RCM IN THE ROYAL NAVY – DEVELOPING A RISK BASED POLICY FOR INTEGRATING SAFETY AND MAINTENANCE MANAGEMENT

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SUMMARY

Reliability Centred Maintenance (RCM) was adopted by the Royal Navy (RN) in 1995 following trials in the HUNT Class mine counter measures vessels which indicated that its adoption could deliver both cost savings and improvements in availability. RCM is now at the heart of the End to End Maintenance Strategy which is employed across all RN ships and submarines, and Royal Fleet Auxiliaries (RFA), and provides a methodology for risk-based derivation of maintenance, and a risk-based tool for planning maintenance to meet the operational need. This paper defines the policy for RCM in the RN and RFA, and how employment of RCM is integrated into the Safety Case regime and the First Sea Lord's Safety Argument to provide an integrated approach to safety and maintenance management. It discusses the potential benefits of RCM, why these benefits are not being fully realised, and what is being done to address these deficiencies.

1. INTRODUCTION

Reliability Centred Maintenance (RCM) was first introduced into the Royal Navy (RN) in 1995 following trials in the HUNT Class of mine counter measures vessels. RCM was imported as Best Practice from the aviation industry, is used in most RN and Royal Fleet Auxiliary (RFA) classes of ship and submarine, and is the mandated maintenance policy across the Maritime Domain offering savings in maintenance, materials and downtime in the order of 40%. This paper will explain the current policy for RCM in the RN and RFA, and how this is integrated into the Platform Safety Cases and the First Sea Lord's (1SL) Safety Argument . It will discuss the implications of these changes for the management of assets and failures, the potential benefits of RCM, why some of these benefits have not been fully realised, and what is being done to address current shortfalls in the implementation of RCM.

2. RCM POLICY

RCM was introduced into the RN because the legacy system of maintenance was unaffordable. It was chosen because it offered effective and efficient management of the material state of RN platforms enabling military effect and Safety and Environmental Protection objectives to be met. RCM forms a key element of the End to End (E2E) Maintenance Strategy, the main components of which are shown at Figure 1. The E2E strategy is owned by the Maritime Maintenance Support Group which sits within the Director Ships Operating Centre in Defence Equipment and Support in Bristol, and provides a focal point for maintenance management and support to RN Ships and Submarines, and RFAs.

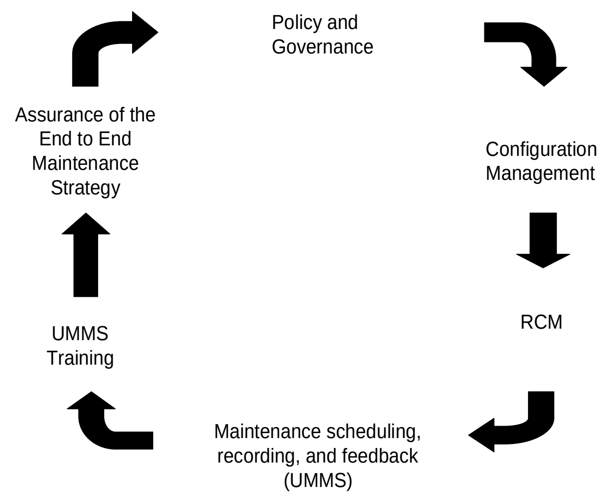

Figure 1. The End to End Maintenance Strategy

The high level policy for RCM in the RN and RFA is captured in the Joint Service Publication (JSP) 886 *Volume 7 Part 8.04* which states that:

> "RCM shall be included in procurement contracts to derive preventive maintenance programmes".

JSP 886 is not contractual but provides policy guidance to platform teams against which contracts can be drawn up. It refers to Defence Standard 00-45 which is the appropriate Defence Standard for the production of RCM. This states:

> "A functionally based Failure Modes, Effects and Criticality Analysis (FMECA) shall be undertaken

to identify and record the primary and secondary functions of the asset, the failures associated with each function and the engineering failure modes that bring about each functional failure"

Defence Standard 00-45 defines the process for developing RCM based on a Functional FMECA in a format which can be used within the Royal Navy's maintenance management system, the Unit Maintenance Management System (UMMS). The policy is based on RCM2 which was espoused by John Moubray. Although maritime projects should be procured against Defence Standard 00-45 there have been recent instances of this standard not being employed, and projects procuring against the Integrated Logistic Support (ILS) standard, Defence Standard 00-600 which merely states that platform teams are to:

"identify and optimize the cost of support options"

The use of Defence Standard 00-600 has led to variations in the nature of RCM derived for maritime platforms; in particular it has led to the submission of Asset-based rather than Functional-based RCM.

3. FUNCTIONAL RCM

Functional RCM is based on a 7 stage process which is methodical, auditable, and focuses on what a system **does** rather than what it **is**. Furthermore it focuses on the function of a **system** rather than an individual **equipment** in isolation, and considers the functionality within a given Operating Context. The seven basic questions of RCM are listed at Figure 2.

1. **Functions**. What is the function of the system?
2. **Functional Failures**. How can the system fail to fulfil its function?
3. **Failure Modes**. What happens when the failure occurs?
4. **Failure Effects**. What are the effects of the failure?
5. **Criticality**. How critical are the consequences of failure?
6. **Preventive Failure Management**. What proactive maintenance can be done to prevent failure?
7. **Reactive Failure Management**. If failure can not be prevented, what reactive maintenance can be undertaken to manage the failure?

Figure 2. The seven questions of Functional RCM

The first 5 stages of this process constitute a Function FMECA. Regarding the first stage, it is important to consider both primary and secondary functions as, in some cases, the failure of a secondary function could be more serious than the failure of a primary. This is illustrated below by examples of a primary and secondary function for an aircraft fuel system:

Primary: To deliver fuel from the storage tanks to the engines at a flow rate of 7-60 litres per minute, at a pressure of 4 bar, and a temperature range of -20 to +40 degrees centigrade.

Secondary: To contain fuel within the system

Analysis of potential failures (stages 2-4) will address partial failures (e.g. flow reduced by blocked strainer) as well as full failures (e.g. pump seizes). The information generated as part of the FMECA allows a risk based approach to be taken in assessing the likelihood of failure, the consequences and the criticality (stage 5) which is assessed as Safety, Environmental, Operational or Non-Operational (Economic). If done early enough in the design of the platform, black boxing if necessary, this information can be used to design vulnerability out of a system where the consequences of failure justify additional investment. Conversely, this process can also allow the design of the system to be simplified where the consequences of failure are found to be less severe. RCM does not, therefore, necessarily add cost to a project if adopted correctly.

Stage 6 of the process will generate one of 2 proactive failure management strategies:

- **Hard Time tasking** (based on calendar time, operating time or cycles).
- **On-Condition tasking** (a range of condition monitoring techniques are currently employed in the RN).

Where failure can not be prevented, one of 3 reactive failure management strategies will be generated by stage 7 of the RCM process:

- **Failure Finding** (used primarily for standby equipments and safety devices such as pressure relief valves, over speed trips, over voltage or over current trips, low pressure cut in switches, smoke detectors).
- **No Scheduled Maintenance** (this is not a "do nothing option" – this is employed where the through-life cost of maintenance is greater than the cost of failure, and the consequences of failure are acceptable).
- **Change action** (required when no pro-active failure management strategy has been found for a failure which jeopardises the Safety of personnel or compliance with Environmental legislation).

From the above it can be seen that Functional RCM, based on a functional FMECA, considers the consequences of failure within a given operating context. In contrast, Asset-based RCM considers the generic function of an asset without giving any consideration to the Operating Context, the failure effects with respect to the platform, consequence of failure for the platform, or the criticality of the failure in terms of risk to Safety or Environmental considerations. It is unlikely, therefore, to generate the appropriate failure management strategy for the particular system within which the equipment is employed.

4. INTEGRATION OF RCM INTO THE PLATFORM SAFETY CASE

The RCM studies for a platform support not just the maintenance of material state, they also underpin the Platform Safety Case which, in turn, contributes to the 1SL Safety Argument as shown in Fig 3. The 1SL Safety Argument presents the case that Fleet activity is safe because 10 Sub-Goals (SGs) are met, and is the subject of a separate paper being presented at the conference.

The Operating Context and system functions are defined by the required capability which determines the design, operating philosophy and doctrine of use. These are, in turn, determined by the Key User Requirements and contribute to 1SL SG3 (Vessels are designed and constructed to enable safety) and SG7 (Vessels are operated within a defined safe envelope).

The Failure Modes, Failure Effects and Criticality will generate hazards which will be recorded in the Platform Hazard Log. Failure Management Strategies (maintenance) will be put in place to manage the failures and the resulting hazards, it is therefore necessary to cross-reference the maintenance tasks to the hazards so that reviews of the hazards will also review the failure management strategies put in place to manage them. This mechanism contributes to 1SL SG2 (Safety Management Systems ensure resources, adequate Hazard identification and implementation of risk controls) and SG6 (Safety Cases exist for all vessels demonstrating adequate risk control).

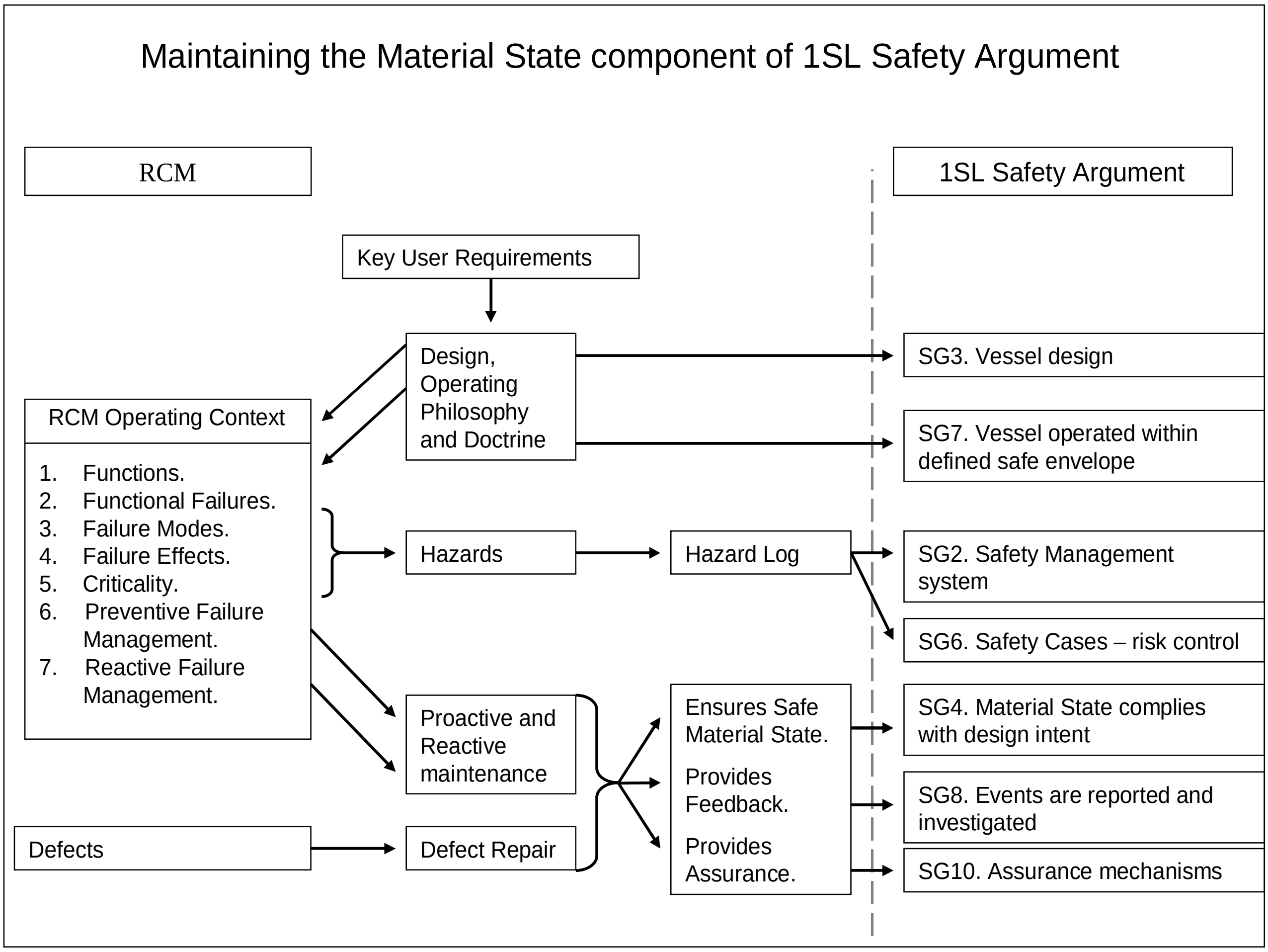

Figure 3. Maintaining the Material State component of the Fist Sea Lord Safety Argument

The preventive and reactive maintenance tasks put in place to manage failure are scheduled within the Unit Maintenance Management System (UMMS). This system also records completion of the tasks and allows the extent of overdue maintenance to be visible to the management team within the ship, the Operating Duty Holder (in Navy Command Headquarters) and the Platform Duty Holder (Team Leader within the Strategic Class Authority) in Defence Equipment and Support. UMMS allows ship staff to raise feedback where the maintenance, design, material or documentation is found to be deficient, and is also used to hold a record of defects (be they raised by ship staff or external authorities). When unable to complete some maintenance ship staff are able to refer back to the RCM study to identify the failure mechanism being managed by the maintenance, and hence the consequences of not completing the maintenance. Likewise, when faced with a defect, they are in many cases able to identify the failure mode in an RCM study, assess the consequences, and develop both mitigation actions and repair priorities as appropriate.

This functionality therefore allows ship staff to ensure that a safe material state is maintained, provides a route for feedback to the design authorities, and provides a mechanism through which assurance can be applied by the Platform Duty Holder and Operating Duty Holder. It therefore supports 1SL SG4 (Vessel's material state complies with the design intent), SG8 (Events are reported and investigated, and lessons learnt), and SG10 (Assurance mechanisms verify that SESB expectations are met).

Since the membership of, and decisions made by, an RCM Study group are documented, and all maintenance has to be approved by the Approvals Group (Platform Group, Equipment Group and RCM Group) before it can go live, it can be argued that the UMMS system provides safe, defensible and auditable maintenance for our platforms. Further assurance in support of SG10 comes from UMMS User Groups and assurance visits undertaken as part of the E2E strategy.
There are potential instances when operational programmes will provide legitimate reasons for deferring items of maintenance prescribed within the Safety Case. In order to assure that the platform remains safe to operate, it is necessary for the risk arising from deferment to be understood in the context of all the other risks including defects, the full extent of overdue maintenance, the operational programme and the availability of suitably qualified and experienced maintainers. Concessions are raised within UMMS either by ship staff or maintenance authorities ashore, and approved by appropriate authorities either within the ship or the Strategic Class Authority (SCA).

Development and implementation of RCM for the platform fulfils a key element of the End to End Maintenance Strategy, see Figure 1. This relies on correct configuration management of the platform which is a key enabler of the Safety Case (SG6), and on correct training of ship staff, waterfront teams, SCA and Strategic Equipment Authority (SEA) personnel to populate and use the maintenance management correctly. The E2E strategy therefore includes training for UMMS, RCM and configuration management systems which is made available to both MoD personnel and industry partners.

5. IMPLICATIONS FOR ASSET MANAGEMENT

The combination of high operational tempo and tight financial constraint has led to increasing challenges for the safe management of RN assets. In addition to long-standing commitments in the Arabian Gulf, North Atlantic, South Atlantic and NATO force structures, the RN is also supporting more recent commitments in the Indian Ocean (anti-piracy and Yemen) and the Mediterranean, as well as training for further potential contingent operations. Asset numbers have, however, reduced from 18 destroyers and 57 frigates in 1980 to 6 destroyers and 13 frigates in 2012. Platforms are required to remain in service beyond their design life – the T23 Frigate had a design life of 18 years against their Cold War concept of operations, but the oldest ship of the class will be 35 years old when she and her class are replaced by the T26 Global Combat Ship.

Year of first of class	Class	Displacement (tons)	Complement	Complement normalised against
1961	Tribal Class Frigate	2,700	253	562
1963	County Class Destroyer	6,200	471	455
1964	Leander Class Frigate (Batch 1)	2,500	223	535
1973	T82 Destroyer	7,100	407	344
1974	T21 Frigate	3,250	175	323
1975	T42 Destroyer	4,100	268	392
1979	T22 Frigate	4,000	223	334
2009	T45 Destroyer	7,350	190	155
2015	T26 Global Combat Ship (Batch A)	6,200	130	125

Table 1: Reduction over time of ship's complement of frigates and destroyers

The single greatest through life cost of a warship is manpower. Every effort is therefore made to reduce the size of the ship's complement by introducing technology. Table 1 above shows how the ships' complement of frigates and destroyers has reduced over time which is made possible by automation and technological advances. The final column shows the ship's complement normalised against a 6000-ton hull for comparison purposes and shows the complement of a modern RN warship being barely a quarter of those fifty years ago.

Reducing levels of manpower at sea drives an increase in equipment protective functionality (which includes increasing levels of redundancy, warnings and automatic shutdown devices) and to increases in automation, allowing warship functionality to be managed by fewer individuals. All of this increases equipment complexity and the quantity of Failure Finding tasks required to ensure that safety devices and automatic protection arrangements are functioning correctly.

Increasing complexity leads to longer times to diagnose and rectify defects at sea, this introduces risk to the operational capability and, potentially, the safety and environmental compliance of the platform. It is therefore increasingly important that the Operating Context is properly understood, the failure modes and associated risks properly captured, consequences understood, and appropriate mitigation strategies put in place. This is why policy in the RN is to adopt Functional RCM rather than other maintenance philosophies – the approach puts appropriate maintenance in place to manage risks to an acceptable level, and prevents unnecessary and costly maintenance being put in place where the risks are acceptable.

6 BENEFITS OF RCM

RCM Offers a range of benefits including financial, the management of safety and environmental issues, improvements in availability, and a reduction in ship staff workload.

6.1 FINANCIAL.

When first introduced it was estimated that Functional RCM could offer financial savings of up to 40% by reducing unnecessary planned maintenance. This was achieved for a number of classes, most recently the T-Class submarines. The best data on savings came from the HUNT class Mine Counter Measures Vessels which were base-lined before the introduction of RCM, with savings calculated to be of £0.5m per platform per year. Savings were estimated and validated over subsequent years for a number of other platforms: T23 Frigates £0.9m per platform per year, Landing Platform Helicopter £0.8m per year, nuclear submarine (SSN) £2m per platform per year. Over the first twenty years of use in the RN, the savings from RCM are estimated to have been £379.9m while the cost of implementation was £51.3m.

Additional financial benefits were derived from extending refit period intervals and reducing the quantity of maintenance in the refit package, both of which were only possible because of the introduction of RCM. The total savings of £218m were derived from the following programmes: T22 and T23 Frigates, T42 Destroyers, HUNT Class MCMV, Single Role Mine Hunter, SSN.

As a consequence of this re-profiling, as refit packages reduced and Continuous Engineering Support was applied based on Condition Based Monitoring, the cash flow was smoothed across the maintenance programme. As an example, traditional HUNT Class Refit Periods used to cost an average of £6.6m. These have been replaced by Ship Support Periods (Docking) which, at the time of transition to RCM, cost £2.2m. Although some of this delta will have moved into fleet time maintenance budget, the cash flow has been smoothed and a reduction of £0.5m per platform per annum was achieved. More recently the T-Class submarine maintenance has been converted to RCM with a financial saving of 40%.

6.2 SAFETY AND ENVIRONMENT.

Safety and Environmental considerations can be better managed because the FMECA methodology is a methodical and auditable process which considers the consequences of each failure (including safety and environmental), identifies the hazards, and puts in place an appropriate strategy to manage them. A significant factor in the loss of NIMROD XV230 in 2006 was that secondary functions had not been fully captured, safety related consequences had not been understood, and appropriate failure management strategies therefore not put in place. The approach documents how the maintenance was derived, and why certain decisions were made. RCM is therefore a safe, defensible and auditable process for generating maintenance.

Application of RCM within UMMS allows ships' engineer officers to monitor the extent of overdue maintenance, understand the risks associated with overdue maintenance, implement alternative mitigation, and justify why the platform remains safe to remain at sea. Over the last 2 years the roll-out of the latest version of UMMS has enabled the number of overdue maintenance tasks across the surface fleet to be reduced from 60,000 to less than 10,000, with a steady downward trend being maintained as data quality and application functionality improves.

6.3 AVAILABILITY.

Maintenance results in downtime which consequently reduces availability. Converting the T23 class to RCM changed 50% of maintenance tasks to No Scheduled Maintenance, thus reducing down time and increasing availability. Since 68% of failures conform to the High

Infant Mortality failure pattern shown at Figure 4, the process of stripping down correctly functioning equipment, maintaining and re-assembling it, is as likely to induce defects as it is to prevent them. Moving away from traditional invasive proactive maintenance will therefore reduce failure and downtime, and hence increase availability.

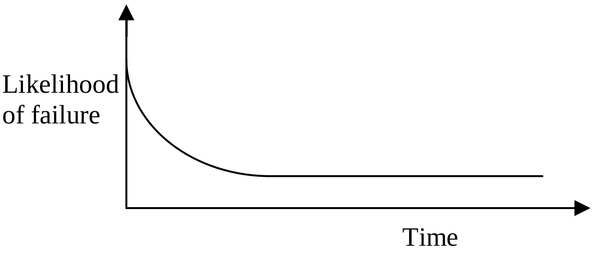

Figure 4. The High Infant Mortality Failure Pattern

6.4 SHIP STAFF WORKLOAD.

Adoption of well generated functional RCM has been found to reduce ship staff workload by up to 50% in T23 Frigates, but more normally 40% (Trafalgar Class Submarines, HUNT Class). While much of the benefit comes from making better use of condition monitoring, the majority of the reduction comes from adopting No Scheduled Maintenance where the consequences of failure are acceptable and the cost of managing failure through life is less than the cost of a proactive maintenance regime.

6.5 USEFUL LIFE EXTENDED.

By adopting more appropriate predictive maintenance techniques, and reducing unnecessary intrusive maintenance, the useful life of expensive equipments can be lengthened without increasing the risk to the availability of the platform.

6.6 BENEFITS REALISATION

These benefits have not, however, been consistently realised for a number of reasons:

- Asset based maintenance is provided by Original Equipment Manufacturers (OEMs) and consolidated by ship builders into an overarching schedule instead of undertaking Functional RCM based on a FMEA.
- There is evidence that old maintenance tasks which have been removed under RCM have been restored by personnel in support organisations who, through lack of training, concluded that omission of the task was an error.
- OEMs make much of their profit on support rather than sales, it is therefore not necessarily in their interests to support a reduction in maintenance through implementation of RCM.
- If OEMs are not trained in Functional RCM they are unlikely to support removal of their recommended maintenance – this can have a particular impact where an equipment is under warranty.
- Systems are, in some cases, operated by ship staff in accordance with the traditional philosophies (e.g. duplex pump sets swapped over every day and run evenly, rather than in accordance with the RCM philosophy of duty and standby).
- Early RCM was poor quality with operating contexts not captured correctly, functions and failure modes missed, and incorrect failure management strategies derived.

A range of actions have been put in place to address these shortfalls. These include:

6.6 (a) RCM Training.

A range of RCM Training Courses has been developed by the RN and is provided to appropriate uniform personnel, MoD civilians and industry partners to ensure that the fundamental principles of RCM are understood, and RCM studies undertaken by suitably qualified and experienced personnel.

6.6 (b) RCM Study Refresh Programme.

All RCM studies should be re-visited periodically based on risk, criticality and quality to ensure that the operating contexts remain valid, the system design and operating philosophy unchanged, and the maintenance up to date with latest developments. Some RCM for RN platforms is “pseudo RCM” which was imported from earlier maintenance systems, and some of the RCM studies are considered to be of poor quality. A programme has therefore been established to review all RCM studies for RN platforms, prioritising on those which pose the greatest risk.

6.6 (c) Liaison with new projects.

It is essential to establish liaison with platform and equipment teams early in the procurement cycle so that the project can, from the outset, embark in the right direction. In the case of the SUCCESSOR Submarine project, not due in service until 2025 and yet to pass Initial Gate at the end of the Concept Phase, the Maritime Maintenance Support Group is already engaged and the project will be the first platform procurement to do RCM studies early in the design process, and to revisit them once the system designs are mature.

6.6 (d) Liaison with Industry.

Liaison with industry is being improved by offering training to industry personnel and undertaking RCM studies at the OEM site with their full involvement. The most recent success was the Reverse Osmosis Plant for T23 Frigates for which RCM training was provided by the Maritime Maintenance Support Group to Salt Separation Services ahead of the RCM study which took place in their facility in Rochdale. This arrangement allowed the study to take place in a conference room alongside the production facility where a finished plant awaited despatch.

6.6 (e) Continuity training.

As personnel move posts, suffer from skill fade, and develop work-arounds for their perceived issues, it became clear that there was a need for continuity training for ship staff, waterfront teams and DE&S personnel in Bristol. The Maritime Maintenance Support Group aims to visit every ship, submarine and shore location at least once every two years to provide tailored training in RCM and the Maintenance Management System, to identify and share best practice, and to provide corrective training where incorrect processes have been adopted. In delivering this function, the training team is able to identify where the E2E strategy is failing to deliver, or where its effectiveness could be improved, and is therefore able to deliver Assurance of the E2E.

7. CONCLUSION

Functional RCM has been selected as the policy for provision of maintenance for RN ships and submarines, and RFAs, and sits at the heart of the platform Safety Cases and the First Sea Lord's Safety Argument. Correct implementation of RCM provides safe, defensible maintenance which captures Safety, Environmental, Operational and Economic impacts, and mitigates them through failure management strategies which manifest themselves as maintenance tasks. As ships' companies reduce and ever increasing use is made of automation, it becomes more important that the operating context for an RCM study is properly stated and understood so that the control system takes the appropriate action when responding to a failure.

RCM, when applied correctly, can deliver through life savings in materials and maintenance tasks in the region of 40%. Additional benefits include a robust management of the failures which have the potential to jeopardise the safety of personnel or compliance with environmental protection legislation. By reducing unnecessary intrusive maintenance, RCM can also reduce down time, minimise the opportunity for inducing new defects during routine maintenance, and hence improve availability.

The benefits of RCM will be realised through a refresh of the RCM studies that have suffered from being done incorrectly, the recommendations not being accepted by incorrectly trained stakeholders, a lack of training, or reluctance by OEMs to accept the recommendations. These issues are currently being addressed through improvements in the training of MoD personnel and industry partners, and improved liaison with new projects and industry teams.

8. REFERENCES

1. JOHN MOUBRAY, RCM2, Elsevier Butterworth-Heinemann, Second Edition, 1997.

2. Defence Standard 00-45 (Using RCM to Manage Engineering Failures), Part 1, Issue 1, MoD, April 2006.

3. Defence Standard 00-600 (Integrated Logistic Support Requirements), MoD, April 2010

4. Joint Service Publication 886 (Defence Logistics Support Chain Manual), Version 2.2, MoD, December 2009

9. AUTHOR'S BIOGRAPHIES

Cdr Chris New joined the Royal Navy in 1983 and studied marine engineering at the Royal Naval Engineering College, Manadon, in Plymouth. He was the Senior Marine Engineer in HMS ILLUSTRIOUS from 1997 to 2000, after which he headed the Command and Control training organisation within what was then the Phoenix NBCD School. He then studied for an MSc in Systems Engineering before, in 2001, becoming the Marine Systems Manager for the Landing Platform Dock. His time in this post saw the introduction into service of HMS ALBION and HMS BULWARK, and the High Voltage and Davit upgrades which sought to address the safety, reliability and maintainability of the propulsion and davit systems. He then spent two years managing Land Equipment Support in Navy Command HQ on behalf of the Royal Marines, and was then the Marine Engineering Availability Manager for Major Warships until promotion to Cdr. He is now the Group Leader for the Maritime Maintenance Support Group which supports Reliability Centred Maintenance across the maritime domain, along with configuration management and tools for the planning, scheduling and documentation of maintenance. He lives in Fareham with his wife, Caroline.

Rob Gay is a Director with PwC's The Asset Partnership based in Sydney. His extensive maintenance and asset management experience is currently being deployed in identifying, developing and implementing Asset Management strategies for the Australian Mining Industry, Australian and New Zealand maritime defence forces, Power Generation, Infrastructure, Utilities and the Nuclear Medical Research sectors. Previous to joining PwC's, Rob gained over 23 years of engineering experience with the Royal Navy Submarine Service culminating in three, working directly under the Director General of In Service Submarines. In these roles, Rob gained extensive experience of the application of RCM to naval platforms in one of the world's largest applications of the process.

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- Chartered Marine and Mechanical Engineer
- Aladon Certified RCM2 Practitioner

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