



White Paper

MAXIMISING MARINE ASSET PERFORMANCE THROUGH COST AND RISK OPTIMISATION

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INTRODUCTION

How Can We Balance Cost, Risk and Performance?

Shipping and Marine Support services (such as to the Oil and Gas industry) are open to tough competition on a global scale with ever increasing demands placed upon lowering cost but increasing safety. Safety critical systems' performance are under the spotlight to avoid past fatal disasters such as Amoco Cadiz, Piper Alpha, Derbyshire, Petrobras 36, Deepwater Horizon and countless other environmental marine pollution incidents while the remnants of the global recession and the state of oil weigh heavily on profit.

Prior to the offshore oil and gas downturn, spending on maintenance costs have risen 10-15% per annum since 1979 with total spends estimated around US\$1 trillion. (Lobley, 2014)

Efficiency through optimisation is at the forefront of those companies that aim beyond survival. Digitalisation is all the rage in Maritime circles where many believe it can provide elusive efficiencies so desperately sought after. However, adding further complexity to already complex systems (Hydraulic, Electrical, Pneumatic, Electronic) creates an exponential rise in the variety and severity of failure consequences (Moubray, 1997). Yet, the unsung burden on Seafarers and operators is the ludicrously, over-specified maintenance programmes often thrust upon already stretched Human Systems and goes largely unnoticed.

This White Paper explores a philosophy that provides a framework specifically developed for Maritime that can achieve true optimisation by balancing Cost, Risk and Performance, and providing the foundation to successfully attain ISO55000 Asset Management accreditation.

It will transform the relationship between those that use it, their existing physical assets and those that manufacture it. It will also enable new assets to be put into effective service with great speed, confidence and precision as well as justifying digitalisation.

Challenges

- What can we do now to drive further operational efficiencies?
- What can we do to optimise vessel and fleet performance?
- What can we do to improve reliability, availability and performance without compromising on safety?
- What can we do with exponential growth in data with interconnectivity?
- How do we defend against additional complexity and potential failures in a connected world?
- How do we overcome resistance to change with the cultural maritime barriers?

Purpose

To assess and analyse marine asset strategy, operations and maintenance to optimise performance through a cost-effective asset dependability strategy.

Goal

To improve dependability through the fleet wide management of reliability, availability, safety and security whilst exercising sound economic judgement.

Tasks

- Analyse marine assets to reduce maintenance costs and workload and increase asset reliability.
- Continuous improvement through the deployment of a learning system and knowledge repository.
- Template and rubber-stamp modelling for scaled fleet-wide rapid deployment.



The adoption of a data-driven philosophy for asset operations, such as Reliability-Centred Maintenance will therefore become even more important in the maritime industry.



<https://to2025.dnvgl.com/shipping/safety-enhancement/>

Figure 1 DNVGL on RCM in Maritime

THE PROBLEM

As alluded to in the opening statements Shipping and Oil and Gas are subjected to fierce competition on a global scale. The additional downturn in the Oil and Gas Industry due to the low cost of oil has meant the oil companies needed to find efficiencies quickly. This had a knock-on effect and rippled throughout the global Maritime and Oil and Gas support industry and still exists today.

Many Oil Field developments were shelved and again this had a domino effect throughout the Maritime and Marine Offshore industry. Charter rates fell overnight for Oil Drilling rigs and all the support vessels associated with the oil and gas industry. No marine asset was protected from this.

Oil Tanker rates struggled too due to the knock-on effect. Container vessels too were not impervious to industry downturns and have struggled due to overcapacity and as such major players have started to consolidate and indeed some well-known major players have indeed gone bankrupt.

A universal feature of traditional ship and rig procurement is the insistence the OEM provides a maintenance programme as part of the supply contract. Apart from anything else this implies the OEM know everything that needs to be known to draw up suitable maintenance programmes. Surprisingly, they know very little of the information needed to draw up truly context-specific maintenance programmes, especially with ships and oil rigs operating in isolation offshore or the middle of the oceans. They also have their own commercial agendas when specifying such programmes, not least of which is to sell spares. There are no failure management policies within Maritime worth their salt.

The combination of extraneous commercial agendas and ignorance about the equipment operating context means maintenance programmes often embody an incredible amount of over-maintenance sometimes ludicrously so, couple with massive over-provisioning of spares. This has also resulted in a phenomenon of Infant Mortality discovered more than 70 years ago that is well-known in the reliability engineering and maintenance fraternity globally and in most industries, except Maritime. We will explain later in this White Paper about Infant Mortality.

Compounding the above, marine assets and Maritime by its very nature is extremely conservative and extremely resistant to change in the advent of innovative technologies. Marine assets (Ships and Oil Rigs) have upwards of 120 different Original Equipment Manufacturers (OEM). Couple this with them all vying to sell Digital Services, one can see how an expensive proposition it becomes for the Shipowner. Not all equipment or systems benefit from Condition Monitoring (CM). CM can be incredibly good or a fantastic flop. Indeed, approximately 20% of known failure modes in any industrial undertaking benefits from Condition Monitoring/Predictive Maintenance and only worth doing less than half (Moubray, 1997).

Summarising the problems, we face, are two-fold:

- *Shipboard Maintenance Programmes are incredibly over-specified, inefficient, expensive, archaic and potentially dangerous due to potentially introducing Infant Mortality.*
- *Digitalisation (Condition Monitoring/Predictive Maintenance) provides defence to approximately 20% only of known failure modes and worth doing in less than half.*

HISTORY OF MAINTENANCE GENERATIONS

Like the Industrial revolution, Maintenance has undergone change throughout the ages from mechanisation through to the digital cyber-physical systems. The graphic below depicts those Maintenance Generations in relation to the Industrial Generations in chronological order.

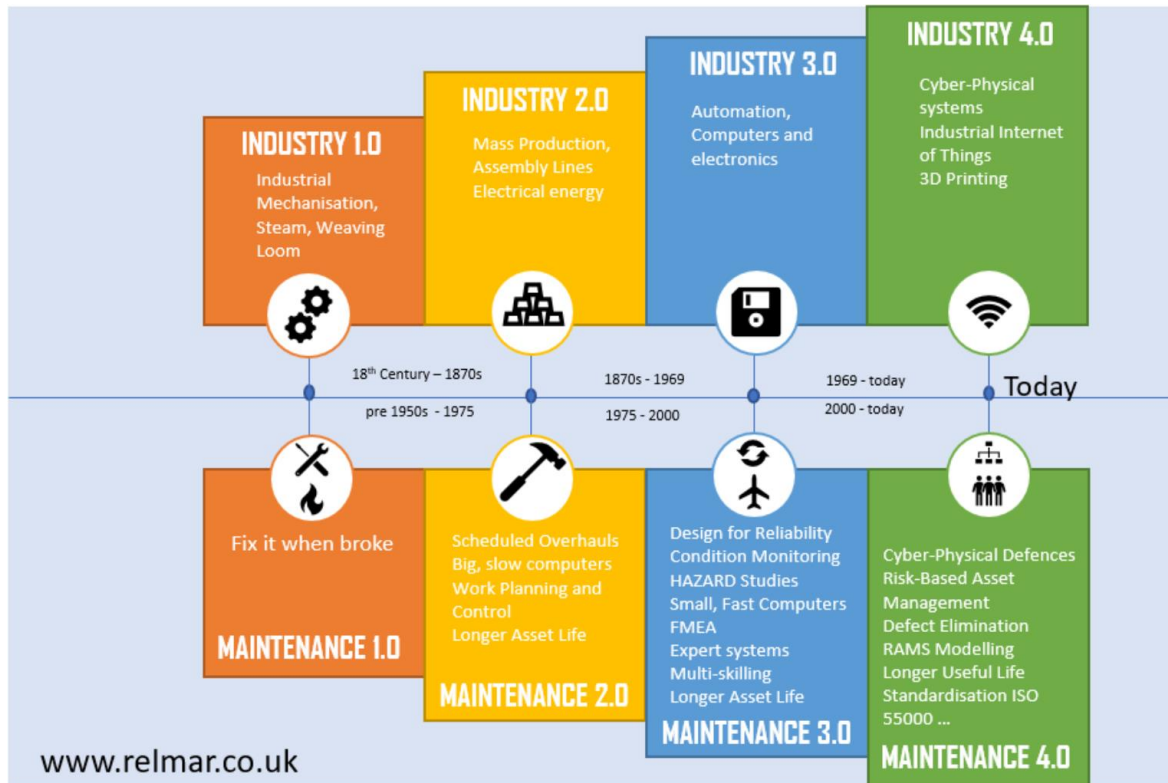


Figure 2 Maintenance Generations versus Industry Generations

A SOLUTION

We believe we have the solution and this solution is not about reinventing the wheel or rudder. No, it is about taking a well proven successful process used extensively in other industry and making it relevant for Maritime. We give you Marine Reliability-Centred Maintenance [m]RCM.

Aviation, Energy, Automotive, Utilities, Mining, Theme Parks, High-Speed Rail Networks, Data Centres and so on...all utilise this subtly sophisticated process but not Maritime or Oil and Gas to any significance. Why? Lack of knowledge, insufficient skillsets such as Reliability Engineering, perceived complexity, transient crew, no historical failure data are some reasons. But these reasons, in our professional capacity and judgement based on our technical and business solutions no longer remain valid.

MARINE RELIABILITY-CENTRED MAINTENANCE [M]RCM

What is RCM?

RCM is essentially a formal application of engineering decision logic supported by experience and sound engineering judgement, something Software or data solutions cannot provide which is knowledge. Data without knowledge is moribund. If RCM is applied correctly, it will result in a recommendation for the most cost-effective engineering failure management programme which will ensure assets continually meet required performance standards. It also helps the Shipowner to demonstrate that it is exercising a "duty of care" towards its employees and the environment as required by national and international legislation.

RCM is a programme to achieve efficient scheduled maintenance for complex equipment that is centred on achieving its inherent safety and reliability capabilities at the lowest possible cost.

Reliability is the probability that an item will survive to a specified operating age, under specified operating conditions, without failure. Maintenance is an integral part of any physical asset be it a ship, plant, aircraft, motor vehicle etc. that commercially realises revenue earning potential of the organisations products and services without which breakdowns and downtime could ultimately fail the organisation.

Shipowners can achieve large cost reductions without a decrease in reliability. A thorough understanding of the failure process in complex equipment/systems (Hydraulic, Electrical, Pneumatic, Electronic) has improved reliability by pinpointing potential failures and facilitating the precise approach to eliminate risk associated with maintenance.

History of RCM

Conrad Hal Waddington (1905 – 1975) was a British Developmental Biologist, Geneticist and Embryologist, amongst other equally distinguished disciplines. During World War II, he became instrumental in Operational Research for the United Kingdom's Royal Air Force Coastal Command, becoming scientific advisor to the Commander in Chief of Coastal Command from 1944 to 1945.

Tasked with increasing the effectiveness of Bomber command (reduce the number of daily grounded aircraft), it was a task that could be perceived not befitting to a person of his background and credentials and rose eyebrows and noted at the time of his appointment was rather odd considering his background. Nonetheless, Waddington and his team set forth to assess the situation.

Waddington's operational research team encountered and identified what was to become known as the "Waddington Effect" during the conduct of an effort to increase the flying hours of the Coastal Air Command's beleaguered air fleet.

It was found that the preventive maintenance (PM) events being employed appeared to induce rather than reduce unscheduled repairs. This disturbing effect was particularly evident "shortly" after the conduct of a PM event and thus resulted premature failure of the aircraft. This phenomenon became known as the Waddington Effect.

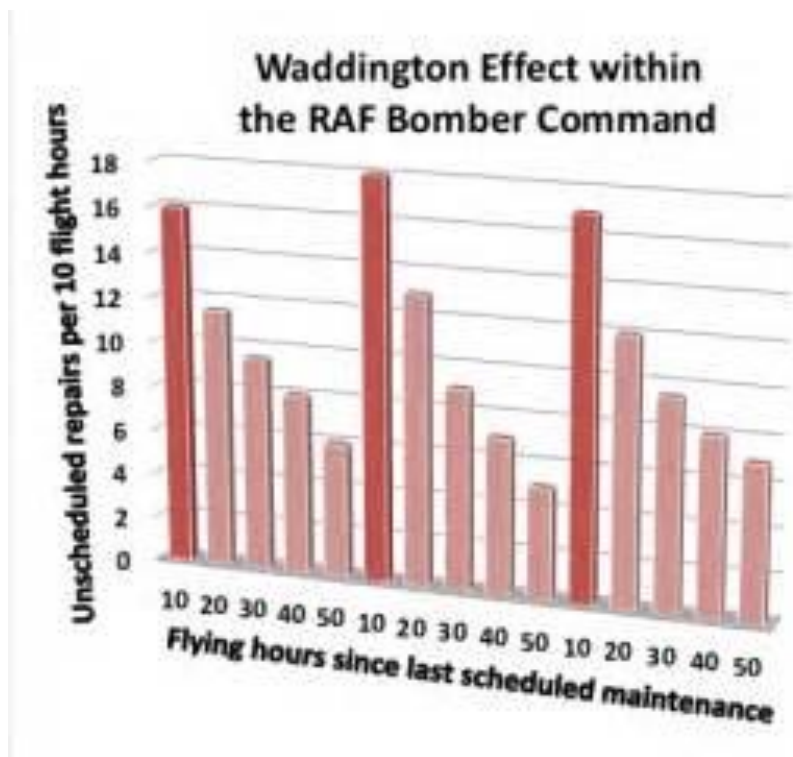


Figure 3 Waddington Effect Plot

Fast forward; the United States Department of Defence commissioned a report into a revolutionary approach to scheduled maintenance and became interested in this approach to make military maintenance programmes less costly. This approach and subsequent report was studied over a thirty year period and called Reliability-Centred Maintenance (RCM), prepared by Stanley Nowlan and Howard Heap of United American Airlines.

The report contained a comprehensive description of the development and application of RCM by the civil aviation industry.

The results from their study correlated precisely with Waddington's findings some 30 years previous. Nowlan and Heap could not have known of Waddington's findings because this operational research was not declassified and released to the public, only during the 1980s; Nowlan and Heap's research was issued 1978.

According to Nowlan and heap (1978) maintenance theory fundamentally and intuitively believed in a cause-and-effect relationship between scheduled maintenance and operability of aircraft that mechanical parts wear out relative to operating age. Consequential assumptions followed based upon actuarial analysis that the more overhauls undertaken on equipment the likelihood of equipment failure would diminish. This precept was incorrect and empirically qualified by conducting intense maintenance activities resulting in many types of failures still occurring over the following years.

Having issued the study into Reliability Centred Maintenance several interesting findings presented themselves inasmuch 89% of failures were not age related, thus 11% being age related.

Failure rate patterns emerged and fell broadly into six categories showing differing curve characteristics. *Figure 3* below quantifies failure patterns of aircraft and marine vessels and *Figure 4* groups those failure patterns that are "Random" and those that are "Age" related.

Essentially, the universal acceptance in reliability engineering found there is no discernible age-reliability relationship i.e. the long-held belief components display a distinct wear-out zone did not hold true and that 89% of failures were random in nature and disturbing inherent stable systems

introduced “Infant Mortality”, by which we mean if there is no specific engineering requirement to maintain, repair or overhaul, justification would be demonstrated to leave in-service. Nowlan and Heap’s seminal works classified six (6) failure patterns that component failures fell in to. Figure 4 describes these failure patterns.

DNVGL, in their research and development publication “Beyond Condition Monitoring”, (Knutsen et al, 2014)” identified and correlated aviation’s six failure patterns with Maritime’s failure patterns and shown below in figure 4

Failure Patterns	Marine Vessels (Extracted Knutsen et al. 2014)	Aircraft (Extracted Nowlan and Heap, 1978)
Pattern A - Bathtub	4%	<5%
Pattern B - Traditional	2%	<3%
Pattern C	5%	<6%
Pattern D	7%	<8%
Pattern E – Random Failure	14%	<15%
Pattern F – Reversed J Curve	68%	>65%

Figure 4 Tabulated Failure Data of Marine Craft versus Aircraft. [Data from Knutsen, et al 2014 DNVGL and Nowlan and Heap, 1978 United American Airlines]

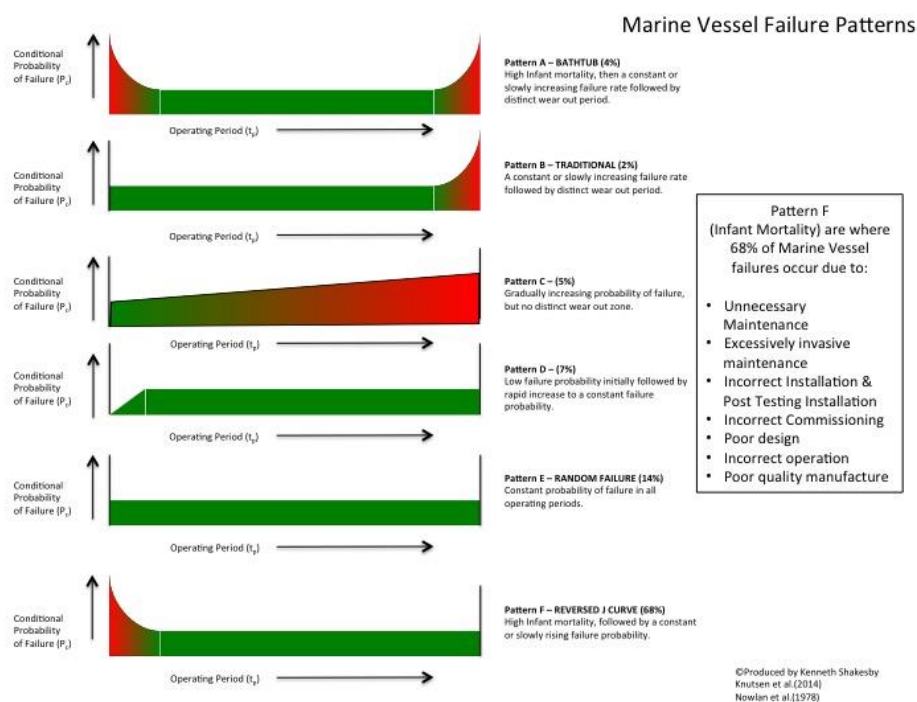


Figure 5 Six Failure Patterns resulting from Actuarial Analyses. [Data from Knutsen, et al 2014 DNVGL and Nowlan and Heap, 1978 United American Airlines]

This very powerful process was successfully implemented in aviation and continues to this day under the term MSG-3 (Maintenance Steering Group). Credited to bringing this subtly sophisticated process to industry outside aviation was John Moubray. Indeed, his seminal book, first published in 1991 Reliability-Centred Maintenance and a further edition in 1997, RCMII gained critical acclaim and powered Industry ranging from Nuclear Energy, Utilities, Oil and Gas, High-Speed Rail Networks, Automotive to name but a few, except Maritime.

Commercial Aviation Success

In 1968, under the new MSG-1 maintenance programme for the Boeing 747-100, United Airlines realised massive man-hour savings compared to their pre-MSG programme. For example, pre-MSG (RCM) the DC8 Airframe expended 4,000,000 man-hours in heavy inspection. Post MSG-1, the Boeing 747-100 received only 66,000 heavy inspection man-hours to a significantly more complex airframe.

According to Intergraph the following tabulated data represents a phenomenal advantage of MSG/RCM to fleets of complex equipment. Cost reductions of this magnitude are of obvious importance to any Shipowner for maintaining fleets of equipment and Ships.

Interval Check	Pre- MSG-3 (Traditional Programme)		Post- MSG-3 Analysis		Man-hour Savings
Months	Flow Days	Man Hours	Flow Days	Man Hours	%
18	16	12,000	7	5,250	56
36	40	30,000	30	25,000	25
108	50	37,500	40	30,000	20

Figure 6 Northwest Airlines MSG-3 analysis of the DC-9. Reliability increased to a phenomenal 98.5%

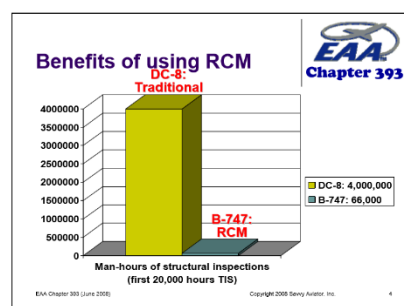
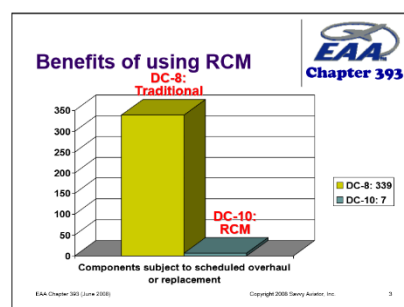


Figure 7 Comparison showing how RCM reduced massively the Maintenance of Aircraft.

The data graph below depicts the increasing number of passengers carried by commercial aviation overlaid by the number of fatalities and the adoption of MSG methodology, the front runner to RCM. It shows dramatically how MSG/RCM has significantly improved reliability whilst increasing safety.

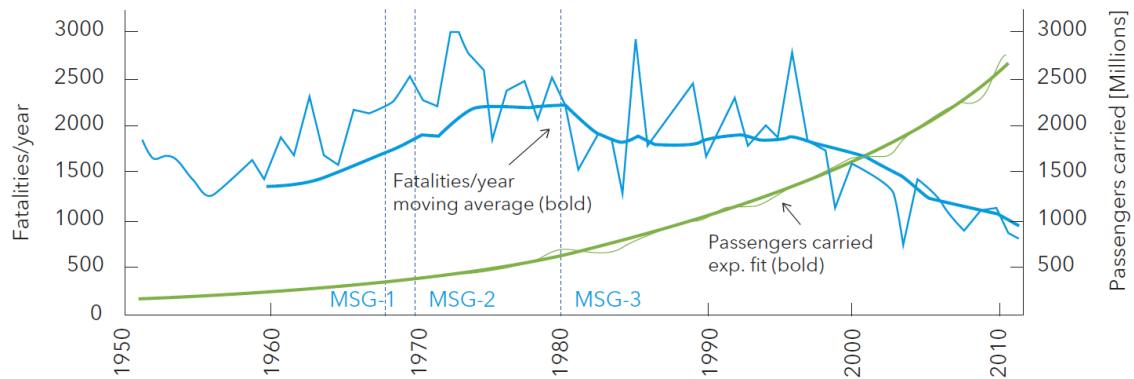


Figure 8 Graph depiction of increasing Passengers carried and reduction of Fatalities due to MSG/RCM Philosophy introduced. Data from the World Bank [4], ACRO [5].

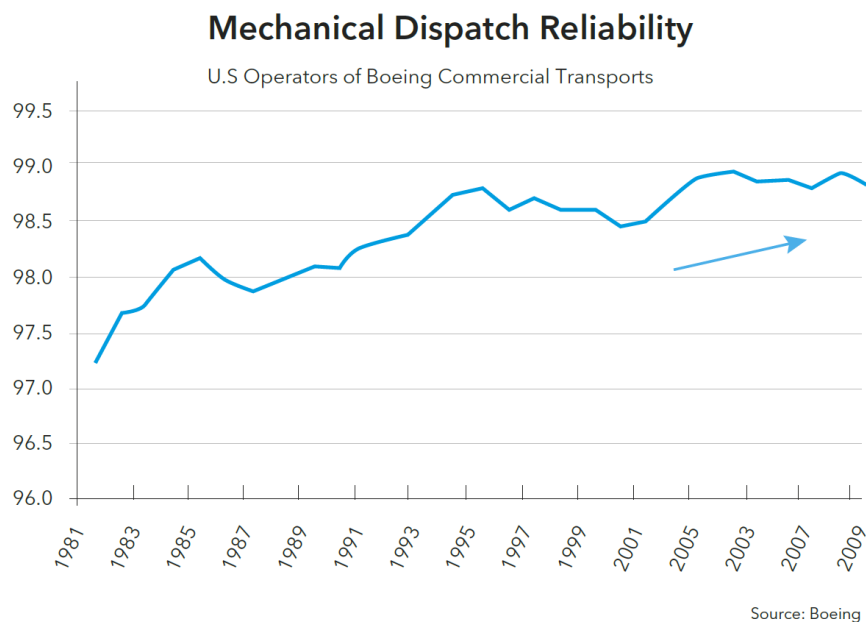


Figure 9 Mechanical dispatch reliability for U.S. operated Boeing commercial aircrafts.

CLASSIC RCM v MARINE RCM SOLUTION

Classic RCM provides significant improvements which has led to its widespread adoption in many industry sectors and has morphed into many variants and across many asset-intensive business structures. It remains the central approach to asset performance management of highly complex and risk averse industries such as aviation, energy, mass transportation and automotive. But maritime beyond the military, has largely ignored the methodology and instead opted for redundancy measures despite the obvious space penalty this incurs on an asset where space management is critical.

Delving deeper in the situation, the realisation emerges that the maritime industry is unique in many aspects and its set of challenges has been managed over centuries and forged into a culture that is highly resistant to change and hard for non-mariners to understand.

The reality of digitalisation across industries will no doubt thrust changes on the maritime world that it is ill equipped to handle. In the disruption that will follow, how will the changes be managed? The conundrum of geographic separation between Mariners at sea and management ashore is exacerbated by contrasted work ethics, ways of living and personal priorities, making the understanding of the Human Systems at play critical to the success of any implementation.

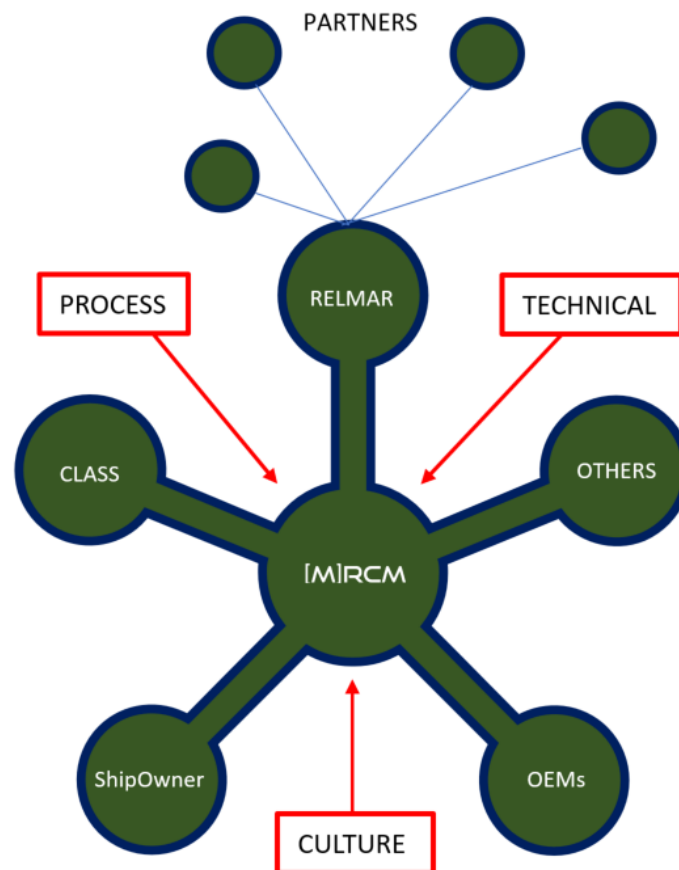


Figure 10 [m]RCM in perspective

What elements of Change Management must be invoked to pave a way for collaboration across an ocean? To place people at the heart of failure and expect success requires us to conjure up the very best from humans; a social cohesion in High Performance Teams centred around multi-levelled collaboration.

Therefore, the future of marine maintenance calls for the breaking down of age-old barriers and eliciting a deep sharing for the benefit of the collective cause, asset performance through dependability.

ENHANCED SAFETY, RELIABILITY and MAINTAINABILITY THROUGH DEPENDABILITY

Safety critical systems are extensively used in many industries, including aerospace, automotive, oil and gas, medical and maritime sectors. They all share a common property – their failure has the potential to cause catastrophic effects on human life as well as the physical and business environments. For this reason, it is expected that safety critical systems possess an elevated level of dependability.

Dependability is the capability of avoiding failures that are more frequent and more severe than is acceptable, and thus dependability assessment should be carried out early in the design phase to avoid unacceptable costs in terms of loss of life, environmental damage and loss of resources by identifying and rectifying potential hazards as soon as possible. The dependability of a system includes, but is not limited to the following characteristics: safety, reliability and maintainability.

There are many widely used classical safety assessment methods available to assist safety analysts in performing dependability analysis of systems. One such method is Failure Modes Effects Analysis (FMECA). It is an inductive analysis method that considers all possible combinations of effects of a single component failure mode(s). This method also provides ways to perform probabilistic analysis to determine criticality of failure modes.

The Fault-Tree Analysis (FTA) is another well-established and well-understood technique, widely used to determine system dependability. FTA is deductive in nature meaning the analysis starts with a *top event* (a system failure) and works backwards from the top of the tree towards the leaves to determine the root causes of the *top event*. After construction of a FTA, the analyses are carried out in two levels: a qualitative and quantitative level.

In quantitative analysis, the probability of the occurrence of the top event and other quantitative reliability indexes such as importance measures are mathematically calculated, given the failure rate or probability of individual system component. The results give the analysts an indication about system reliability and help determine which components of a system are critical. Analysts can then put more emphasis on these components by taking necessary steps such as including redundant components.

The usual quantification methods for classic fault trees do not consider uncertainty in failure data. If uncertainties are left unresolved there is a chance of misleading results.

Marine Reliability-Centred Maintenance provides robust defence mechanisms at the “coal-face” to deal with consequences of failure be it technical or financial. It is a logical approach to reduce or eliminate failures to tolerable levels within the cultural idiosyncrasies of the Maritime industry.

RELMAR’s Marine RCM approach improves reliability, availability and maintainability through the development and use of RCM processes to thoroughly analyse functional failure processes with a well-structured logical programme to ensure the asset continues to operate according to how the user wants it to operate. Our Marine RCM programme is not only about maintenance but about change management at the human level.

A holistic approach is utilised with which the following results are expected:

- A maintenance programme that provides comprehensive vessel coverage.
- Change Management at the human level.
- Precise management of scheduled and unscheduled maintenance.

- Integration of all maintenance activities whilst focussing shipboard crew towards a common goal and shore side support.
- Improved understanding of vessel systems and how they can fail.
- Validated documentation including revised standard operating procedures demonstrating industry best practices.
- Provision of logical base for lean process improvement in supply chain to ensure efficient vessel function.

Maintenance Efficiency

Throughout the entire [m]RCM process, RELMAR analysts consider every reasonable likely failure mode through a task-oriented, iterative process. It is a rigorous process that by design determines optimal scheduled inspections and tasks with engineering justified periodicities (frequency x interval).

Maintenance efficiency measures how well the maintenance function is using resources at its disposal. This is achieved by less routine maintenance, better buying of maintenance services (field support costs) – Field Technicians employed by OEMs attend our Marine RCM meetings that leads to the exchange of knowledge and as such provides a quantum leap in the ability of the ship's crew to solve difficult problems on their own.

Additionally, clearer guidelines for acquiring new maintenance technology is developed that decides whether a proactive task is technically feasible and worth doing applying directly to the acquisition of condition monitoring equipment.

BUSINESS BENEFITS EXPECTED

Marine RCM in Perpetuity

The application of Marine RCM will lead to a far more precise understanding of your assets and how your assets can fail. Not only will this provide quantum leaps in knowledge by your Shipboard Crew but essentially will reduce over reliance on expensive OEM Field Technicians. It will provide a scientific view of what must be done to cause them to continue to fulfil their intended functions. However, science and analysis are never precise and the very essence of scientific understanding allows for change based on new evidence coming to light. This is Marine RCM in perpetuity always seeking to improve based on new findings. It is a living, breathing through-life philosophy always seeking the path of least resistance to improve the corporate bottom line without compromising on safety and reliability.

What Marine RCM Achieves

Benefits achieved are as follows:

- Greater Safety and Environmental Integrity
- Improved Operating Performance (Output, Quality and Charterer Service)
- Greater Maintenance Cost-Effectiveness
- Longer Useful Life of Expensive Items

- A Comprehensive Database
- Greater Motivation of Individuals
- Better Teamwork

By adopting our Marine RCM Programme – your business can expect to achieve levels of asset reliability and availability never anticipated, in much the same way other adopters have benefited. It will display commitment to all stakeholders and set the foundation to accelerate your organisation to achieving ISO55000 Asset Management certification.

Having this effective programme in place and then integrating it with your CMMS/EAM system ensures that future efforts of data capture are executed in a manner that supports the principles of responsible asset stewardship.

PERFORMANCE BASED PLANNING

The analysis process is led by a multi-disciplined team of highly skilled analysts and engineers trained in [m]RCM processes, reliability engineering and naval architecture with coal-face experience. The initial analysis is a Situational Inquiry that gives holistic insight into all aspects of the systems under review and is a critically vital component of the [m]RCM project, providing clear inputs for achieving project deliverables.

To gain as accurate a picture as possible of the technical, contextual, and commercial environment in which the assets are expected to perform will clearly highlight where changes in strategy and behaviour are required to achieve the technical and commercial performance goals the shipowner seeks.

RELMAR's [m]RCM methodology is initiated and validated against SAE JA1011/1012 standards as well as IEC60300 Dependability Management. [m]RCM training will be undertaken, equipping the shipowner with the skills and tools required to contribute to the technical analyses.

RCM Sequence of Activities

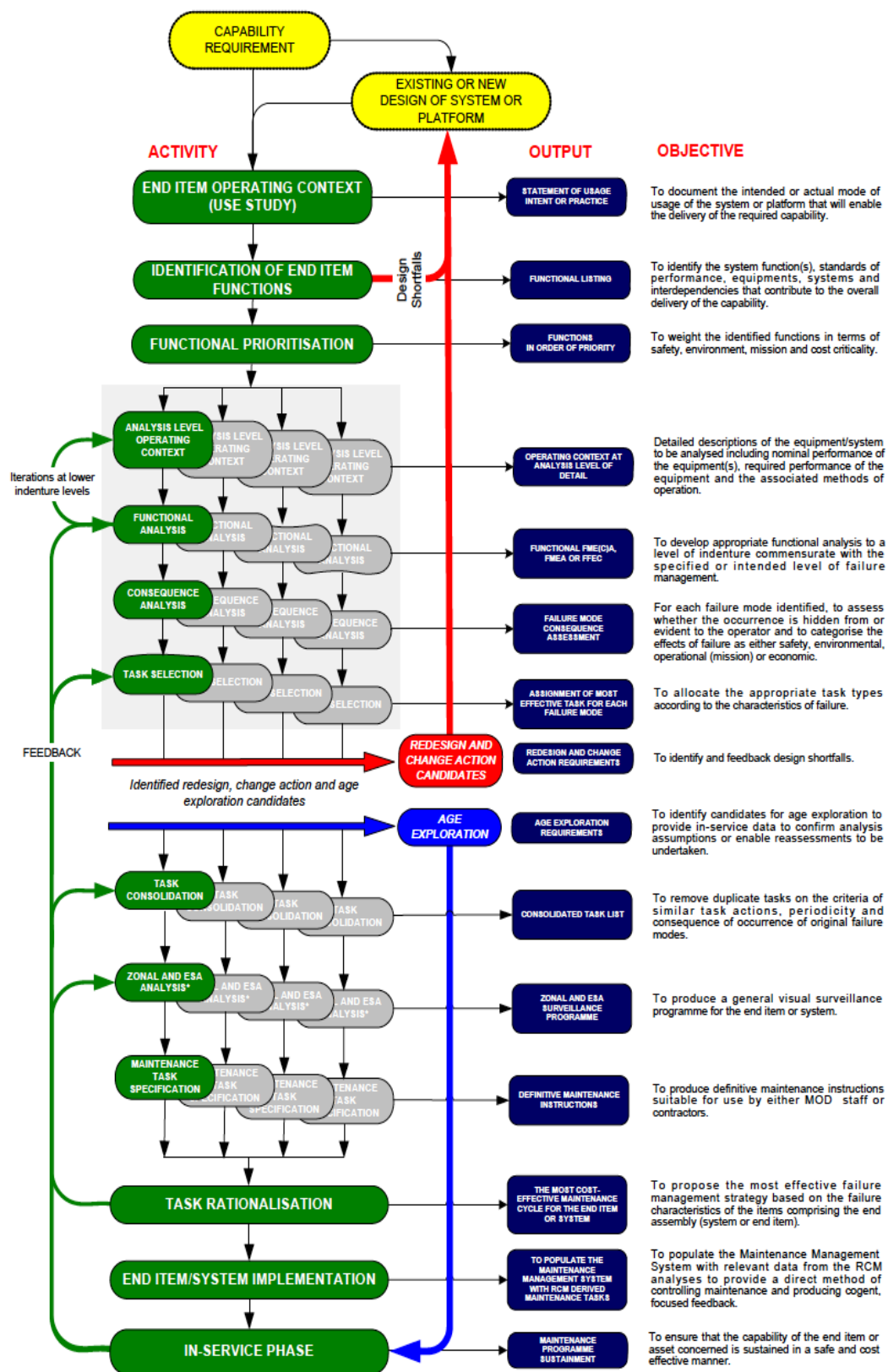


Figure 11 UL MoD RCM Sequence NES0045

CONTINUOUS IMPROVEMENT

Overview

Post-deployment support and remote monitoring provides performance data to either redesign the maintenance and / or business processes where necessary, or confirm the viability of the new processes and allow for the development of templates which can be used for rapid deployment on other assets where system comparisons can be made.

RELMAR supports asset through-life dependability through a continuous improvement program that:

- Ensures professional Reliability Engineering and software support.
- Removes operational burden of Reliability Engineering practices on client resources.
- Provides monitoring of KPIs through a client dashboard.
- Allows continuous improvement of Task Packages as history data becomes available.
- Centralises fleet learning in a “reliability knowledge pool”.
- Facilitates professional development of fleet templates.
- Provides justified recommendations for re-design.

Remote Monitoring

The package includes:

- Dedicated asset technical support.
- Dedicated licensed suite of software managed by us, on your behalf.
- API interfaced to existing asset CMMS and ERP.
- Enterprise Platform for web-based dashboard customised to your needs.
- Continuously improving Fleet Knowledge Repository accessible via web portal.

Templating

Once monitoring data confirms the performance and reliability outcomes desired, the selected technical, business, and commercial processes will be templated, to deploy further [m]RCM processes to other systems and assets within the fleet.

Outcomes

- On site hand-holding and post-deployment support.
- Set up remote monitoring systems.
- Provide a client “dashboard” for shipowner to track performance metrics.
- Provide methodology for vessel-based API interfacing.
- Provide client-access to the Knowledge Repository.
- Ongoing redesign and improvement recommendations.
- Templates for rolling out RCM to other systems and assets within company fleet

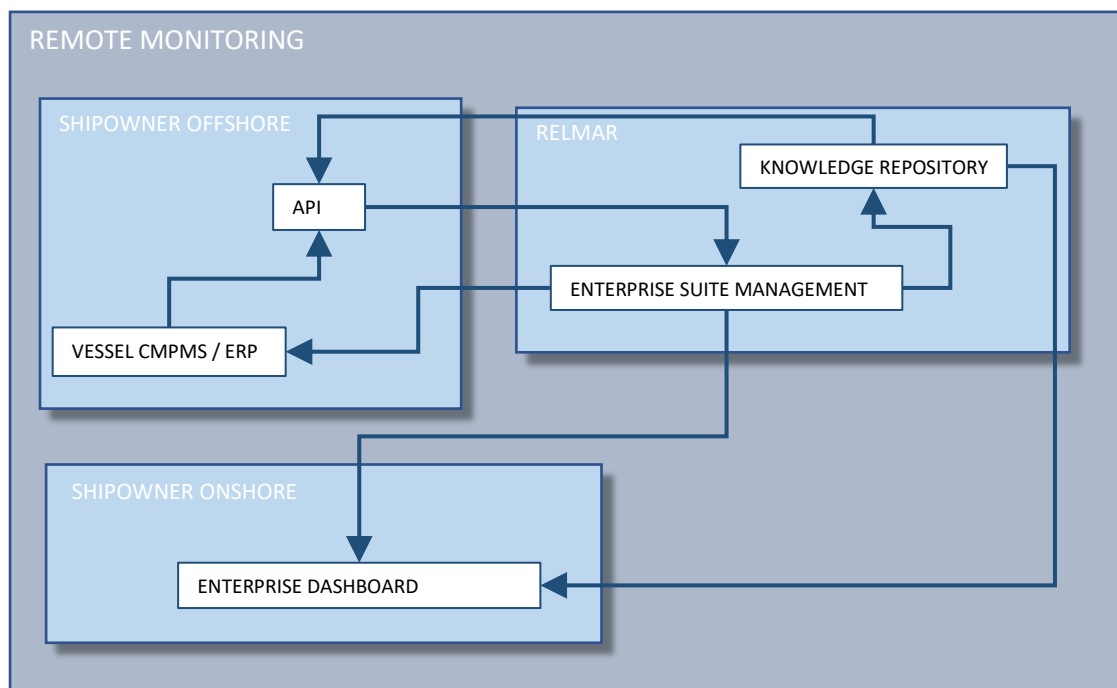


Figure 12 RELMAR Remote Monitoring Process Flow

CONCLUSION

You will find very little information publicly on what RCM has achieved for individual organisations simply because it is a competitive advantage whereby they have utilised maintenance as a profit generator and not a necessary evil. We can help you achieve the same benefits.

By adopting our Marine RCM Programme – your business can expect to achieve levels of asset reliability and availability never anticipated, in much the same way other adopters have benefited. It will display commitment to all stakeholders and set the foundation to accelerate your organisation to achieving ISO55000 Asset Management certification.

Having this effective programme in place and then integrating it with your CMMS/EAM system ensures that future efforts of data capture are executed in a manner that supports the principles of responsible asset stewardship. This data belongs to you.

We suggest a pilot study on your marine asset either end-item study or on mission critical systems to see how [m]RCM can benefit your marine asset maintenance and your business metrics.



For more information, visit our website at

www.relmar.co.uk or contact:



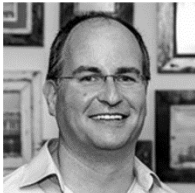
Kenneth Shakesby, CEO
MSc, Master Mariner
20+ years experience



Jason Falken, CINO
BSc, MBA
15+ years experience



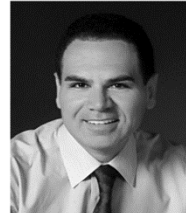
Chris James, Director of RCM
Training & Facilitation
BSc
25+ years experience



Peter Wingrove,
Director of Human Systems and
Communications
BA, MBA
25+ years experience



Dr. Sohag Kabir, Consulting
Reliability
Engineering/Computer
Science
MSc, PhD
10+ years experience



Dr. Ozgur Ozguc, Director of
RCM Structures
Naval Architecture
MSc, PhD
16+ years experience

Kenneth Shakesby	Jason Falken	Peter Wingrove
Chief Executive Officer	Chief Innovation Officer	Director Human Systems and Communications
kenneth.shakesby@relmar.co.uk	jason.falken@relmar.co.uk	peter.wingrove@relmar.co.uk

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