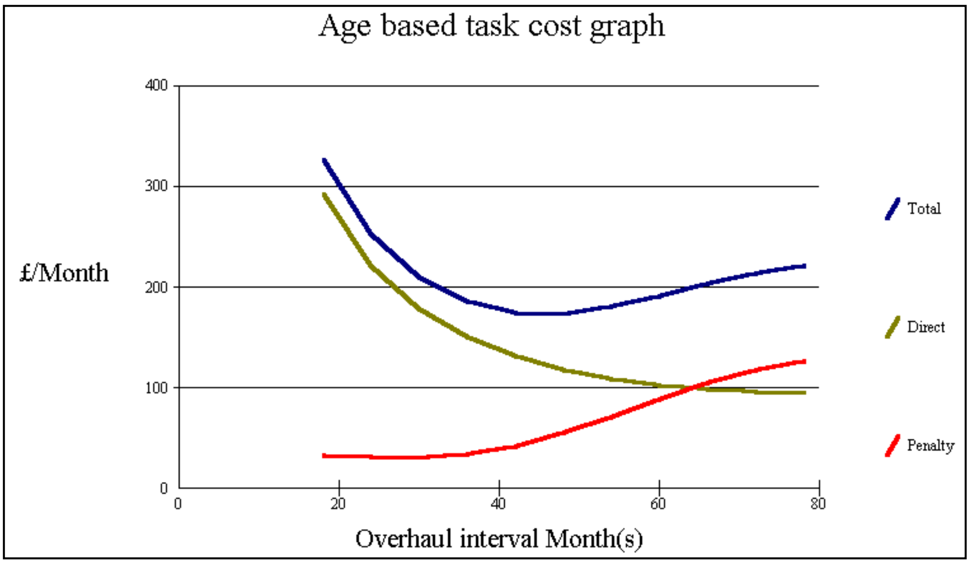
In general, the data is entered by range-estimated examples (e.g."50-60% would reach 5 years without major failure"). Survival (or cumulative failed) information is certainly easier to estimate than instantaneous probabilities (hazard rates) but it is also possible to use more detailed reliability information if it is available. Otherwise, curves are fitted to the estimates, drawing from a range of common curve types depending upon best-fit criteria.

Clearly, an interface with existing Failure Modes & Effects Analysis (FMEA) or Reliability Centred Maintenance (RCM) studies is essential. This can populate the failure mode descriptions and provide some starting points to the estimation of probability patterns (usually in the form of estimated mean failure rates or deterioration timescales). An early discovery has been the serious inadequacy of Weibull plots - due to the usual combination of limited (and often poor quality) historical data and multiple (interacting) failure modes. MACRO is making radical improvements in the description and usage of failure patterns and reliability modelling. By separating censoring events (e.g. repairs that 'reset the clock') from the patch-and-continue variety, and by developing the necessary combinatorial mathematics, up to 5 different groups of failure modes can be described, each allowing any combination of reducing, constant or increasing probabilities. To describe this complex (and more realistic) profile of events, each pattern is described by range-estimates of the cumulative effects - the "Survival Curve" (see below). A range of curve-fitting routines are then applied and the results displayed - in any of three forms (Survival Curve, Failure Density or underlying Hazard Rate).





CALCULATED RESULTS:



Note that the costs and consequences of failure are a) split into direct and indirect components and b) each capable of further distribution description (“varies” allows entry of an histogram of examples, “increases” allows a trend of increasing cost-per-occasion. Similarly, the method allows splitting of individual failure modes into separate patterns of probability or consequence - so a “what if?” can evaluate the impact of reducing or eliminating component problems. This is the first time that ANY analysis tool has been able to handle such multiple, interacting reliability factors.

8. Other Influences

8.1 Operational efficiency

One of the commonest opportunities for cost savings is in energy and materials consumption, or production output efficiency - and there is often a close relationship between reliability and such operational performance. Yet rarely has this been explored or successfully handled in a flexible manner. MACRO has incorporated facilities for evaluating and optimising the combination of risks and efficiencies. whether the latter manifests as variations in energy or consumables (inputs), or as degradation of productive output (volume or quality). Examples (already studied and optimised) include the de-coking strategy for an industrial furnace - a combination of efficiency-oriented maintenance with reliability/availability repercussions.

8.2 Lost opportunity costs

Perhaps the single most elusive piece of data in the puzzle. Uncertainty in reliability data is often swamped by the lack of knowledge about the financial consequences of downtime. Here MACRO provides some important lessons - forcing the cost of unavailability, lost opportunity and other 'intangibles' out into the open. Considerable scope is possible in the use of reference examples, "what if?" sensitivity testing and standardisation. Some guidelines on criticality analysis and process mapping (failure consequence assessment) are being generated. This is also an area of potential direct interfacing with process and plant availability simulators.

8.3 Special cases

There are several other ‘special case’ areas of influence upon maintenance and replacement justification and timing:

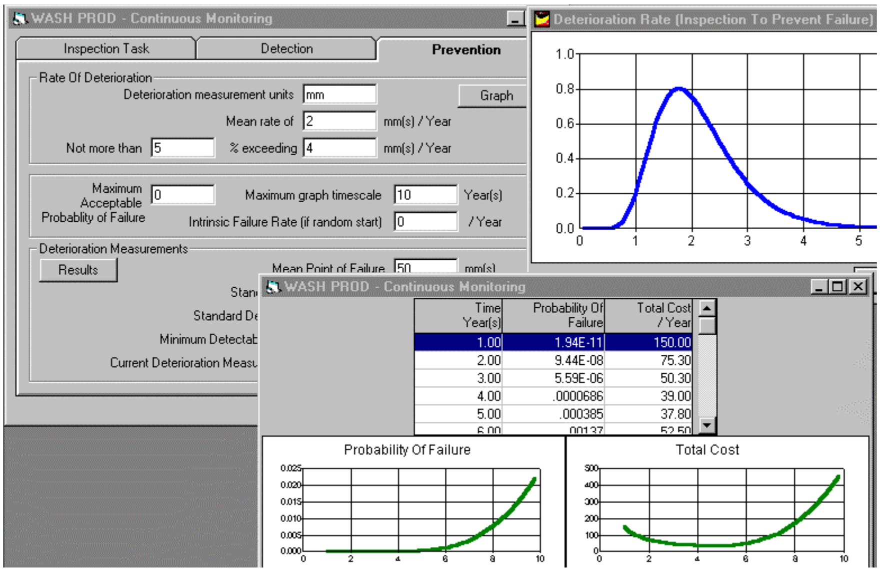
Firstly, there is the issue of maintenance cost escalation. This includes costs that are themselves a function of time (for example, the degree of preparation required before painting, which increases with time since it was last performed). In addition Legal, safety or environmental constraints may also apply - MACRO methods will include calculation of the “premium paid for compliance”, over and above the direct cost/risk impact to the company.

Specific downtime or business-related opportunities may exist for certain intervals or 1-off occasions.

Warranties or service agreements may affect the economic consequences of some of the failure modes. Each of these factors has been considered for breadth of applicability, form of presentation and practical handling method.

8.4 Risk-based Inspection

Perhaps the most radical developments are occurring here: while many organisations are now talking about RBI, and the American Petroleum Institute is developing guidelines, MACRO is putting together the toolkit. Whether inspections are aimed to diagnose deterioration and anticipate failure (condition-monitoring), or to discover latent/hidden defects (functional testing), the uncertainties of deterioration rates, ultimate failure points, detection confidence, failure consequence etc. all need to be handled in a more audit-friendly manner than the existing “worst case assumption” methods. The MACRO module has already developed new algorithms to evaluate these and to test for sensitivity in the face of weak data. Analysis facilities and guidance are expected for public release towards the middle of the year.

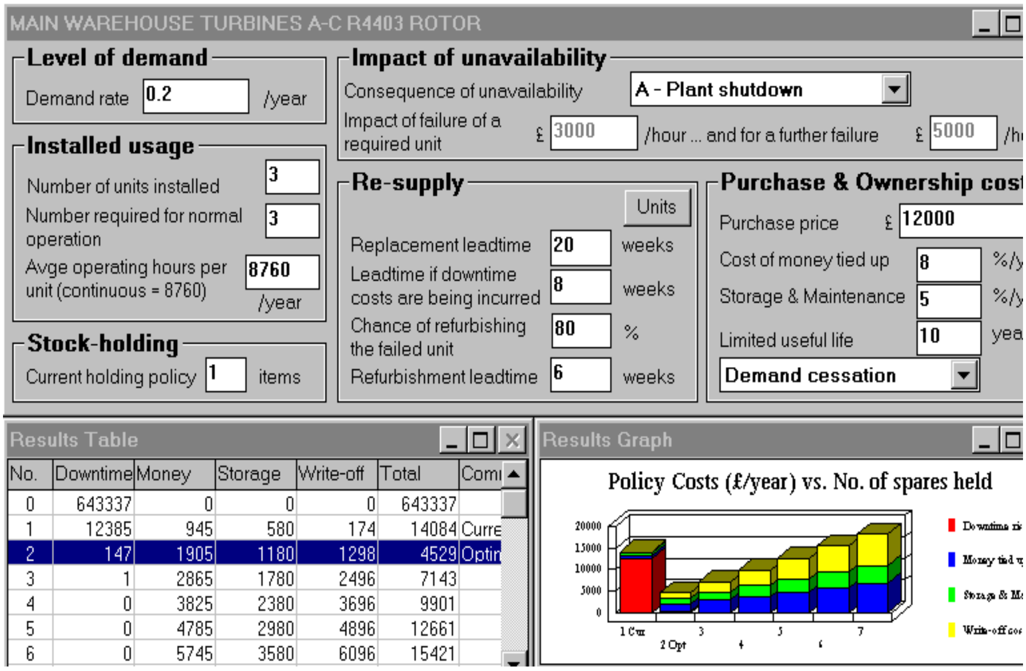


9. An example: evaluating spares requirements

The areas of spares and materials are relatively well researched and partially developed in various forms already. MACRO has collating these facilities and is extending them to a full cost/risk evaluation of spares, materials and supply-chain strategies. Some innovations have been needed and developed to handle factors not incorporated before: the project has completed a slow-moving spares evaluation method, APT-SPARES, which exceeds the capabilities of any other existing algorithms. Until this point, the state-of-the-art was represented by some risk analysis tools that perform basic queuing theory calculations, using Poisson models for demand distribution. On the economic side, such tools consider the cost of capital tied-up, storage and maintenance costs and some provision for depreciation or loss in re-sale value (not to be confused with the depreciation applied for taxation purposes). APT-SPARES adds, among other factors, the whole area of criticality (or stock-out consequences), the various forms of replacement timescale that are possible (emergency re-order, workshop repair etc) and constraints on useful life for the spare (technology overtake, shelf-life, cessation of usage/demand). This necessitates a much-escalated calculation of conditional probabilities as the Markov model has more states and possible combinations. The resulting analysis is a combination of generated probability distributions, iterative sampling, sensitivity and confidence testing, and economic calculation.

A printout of the APT-SPARES module is attached to illustrate the type of analysis report being generated by MACRO. The user interface concentrates on the "what if?" style of operation, with a choice of 'single analysis' and 'batch' studies (the latter provides a spreadsheet layout, allowing block assignment of variables, global "what ifs?" and various database views). Results of the real-life application of APT-SPARES have already revealed big opportunities across a wide range of assets within a company. In one case, £6-8 million is being saved on the spares requirements for a new petrochemical installation. In another, stockholdings have been reduced from £900k to £350k as a direct result - without jeopardising risk exposures.

In this simple example, we present the output of one study on one type of equipment. Turbine rotors are expensive, have long replacement leadtimes and are generally very reliable. Nevertheless, the turbines are also usually very critical - failure consequences can be great in terms of process downtime, performance losses, alternative generation costs etc.. Consequently, for a population of three such turbines, a spare rotor was considered worthwhile. Application of a more comprehensive cost/risk analysis, as evaluated by APT-SPARES, in this case supported a change in the holding policy (to the holding of two spares), despite the relatively high cost of such equipment and the high reparability of any failures that might occur (80% estimated reparable within 6 weeks). The net benefit of holding a second spare is worth £10,000/year (combined effect of risk reduction and extra costs involved).



10. CONCLUSIONS

The justification for engineering, resource and maintenance strategies is not robust, complete or defensible if it excludes risk exposures and probabilistic factors. Yet conceptual complexities, lack of relevant data, and limited time for decision-making all conspire to make rigorous cost/risk evaluation a challenge. In this paper, however, a project has been introduced that is tackling some of the core issues head-on: i.e. the systematic treatment of cost and risk 'trade-off' where hard data is most limited. Such handling of uncertainty is a fundamental element of effective life-cycle management of physical assets. The generic principles being developed as part of this project are clearly applicable across the whole range of industrial operations. The specific results already attained reveal how important this area is becoming and how urgent is the adoption of basic skills and tools.

The MACRO Project is an interesting and promising development - innovative thinking has been brought together from a range of organisations who are all committed to implementing cost/risk decision-making in their respective activities. The tangible results are already emerging.

10.1 References:

(1) MACRO project feasibility & definition, The Woodhouse Partnership Ltd, 1996

(2) The MACRO project, ESREL 1997 conference proceedings, Lisbon

(3) Managing Industrial Risk, J.Woodhouse, Chapman & Hall, 1993, London