ASSET MANAGEMENT – LATEST THINKING

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1 Introduction

An Asset Manager has to be all things to all people. He or she is the point of contact between business objectives and the considerable complexities of technical and human issues. With business performance *accountability* and technical *responsibility*, the Asset Manager is a professional translator – converting options such as new technology opportunities, maintenance strategies, design changes or asset replacement decisions into business or economic language, often with little or no hard data to work with. The newly emerging management science of Asset Management is trying to deal with these requirements; equipping engineers to become businessmen, and introducing some structured methods for handling reliability, performance, maintenance, safety, environmental, staff motivation and other headaches.

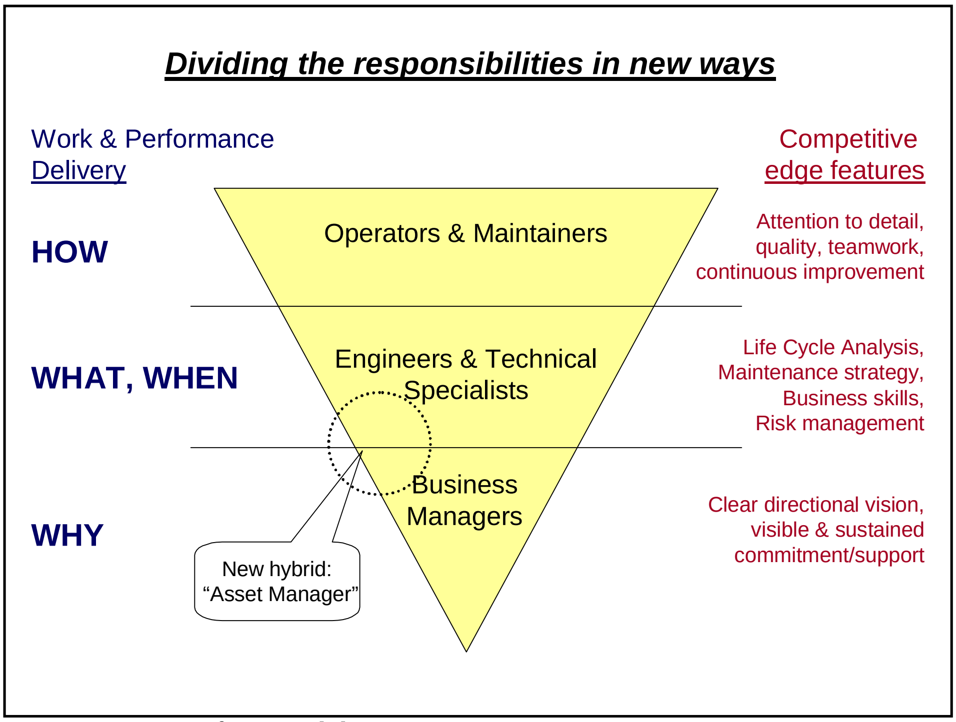

Figure 1 Division of responsibilities

1.1 The challenges

So what are the specific problems that need to be dealt with? What are the constraints that encourage continued departmental focus (e.g. "*Maintenance* Management") at the expense of a more business-oriented *Asset* Management? What are the reasons for continued short-termism (such as choosing the cheapest option, regardless of performance or longevity), rather than the 'Life Cycle' view? I suggest that there are some technical ones, some human ones and some philosophical ones. Certainly the technology has a long way to go in terms of condition monitoring, expert diagnosis, reliability anticipation and resource optimisation. But the current rate of change is already so fast that it is the human capacity to keep up that is usually the limiting factor. The philosophical developments, on the other hand, are a combination of the necessary culture change, re-designing the performance measures (to motivate in the right, consistent direction) and increasing appreciation of what technology and understanding can achieve in practice.

Over the years, I have written extensively on the subject of key performance indicators – design, overlap & de-confliction, the balancing of data volume and understandability, the occasional advantage of conflicting objectives (provided that means of resolving conflicts are also provided). The latest fashion for 'balanced scorecards' goes some way towards a holistic view but fails to address the relative priorities of dissimilar objectives (such as safety, performance and cost control). Similarly, the levels of sophistication in Asset Management are revealed by the dominance of a particular maintenance style: moving from *reactive* to *periodic*/*preventive* and on to *conditional/predictive*. The culture changes underpinning such evolution are very profound – a shift in thinking from the world where good 'fire-fighters' are acclaimed to one in which 'boring and predictable' is good; where managers are coaches, not controllers, and where engineers also have business and communication skills.

1.2 Who has been doing what

There is a very wide spread in the UK understanding and application of Asset Management concepts. This spectrum is roughly aligned to the perceived criticality of the companies' physical assets. Thus airlines, power generators, petrochemical and other process companies have tended to develop, test and implement more sophisticated tools and techniques. Reliability analysis, expert systems, interactive video and remote data acquisition are expensive and complex areas, only likely to be worthwhile if the penalties for failure are high.

On a slightly different slant, however, the disciplines and procedures that deliver the new concepts to a wider practical usage have generally emerged from the most highly structured or regulated industries - the armed forces, airlines and nuclear sectors. From these groups there is a spreading and translating process to other industries. The developments of Integrated Logistics Support and Reliability Centred Maintenance are good examples: both started around 20 years ago in earlier guises but are being widely adopted as standard ways of applying sensible logic without needing to be an expert. Their cross-industrial applications have sometimes suffered from poor implementation, but the underlying rigour and cost/performance value is undeniable.

Another significant source of methods and understanding lies in the manufacturing sector. Here, particularly from the Japanese motor industry, the team-working, shared responsibility and continuous improvement processes have emerged. Total Productive Maintenance and Total Quality Management offer help in one of the most intangible of Asset Management responsibilities – the attitude, motivation and performance of the workforce.

1.3 Putting the components together

Taking a step back, any integrated implementation of Asset Management must consider a mix of techniques, tools and strategies, customised for the profile of assets to be managed, the culture of the workforce and industry, the historical 'baggage' of previous successes and failures, and the degree of flexibility needed to cope with ongoing rates of technical and commercial change. To develop such a customised route-map, however, requires a) a good understanding of the current corporate strengths and weaknesses and b) a very broad awareness of what can be achieved in which areas, at what rate and with what benefit. Such a master plan can only be developed with strong management leadership, a perceived imperative to improve (survival or profit threats, technology or market changes etc) and some specialist expertise to navigate the over-familiar trees and woods.

This usually emerges as a 2-tier implementation plan – a short-term realisation of known opportunities and "quick wins", often obtained by rationalising and coordinating existing fragmented processes, and a longer-term programme of fundamental change (typically a 3-5 year horizon). Maintaining momentum along this path is only possible if the short-term benefits are redeployed to deliver the long-term big prizes. Yet the payback for those who succeed is vast – ranging from company survival to substantial competitive advantage. A typical case involved a petrochemical plant with a 7-year Operational Reliability improvement initiative. On international benchmarks it rose from the middle of the 3rd quartile to number 4 worldwide, with availability rising from 77% to 98% and net cost savings of over £53 million/year. UK utility industries are at the early stages of developing such an holistic approach, but can expect Asset Management to be one of the decisive factors in survival, regulatory treatment and company performance.

The following discusses some of the critical success factors in establishing an integrated Asset Management regime.

2 Work strategy versus Work administration

One of the first key distinctions to be made is that between directional decisions and administration efficiency. While both are needed to correctly manage the assets, they do so by very different routes. Attention to the latter without addressing the former can result in "doing the wrong work 10% quicker", and getting the decisions right but not acting upon them effectively is a similar waste. There has been disproportionate attention applied to the administration area over the last 10 years – it is time for a more balanced view, and any audit of Asset Management activities should certainly consider both areas. It is the right hand side of the following Figure 2 that holds the greatest scope for quantum improvement.

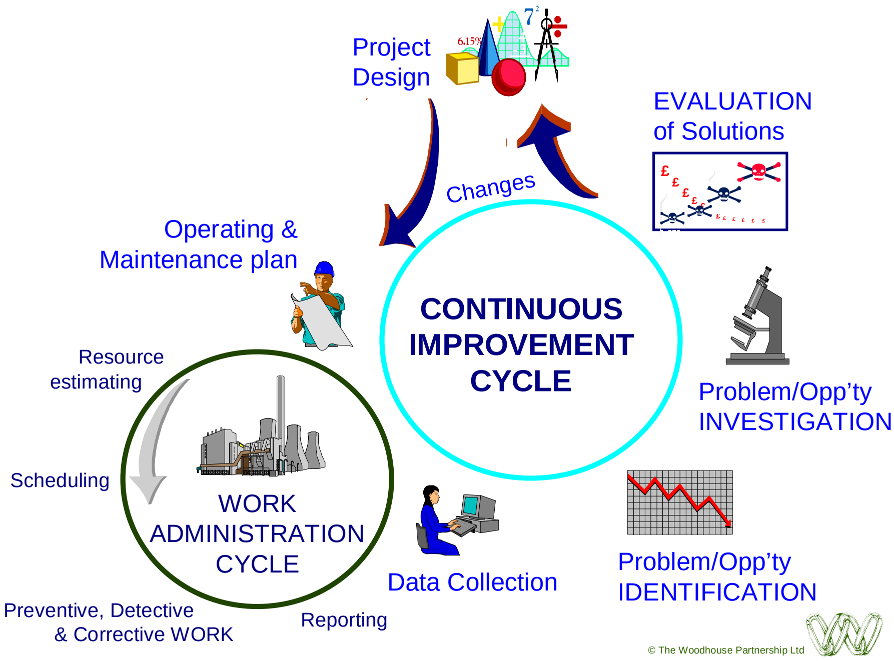

Figure 2. Asset Management Processes

The innovations and technical developments are affecting all parts of both cycles. In the *work administration* section, computer-assisted generation of work orders, assembly of relevant resources and communication with craftsmen (radio links, hand-held terminals etc.) are all aimed at getting the (right) job done more efficiently. In contrast, the development of maintenance strategy rules, on-line condition monitoring, expert system diagnosis and cost/benefit analysis tools try to improve the decisions about *what maintenance is worthwhile, and when*. Let us have a look at the current state of play in each field:

3. Work Management

The main item of interest here is the central administration computer system. British industry has reached the stage at which a 'computerised maintenance system' is an expected advantage and the vast majority of companies either have installed or are intending to install a system for at least basic work control. The common features are

3.1 Asset Register - ranging from a coded equipment list to a fully fledged technical information database, merging diagrams, technical specifications and even video clips of the equipment and how it works. As 'multi-media' loses its early life, computer-enthusiast flavouring, it will undoubtedly make the storage and retrieval of text, diagrams and film clips much easier and cheaper. So the 'static data' relating to physical assets will improve dramatically in both function and price. Some companies have spent, and are spending, millions on this area alone. Keeping track of the several hundred thousand individual items on an oil rig or commercial airline fleet warrants sophisticated database technology. Merely keeping design drawings up to date takes substantial manhours and computing effort.

At the simpler end of the scale, an asset register can be built up on the simplest of stand-alone databases. A copy of dBase or Microsoft Access, a personal computer and about 3 days of programming should yield an adequately flexible central register of what equipment is where and the primary characteristics of supplier, technical data, age etc. Alternatively all 'maintenance management' systems on the market necessarily include such an asset register facility and some are priced under £2,000. Barcodes are also providing a low-cost way of setting up and maintaining asset-related information. Remote hand-held readers are improving the accuracy and ease of data acquisition so equipment movements or changes can be more readily recorded.

Note that an <u>asset information system,</u> as described here, is often referred to as an asset *management* system (usually by software vendors). I would argue that the latter should refer to the wider role of information, action, review and improvement (the pair of cycles in Figure 1). An asset register, with basic identification information, is a prerequisite before maintenance tasks can be issued and controlled effectively. You need to know what you have got first of all.

<u>Range of technology/sophistication:</u>
Minimum level for 'Asset Management': A central, regularly updated, equipment list.

Top of the range: Integrated, on-line technical & commercial specifications, linked electronic drawings, GIS and picture/video information.

3.2 Planned Maintenance

PM modules are often the reason why a computer is introduced for maintenance management. Keeping track of what job is due on which piece of plant is largely a diary management exercise. It can be done on wall charts, card index or reference books. Computers just do it quicker, with greater reliability (usually!) and larger capacity. The scope for sophistication lies in how the work is prepared, triggered and issued. Increasingly the role of a maintenance planner is being supported by greater access to previous work history, resource availability and 'smoothing' techniques that allow a closer match between required and available manpower or materials. The fit will never be exact - there is in fact an optimum degree of mismatch, representing a contingency 'buffer' of available labour for some of the time and a reliance on external resources (usually contractors) for exceptional demands. It requires discipline to use computer software to assemble the jobs, record or retrieve standard task descriptions and to link jobs to resources. This discipline is generally worthwhile anyway. Although it is sometimes presented as a case of running around to 'feed the machine', the rigour and thoroughness demanded by most software systems is there for a purpose - to maintain information integrity and the subsequent usefulness of historical data.

The triggering of planned maintenance tasks is a big subject. Here lie the results of lengthy discussions about fixed intervals, calendar or usage-based, inspection and condition-monitoring strategies. Whatever the agreed strategy for the process/system/equipment in question, the work scheduling stage must be able to respond to the appropriate triggering circumstances.

3.2.1 Fixed-interval tasks

In some cases, this will mean a simple date-triggered job, based upon the preconceived calendar interval. Any maintenance management system should be able to do this. Useage-based intervals require some form of counter - operating hours, numbers of cycles or similar. This in turn demands either more recording (the actual progress of the counter must be monitored so that the trigger can occur at the appropriate time) or further technology (linking the planned maintenance module directly to some measure of progress). The efficiency of such a mini-feedback loop varies widely. It does not take long, however, for poor recording to result in inappropriate maintenance timing and consequent plant unreliability or reduced performance. If operating use is a better measure of equipment deterioration <u>and it can be recorded continuously</u>, then it will always be a more effective criterion for fixed interval maintenance tasks.

<u>Range of technology/sophistication:</u>

Minimum level for 'Asset Management': Wall chart/card index system.

Top of the range: Computer-based job planning, integrated resource allocation and smoothing, dynamic scheduling

3.2.2 Condition-based tasks

Condition-based tasks are, potentially, more cost effective still. Performing work only when it is known to be needed clearly represents the ideal. To do so, however, there are several hurdles to be overcome. For a start, greater knowledge of the potential failure or deterioration mechanisms is required. We need to know what to look for. In the triggering of work, there is also the new distinction between data collection effort (inspections and diagnosis) and the preventive/corrective actions that result. The work administration system will have to cope with a variety of 'alarm bell' conditions and be able to initiate maintenance tasks in response.

<u>Range of technology/sophistication:</u>

Minimum level for 'Asset Management':	Active monitoring by operators.
Top of the range:	On-line monitoring with neural network assessment of incoming data.

3.2.3 Periodic inspection

Since the condition monitoring can itself be periodic or continuous, there is often a diary mechanism in the background to trigger any discrete inspection jobs. Thereafter, the efficiency of work control will depend upon the information sought. If the inspection is targeted to find existing (hidden) defects, then the discovery must trigger appropriate corrective action. Higher levels of efficiency will be obtained if the repair can be made on the spot, but this requires preplanning the relevant resources (tools, time and materials) to a level of expected demand. Alternatively, the inspection results can feed a job triggering mechanism 'back at base' - rather like the operating use counter.

The capabilities of technology are rather stretched in this area. Certainly the inspections can be triggered without problems and even automatically grouped into convenient 'inspection rounds'. Diagnostic guidance (what to look for, based upon previous discoveries and the symptoms available so far) can also be very elegant. Expert systems have been used successfully, but only in certain specific ranges of interpretation complexity. If there are too many possible circumstances or combinations of symptoms, the expert system spends all the time learning and the physical circumstances are likely to change before confident diagnostic help is available. For the simpler cases, the human brain is still the best method for spotting patterns or inferring cause-effect relationships. It does benefit, however, from some prompting or checklists. Examples in the process industries have revealed that diagnostic error (missed warning signs or incorrect interpretation) can be as high as 50% for casual walk-around inspections and can be reduced to less than 1% by following a checklist. Thankfully airline pilots know this!

Computer-generated checklists can select appropriate lists of possible symptoms so, if a piece of paper is not good enough for you, the era of remote hand-held devices linked directly (by radio, infra-red or ultrasonics) to the asset information system and previous maintenance history is not far away.

<u>Range of technology/sophistication:</u>

Minimum level for 'Asset Management':	Disciplined inspections & trend analysis.

Top of the range:	High tech. monitoring devices, trending, expert and neural net analysis systems.

3.2.4 Continuous monitoring

The advent of reliable detection and communications hardware has opened up many avenues of possible on-line monitoring. This is definitely the fastest moving area of improved maintenance efficiency. Just as there are hundreds of types of measurable characteristic, so there are now hundreds of ways of monitoring and reporting the symptoms. Vibration alone has blossomed into a sophisticated science, dealing with erudite refinements of broad and narrow band spectra, shock pulse, proximity analysis and kurtosis. A lot of money has been poured into both the measurement and the interpretation techniques and with good reason. Whereas human senses can pick up a wide range of warning signs, and often complex combinations of signals, they are not sensitive enough to give adequate reaction time for many types of deterioration. Given the greater and greater dependency on high speed, high performance equipment, the failure modes become correspondingly more dramatic and fast acting. Alongside the natural desire to do maintenance only when it is needed, there is an increasing urgency to get early indication of that need. Without trying to list the many high technology techniques that are now available, I will observe that it is the same pressure for earlier warning that is driving the current organisational moves towards 'first line maintenance' and the natural role of an equipment operator as an on-line condition monitor. A suitably trained human brain is still one of the best possible methods for spotting incipient trouble.

3.3 Maintenance History

Once work has been triggered and performed, the recording of the event is the next area of efficiency variation. Here the disciplines really count. There seems little incentive to spend time and effort completing reports when the subsequent use for that information is either remote or minimal. All computer-based maintenance management systems offer some form of history module, semi-automatically recording as much information as possible from the original job planning stages. This is an attempt to reduce the feedback obligations to just a confirmation of job completion, along with any exceptions or variations. Emergency and other reactive tasks, whose work orders are often raised only retrospectively, will always require a deliberate reporting effort. Some advances in multiple choice and pen-based reporting are being developed to further ease the burden but, given the variety in possible information and interpretive feedback, the primary mechanism is still human discipline.

The history gathering is often a weak link in the chain. There is usually no real incentive for tradesmen to provide the data and consequently the information that is collected is often poor or irrelevant. No matter how sophisticated the other aspects of asset management, when it comes to maintenance history, very little meaningful use is being made of it. There are two technical reasons in addition to the human motivation one. Firstly, until the methods for using the data are fully understood and in place, it is difficult to know what data is needed in what form. I will expand on this a bit later. Secondly, there is an intrinsic problem with the usefulness of maintenance records - *the more important they are, the less you will get*. This stems from the natural requirement to avoid high impact breakdowns. Historical evidence that would help you to justify preventive actions is censored by success. History will increasingly describe just the preventive jobs themselves, and less important corrective ones. As a way of proving that previous maintenance strategy was correct, this may be useful (but even then, how do you know you are not over maintaining?). For quantitative analysis of reliability patterns, maintenance history is, and will always be, rarely adequate on its own.

<u>Range of technology/sophistication:</u>

Minimum level for 'Asset Management':	Systematic log of planned & corrective jobs.
Top of the range:	Work order closeout procedure with failure cause and cost analysis.

4. Maintenance Direction

The management and direction of maintenance effort is the activity that raises work control into asset management. This covers the cycle of problem identification and interpretation, evaluation of solutions and corresponding adjustment of strategy and resources. Here both the technology and the human ability to understand it are limiting factors.

4.1 Problem finding & investigation

At one level, the problem *identification* methods are well established. Top-10 reports of failure rates, total maintenance cost, downtime or spares consumption have been providing useful pointers to problem areas for many years. The advent of computers has been of great help, correlating failure types, producing rapid ranked lists and even allowing 'drill down' into whatever history has been recorded in the search for clues about root causes. In general, the technology has only succeeded in identifying where the problems lie, not in the *nature* of the problem or the reasons for it. A good example of this difference lies in the use of Mean Time Between Failures as a reported statistic: MTBF is very useful indeed for seeing where the problems are, and how big they are, but is it quite useless in determining *why* the failures are occurring and what, therefore, could be done to prevent them. For the latter decisions, it is the *pattern* of risk (how it changes with time/use/???) that matters. This is a whole order more difficult to establish from historical data - so engineering knowledge/experience, expectations, inference and range-estimating are the prime sources of information.

At the academic cutting edge, the reliability gurus have for some time (over thirty years) been studying the relationships between probability (and consequences) of equipment failure and preventive maintenance or replacement timing. There has been, however, a big gulf between the theory and the practice. Even now, the boffins argue about the validity of particular mathematical models in application to specific failure modes. The 'Bath-tub' curve is one such area of controversy but it need not be. Despite the claims of various organisations for certain intrinsic patterns of risk, there is a more fundamental concept at stake. Everyone knows and can recognise that there are risks that <u>reduce</u> with time, <u>increase</u> with time or are <u>constant</u> with time. Any combination of failure mechanisms is likely to result in a mixture of these components. Whether they combine to form a nice symmetrical 'Bath-tub' shape is not the issue (indeed it would be a strange coincidence if they did). The significance for maintenance strategy purposes lies in the existence or not of these components of risk.

Increasing risk is treatable by timely preventive action. Reducing risk is a disincentive to interfere - the longer the item is left, the more reliable it becomes. Constant probability cannot be affected one way or the other by deliberate maintenance (a design or operating change is required).

The barriers to progress are bolstered by three common mistakes in reliability or maintenance history analysis. They are:

4.1.1 **Historical failure patterns do provide enough data for risk models**.
The distribution of actual failures is mistaken for the probability of failure. In fact these are quite different things. If you plotted the distribution of human deaths with respect to age at death, there would be an apparent 'bath-tub' of infant mortality, 'random' and age-related increase. But the graph is not the probability graph that the Bath-tub pundits are referring to. The number of deaths reaches a maximum frequency at around 65 years and then falls away again. There are very few deaths of 105-year old people (or failures of very old equipment) *but this does not mean that the risks (for a 104-year old) are small!* The probability of failure, *given survival so far,* is high and rising. Observed (historical) failure patterns are thus a combination of how many have reached each point, and the failure probabilities that they then faced.

It is quite a complex job (but well proven mathematically) to convert the observed pattern into the underlying risks that must exist to generate it. Computers can do the maths. very fast - and need to because it is the probabilities of failure (called the Hazard Rate) and not the resultant symptoms (the Density Distribution of failures) that are needed to justify preventive action.

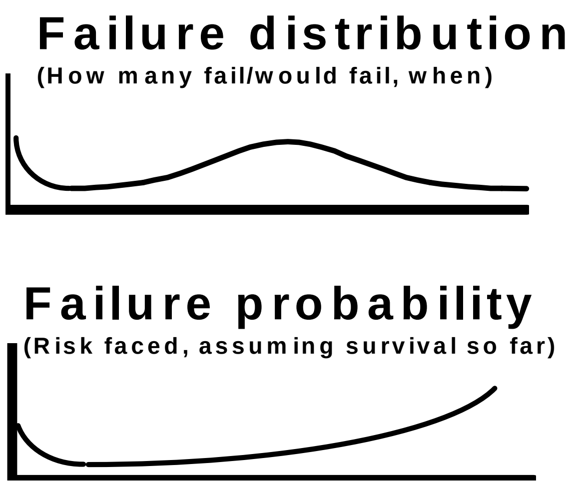

Figure 3. Failure Distributions vs. Underlying Probability Patterns

4.1.2. Randomness and non-randomness
The second common mistake is that of mixing up timescales. A failure may be random with respect to calendar time or equipment age but there is always some timescale, usage or other criterion that it is not random with respect to. The art of problem-solving in asset management lies in finding correlations between equipment

failure and some determining circumstances i.e. non-randomness. The foreign object damage may be random with respect to pump age, time since last overhaul or day of the week, but it is quite likely to be related to upstream filtration actions. Exactly the same failure or maintenance history can reveal quite different patterns when plotted to different timescales. An automatic assumption, that is made far too often, considers failure probabilities only in relation to equipment or component <u>age</u>. Very rarely is this the most appropriate timeframe. There are many intervening actions, influences and alternatives with a much higher chance of correlation to failure frequency. As far as I am aware, only one piece of computer software has so far been developed that can handle these multiple interacting failure modes and timescales (RELIAN™). I have seen it used for pattern-finding in the maintenance history of turbine generators, gearboxes, motors and water pumps. The more familiar "Weibull Analysis" techniques can only generally be used when there are enough examples of a single consistent failure mode (to discover whether the risks are reducing, constant or increasing). This circumstance is so rare that it makes the technique quite impractical.

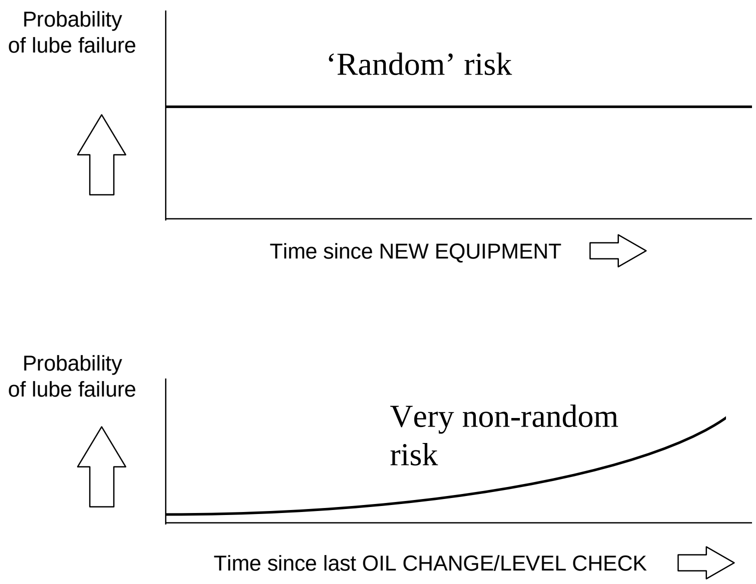

Figure 4. 'Random' is relative: lubrication failures example

4.1.3.   **Which jobs reset which deterioration "clocks"**

The third area of frequent error lies in the responses to failure. Entirely dependant upon the timescale being considered, the repair of a breakdown can effectively 'reset the clock' of subsequent risks or simply return the equipment to an operating state. Clock-resetting events have a quite different impact on the future need for

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maintenance. The scheduled overhaul in 4 weeks time is no longer appropriate if the work was effectively carried out in response to yesterday's failure. The Patch-and-continue events, on the other hand, can accumulate with increasing urgency for some larger, condition-restoring maintenance task. This is a complex subject, not suitable for detailed coverage here. An important observation, however, is that most computer-based planned maintenance systems *do not take account of intervening failure repairs when scheduling the 'next due' dates*. It is often left to the planner to notice if any repair work has 'reset the PM clock', and to suppress or reschedule the next planned occasion. If he does not, the system will result in automatic over-maintenance.

<u>Range of technology/sophistication:</u>

Minimum level for 'Asset Management':	Regular Top-10 reporting & investigation.
Top of the range:	Systematic reliability and root cause pattern-finding, on-line CBM, deterioration modelling, RAMS simulation.

4.2 Evaluation of Solutions

So the technology and concepts that help to interpret problems are difficult. Most interpretation is still based, therefore, on human judgement, using the basic logic of root cause investigation and common sense. The same is true for a quite separate activity - the cost/benefit evaluation of possible solutions. Simple evaluations of a proposed action are common (averaging the total cost of the current situation, estimating the amount of improvement, and performing a 'payback' assessment for the one-off costs of change). These often stretch to include the discounted value of future costs or benefits. But they rarely extend into the effects of changing maintenance intervals or condition reaction points upon plant reliability or total cost of operation. Again, the mathematics are too nasty and the available information is not considered adequate.

One area in which complex effects can be considered is through simulation. This is becoming an increasingly acceptable way of calculating part of the cost/benefit equation. The computing speeds are rising to a level at which 'what if?' simulations can form a natural part of the asset manager's weaponry. They will soon join the calculators that already exist for evaluating the optimal degree of maintenance, inspection, spares and asset replacement (as generated and collated under the European MACRO project[x]). In each case, the potential benefits are massive (*average* payback is 4-6 months!) Nevertheless the evaluation techniques are still waiting for a wider level of understanding in how, where and why to use them. The acceptance and understanding are slow to catch up.

<u>Range of technology/sophistication:</u>

Minimum level for 'Asset Management':	Spreadsheet cost/benefit evaluations.
Top of the range:	Deterioration modelling & cost/risk optimisation, Life Cycle Costing

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[x] Eureka project EU1488

5. Maintenance Strategies

Finally let us return to the most fundamental engine of asset management, the directional decisions about what maintenance to do and when; the overall framework for evaluating problems and their potential solutions. Here there is a lot of current excitement. Rule-based procedures such as the civil aviation MSG-3 and its multi-industry progeny, RCM, use key characteristics to choose between fixed-interval, inspection- or continuous condition-based maintenance and 'design out' options. The present enthusiasms and vast expenditures (one large UK company has spent $12 million on Reliability Centred Maintenance studies over the last 5 years) are undoubtedly due for a rationalising, however. Similarly, Total Productive Maintenance (TPM) from the Japanese motor industry tackles *part* of the problem (the operator/maintainer interface and the “cleanliness is next to Godliness” attention to detail). However it is unlikely that a single mechanism could ever exist to handle the variety of industrial operating constraints, reliability and efficiency characteristics, maintenance requirements and responsibilities, and cost/benefit evaluation of appropriate strategies. A blend of techniques will nearly always be needed.

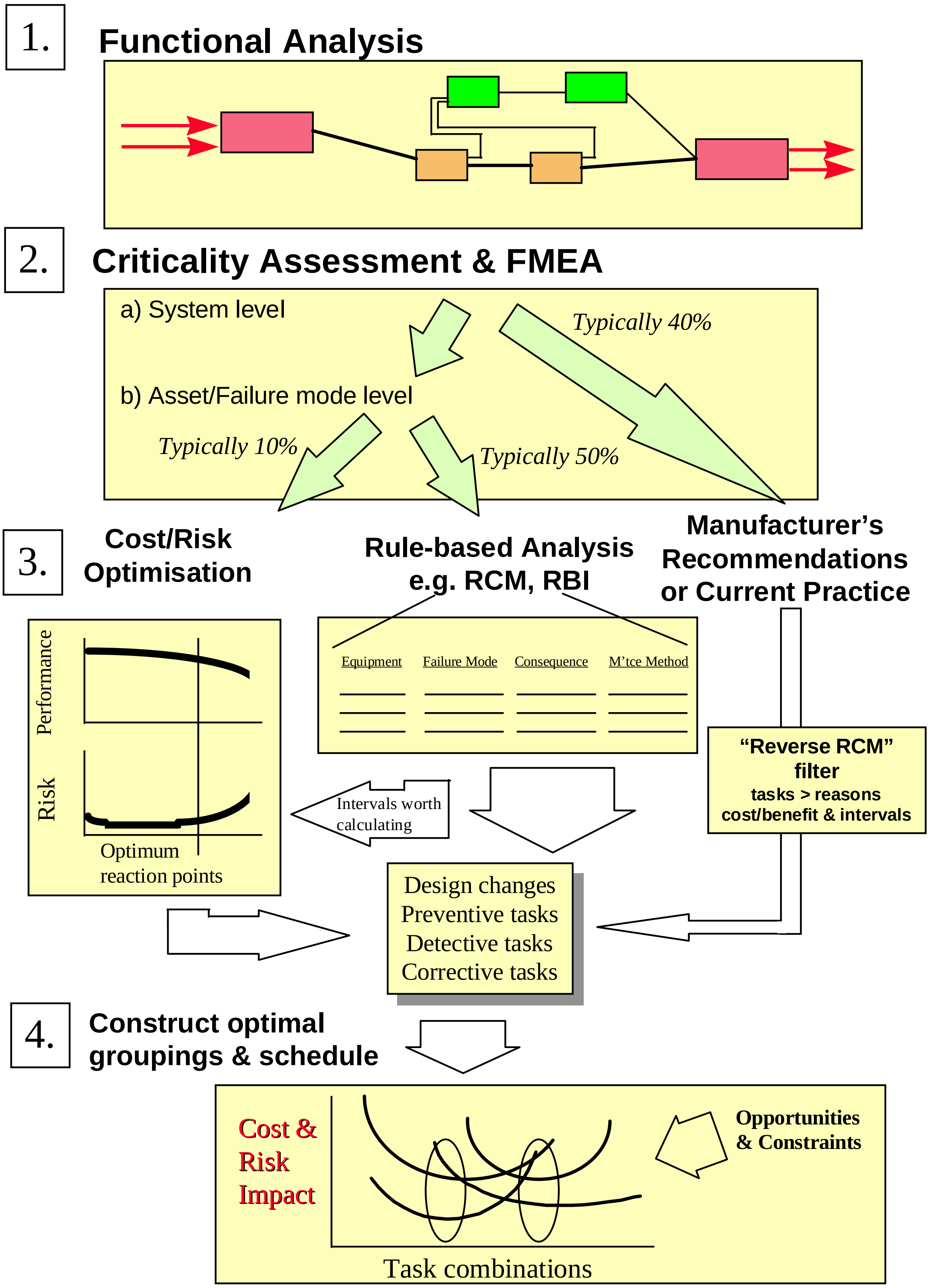
Figure 4. RCM benefits from application to criticality-selected systems (on an oil rig)

1993/4 results

(top 40% of systems covered) SYSTEM ANALYSED	Preventive Maintenance annual manhours Before RCM	After RCM	Analysis cost (£)	Annual saving (£/yr)	**'Payback'** (saving/cost)
Fire & Gas detection systems	11221	3574	37,050	386,100	**10.42**
Water injection systems	619	173	3,250	22,490	**6.92**
Seawater handling systems	580	238	2,600	17,225	**6.63**
HVAC	1176	344	6,500	41,990	**6.46**
Cranes & lifting gear	623	263	3,250	18,200	**5.60**
Main oil production system	1927	918	13,000	50,960	**3.92**
Emergency fire pumps	1173	986	2,600	9,425	**3.63**
Gas processing	2138	1765	14,300	18,850	**1.32**
Electrical equipment	2859	2386	55,900	23,985	**0.43**
Totals:	22316	10647	138,450	589,225	
				Average:	**4.26**

At least in the meantime there is considerable advantage in the training, conceptual understanding and disciplines that FMEA, RCM, TPM and RBI (Risk-Based Inspection) and similar procedures introduce. The fuller picture should be expanded, however, to direct levels of analysis effort that are appropriate to the criticality of the plant involved. This may result in anywhere between 30 and 60% of equipment being analysed in template and ‘rule’ style; the remainder split between 'high criticality' (warranting more detailed, quantitative analysis) and the 'low criticality' items that are not even worth an FMEA study.

Figure 5. Combination of tools for “what maintenance & when?”



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Once a review of maintenance strategy has been performed, either in a greenfield, new project circumstance, or as part of a refinement of existing practices, there remains a final step. The component maintenance tasks and frequencies must be assembled into a co-ordinated plan. This offers further scope for substantial cost savings, yet is often a stage left to unaided human judgement. Comparing the alternative schedules for work packaging would be a tedious job yet the impact on requirement for equipment downtime and shared access or resources can be great. Some planning tools allow this 'what if?' facility but rarely do they take account of the *cost of compromise*. Bringing one task forward to coincide with another, or delaying one until the plant is shut down for other reasons, has cost, risk and availability implications. Again, the interrelationships can be handled at high speed in a computer, but the value of this final optimisation task is not yet widely appreciated. It will come.

<u>Range of technology/sophistication:</u>

Minimum level for 'Asset Management':	FMEA methods applied to main systems.
Top of the range:	Systematic function/process mapping, criticality system, FMECA, RCM/RBI ruleset & template, quantitative risk/deterioration modelling, cost/risk optimisation of intervals, work package & scheduling optimisation .

6. Conclusions

So, where do we stand? Much development has occurred, particularly in the work control and asset information areas. Computers have wheedled their way into the maintenance department, often despite the conflicting priorities of finance and production departments. It continues to be difficult to justify expensive new technology in an area where most of the benefits are felt indirectly or accrue in other areas of the company. Nevertheless the boardroom has increasingly acknowledged that a 'maintenance management system' is acceptable and necessary.

The front-line areas of innovation are those of condition monitoring and reliability/maintenance strategy analysis. In the former case, the techniques, tools and understanding are moving fast and roughly in parallel. On the other hand, the 'science of maintenance', as represented by reliability concepts, maintenance strategy review and cost/benefit analysis, is technology lead. Simulation, cost/risk optimisation tools and sophisticated reliability modelling aids have been around for some time. Understanding and the use of such understanding are the limiting factors.

This is one reason why professional bodies such as the Institute of Asset Management are so important. We need to increase the spread of understanding, of successes, failures and innovations at a greater rate. The business demands can only get greater so all of us are under increasing pressure to improve professionalism, discipline and cost/benefit accountability. We cannot afford to reinvent the wheels individually or learn by trial and error - it takes too long and is too expensive. Just as importantly, however, we have also got to be interested in the methods for improvement, and to enjoy our jobs. Asset Management is complex and affects all parts of the business but it hold massive opportunities and, providing we can keep our heads above the water, is good fun!