Optimising Availability, Capability, and Affordability across the Fleet: A Total Life Cycle Management Approach for Improving Seaworthiness

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Abstract Australia is embarking on the largest reconstitution of its navy in the post-WWII era. In 2016, Australia’s federal government unveiled a national shipbuilding strategy for continuous build of more than 50 ships and submarines in Australia. Investment of this magnitude significantly increases the future need for in-service support, maintenance, modernisation and life cycle management of the nation’s major fleet units. Over the past couple years, Chief of Navy has repeatedly advocated cooperation between Defence and its industry partners to implement total asset management as the standard practice for sustaining ships and submarines. As new shipbuilding programs progress from concept and design to construction and delivery, existing platforms will continue to age; requirements to provide maritime capability to the country’s operational commanders will not be relaxed and may actually increase with rising geopolitical tensions in the Indo-Pacific region. An ethos of life cycle management within both Navy and Australia’s defence industry necessitates asset management principles and practices be applied within each class of ship to optimise availability, capability and affordability in support of national maritime defence strategy.

1 Introduction

In its most recent Defence White Paper, the Commonwealth of Australia (CoA) unveiled a national strategy for continuously building ships and submarines heralding the largest reconstitution of the Royal Australian Navy (RAN) in the post-WWII era (2016). Public announcements of naval ship acquisition programs delivering more than 50 vessels over the coming decades have buoyed the shipbuilding industry. Investment of this magnitude will significantly increase future sus-
tainty needs which undoubtedly means a proportional increase in maintenance, modernisation and in-service support across every vessel’s life cycle. About 10 years ago, Defence recognised problems with short-, medium- and long-term warship and commissioned separate studies to investigate the causes. Paul Rizzo\(^2\) and John Coles\(^3\), appointed independently by the CoA, thoroughly reviewed and assessed in-service sustainment of naval vessels. Recommendations from both reviews identified necessary changes in sustainment practices, contracting methodology and the overall approach to managing ships and submarines, including improvements to guarantee the RAN can own and operate seaworthy vessels.

Over the past six years, CoA reforms have placed significant emphasis on maintenance management and capability enhancements through in-service sustainment to deliver seaworthy warships. Coles (2012) (2014) (2016) and Rizzo (2011) both cited asset management as a key aspect to sustaining naval vessels across the life cycle. Moreover, the RAN’s current Chief of Navy (CN), Vice Admiral Tim Barrett, actively promotes and advocates Defence and industry cooperation to ‘to think differently about our approach to acquisition and asset management’ (2015b). His call mandates government and commercial entities to collectively implement asset management standards and practices to better maintain and modernise RAN vessels. Defence’s Capability and Acquisition Sustainment Group (CASG) and the RAN recognise the need to shift away from rigid sustainment regimes that concentrate on conducting static time-phased maintenance and upgrading capability only when permitted by operational schedules to a more holistic, life cycle approach utilising fundamental principles and practices of asset management. Strategic arrangements, formal agreements and fundamental changes to government contracting in the past five years signal the shift towards using asset management for naval ship sustainment.

This paper provides background to Australia’s maritime defence posture and the importance RAN ships and submarines play within the context of national security strategy. A short asset management discussion and its applications within

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Australia and allied navies highlight important aspects of applicable practices and principles. Basic concepts of asset management are explored with a focus on the concurrent achievement of three main components in asset management: availability, capability and affordability. Availability and capability, in the context of RAN warships, are defined to ensure a clear understanding of the applicability to fleet life cycle management. Affordability is then discussed as a key component to be considered within the wider scope of Defence and asset management. Identified lower level objectives specific to naval vessel sustainment will illustrate how asset management can improve seaworthiness across each vessel’s life cycle. The conclusion summarises the overall positive effect asset management brings to improving seaworthiness and identifies a recommendation for establishing dedicated asset managers for each ship and submarine.

2 National Defence from Seaworthiness

Geopolitical tensions in the Indo-Pacific Region will continue to rise in the coming decades (Ghosh 2014). Within twenty years half of the world’s submarines are expected to be operating in this region (DOD 2016c). Australia patrols one of the largest maritime domains in the world and must have the ability to not only defend but enhance its interests in the Pacific, Indian and Southern Oceans. Australia’s defence in the 21st century will increasingly rely on maritime superiority in those regions designated as vital to the country’s national interests (DOD 2016b). This may involve Australia operating independently in the Indo-Pacific region or with joint coalition forces requiring the RAN to provide capable ships and submarines to operational commanders when needed. In some cases, RAN vessels will need to conduct offensive operations to defend the nation (or its allies) by either deterring potential adversaries or defeating openly hostile forces. National security includes not just defending the country but also engaging in offensive operations either alone or in coalition with allies when the outcomes support Australia’s current and future national interests. The RAN’s current six Collins class submarines (CCSMs) and twelve future submarines, to be delivered by the SEA1000 program, have a significant impact on high-level maritime warfare through inherent stealth, long-range endurance, formidable striking power and advanced intelligence gathering capabilities (RAN 2010). Surface combatants like the newest Landing Helicopter Dock (LHD) amphibious ships, Aegis-equipped Air Warfare Destroyer (AWD), and Armidale class patrol boats (ACPBs) provide a range of maritime defence from Australia’s coasts to the furthest reaches of its regional maritime envelope.

2.1 Australian Naval Vessel Sustainment

RAN vessels provide a valuable arm to the Australian Defence Force and the nation’s defence strategy (Defence 2016b) and should be considered strategic na-
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tional defence assets. The term “asset” correctly describes RAN warships, however this terminology should not be limited to discussions of national security, Defence operational planning, or naval inventory. Naval platforms, ships and submarines, are assets in the truest sense and must be managed as assets. Australia has taken significant steps in the recent past to rectify a recognised problem with material availability, capability and affordability. Asset management principles and methods can be applied holistically across the life cycle of fleet assets to optimise operational availability, functional capability, and adherence to technical standards in a fiscally responsible and worthwhile manner to deliver improved seaworthiness across the fleet. Senior RAN leadership openly acknowledge that both Defence and industry participants must pursue and establish asset management as a method to better manage the life cycles of maritime platforms (Barrett 2015c).

Several years ago, Defence implemented the Warship Asset Management Agreement (WAMA), a naval sustainment initiative where CoA and key members of Australia’s defence industry – BAE Systems, Saab Australia, Naval Ship Management (NSM) – share responsibility for providing seaworthy ANZAC class frigates. In 2016, Defence cemented this strategic arrangement by renewing the agreement in an 8-year contract streamlining multiple existing contracts for the whole-of-life sustainment for the ANZAC class frigates (MinDef 2016). This alliance signalled a shift from previous short-term and unpredictable naval ship maintenance contracts to a new long-term, performance based contracting methodology for the repair and maintenance of the Navy’s major surface fleet units (UGL 2016). NSM, a joint venture between Babcock Australia and UGL, leads the asset management effort within the WAMA.

Last year, CASG awarded a new performance-based In Service Support Contract (ISSC) to Thales to remediate problems identified through the realisation that ‘the sustainment of Armidale-class patrol boats (ACPBs) has not allowed the fleet to meet required levels of availability’ (Stewart 2015). As the ACPB fleet sustainment manager, Thales subsumed training, supply, engineering and maintenance services under an overarching Asset Management Services label (Thales 2016). Also in 2016, BAE Systems was awarded the initial 5-year contract for sustaining the AWDs which included asset management methods that ‘ensure the ships are both mission capable and available for service’ (ADM 2016). This announcement came on the heels of BAE Systems’ being awarded the maintenance contract for the two LHDs. BAE Systems’ ship sustainment philosophy centres on ‘maintaining the availability of the asset as opposed to a time based decision based on a ship’s availability’ (Kerr 2016).

In response to Coles’ report, Defence moved away cost-plus reimbursement type contract for CCSM sustainment and agreed with ASC (formerly Australian Submarine Corporation) to a performance-based ISSC (Thomson and Tenzo 2015) replacing the Through Life Support (TLS) contract for the six submarines to one
that targeted maintenance and modernisation efforts in a “whole of platform” manner (DOD 2012). More recently, ASC’s role within the Submarine Enterprise has been expanded to include overall life cycle management of the entire class.

Defence has redirected its materiel sustainment philosophy to one that appreciates the benefits of naval ship asset management by partnering with Australia’s defence industry to manage the life cycles of its warships. Coles and Rizzo both highlighted the need to manage ships and submarines as assets. Following recommendations from both reports, Defence has continued with other initiatives to not only improve the overall material condition of maritime platforms but to fundamentally change Defence’s approach to managing the total life cycle of its naval assets. CASG’s recent asset management efforts align with life cycle management practiced by some of Australia’s closest and oldest allies.

2.2 Asset Management in Allied Navies

Several Western countries – Canada, Great Britain, USA – actively use asset management methods to plan, procure, operate, maintain, modernise and dispose of naval platforms. Canada and Great Britain outsource the life cycle management of ships and submarines to notable defence companies through performance-based sustainment contracts. The United Kingdom’s Ministry of Defence (MoD) uses a Contracting for Availability (CfA) approach to optimise maintenance and reduce costs for Trafalgar Class submarines (MoD 2016). The Royal Canadian Navy awarded Babcock’s Canadian business the Victoria In-Service Support Contract (VISSC) for ‘project management, record support services, engineering support services, materiel and logistics support services, and maintenance and support services’ (GoC 2016) for four submarines. The United States Navy (USN) does not outsource assets’ life cycle management to the private sector, but it does operates a robust maintenance and modernisation program for nearly 300 naval vessels. Each type of USN seagoing vessel – surface ship, submarine, aircraft carrier – is managed by a separate Type Commander (TYCOM). Each of the three TYCOMs manages their assets slightly differently because of the stakeholders associated with different vessel types, but fundamental aspects of asset management still abound throughout the organisation and its policies and the execution of life cycle sustainment. USN policy does not specifically identify asset management as the methodology but the life cycle approach to managing all types of vessels exhibits all the hallmarks of asset management as prescribed in internationally recognised standards, namely ISO 55001.
Asset management, applied to maritime platforms, is scalable as described through allied navies’ examples cited above. The concepts and principles can be applied relatively easily to Canada’s fleet of four submarines or expanded to meet the needs of the US Navy’s large and diverse fleet. Implementing asset management within Australia’s fleet can be accomplished following a similar framework complemented with the appropriate principles and practices. Asset management concepts have already gained a foothold in Defence but a wider and more comprehensive application can deliver greater seaworthiness across the fleet.

2.3 Seaworthiness in the Royal Australian Navy

Seaworthiness involves a ‘whole of system approach’ that includes materiel, technical and operational systems (Ruting and Cordner 2016). Figure 1 shows the relationship of these three elements to the Seaworthiness Management System. Navy needs seaworthy ships and submarines that can fight and win at sea through the conceptualisation, design, construction and maintenance of naval vessels through seaworthiness over the life cycles(s) through technical mastery and business excellence and through cooperative engagement by both Department of Defence and defence industry sectors (RAN 2013). Seaworthiness presides over three main aspects required to sufficiently manage a naval vessel: operations, technical integrity and support functions. These fundamental elements of seaworthiness reside at the nexus of effective fleet life cycle management and involve all factors affecting naval vessel management in both the short-term and long-term. Decisions that influence longer-term consequences range from good to bad and can have deleterious effects on missed business opportunities, unmanageable technical debt, or failure to provide the desired capability (Lane et al 2013) if a holistic life cycle approach is not carefully considered and scrutinised.

![Image of Seaworthiness Management System](image-url)

*Figure 1 Elements the Seaworthiness Management System (HNE 2013 Blueprint)*

Ships and submarines must be maintained and modernised to meet seaworthiness standards to alleviate material deficiencies that can negatively affect operational readiness. In July 2012, Defence initiated reforms to ‘ensure technical integrity of maritime materiel is achieved (and to) improve operational availability and outcomes’ of RAN platforms. Rizzo cited life cycle management as a key focus area and dedicated an entire chapter to Asset Management as a methodology ‘to manage activities and practices over the whole life cycle’ of a maritime plat-
In 2011, Defence wanted to investigate and analyse availability, maintenance, and obsolescence problems in the CCSM Program. In his own report, Coles specifically cited ‘the absence of application of an asset management strategy’ (2012) as a major contributor and key factor to poor performance of CCSM Program. Based on conclusions and recommendations contained in Defence’s *First Principles Review*, CASG and the RAN have moved towards managing RAN ships and submarines as assets (Peever et al 2015). Implementing asset management is both pertinent and necessary. Recent commercial arrangements, reforms to CASG’s contracting schemes, and the overall approach to sustainment and modernisation illustrate the veracity of this new approach.

Asset management stresses the importance of ‘integrating asset-related decisions with organisational/business goals, whilst ensuring equal or higher return on investment’ by ‘minimising cost, or total asset life cycle cost, through careful acquisition, maintenance, and disposal policies’ (Dwight and El-Akruti 2009). Education and professional development of persons equipped with skills for capability management and whole-of-life asset management in complex sustainment roles will drive improved performance (Purcell 2012) in Defence’s naval vessel sustainment programs. Life cycle management of ships and submarines gives assurance that naval vessels assets will remain seaworthy and fulfil their required purpose through: developing and implementing processes that connect the required purposes and performance of the ships and submarines to RAN objectives; implementing processes for assurance of capability across all life cycle stages; and implementing processes for monitoring and continual improvement.

The cited strategic reviews and studies and the ensuing revised contracting initiatives clearly indicate Defence’s demand for improved management and performance to deliver greater capability and operational availability ($A_c$) for RAN platforms. Defence realises the benefits directly attributable to life cycle management and a “whole of life” approach to managing the sustainment, maintenance and modernisation of RAN ships and submarines. Establishment of the RAN’s Seaworthiness Board and other Department of Defence actions show stalwart support for asset management methodology as the preferred organisational approach to improving capability, $A_c$ of ships and submarines, and safeguarding the billions of dollars invested in maritime materiel. Regardless of whether CASG has overtly stated the ascendency of asset management as a key priority, it has nonetheless been thrust to the forefront of competencies required for providing maritime platform maintenance and in-service sustainment contracts. Asset management principles and practices, if developed and implemented appropriately, will improve seaworthiness across the fleet.
3 Asset Optimisation across the Life Cycle

Asset Management incorporates activities required to effectively and efficiently meet the organisational objectives through identifying what assets are needed, funding requirements, acquiring those assets, providing logistic and maintenance support for assets through life including renewal (e.g. modernisation) and eventual disposal (Hastings 2015). Availability, capability and affordability comprise the three fundamental elements of asset management; the degree of asset management success is directly proportional to the magnitude of concurrent achievement of these elements across the life cycle. Figure 2 graphically shows the asset management “sweet spot” where the overlap depicts concurrent achievement of all three elements. Optimisation is achieved through policy directives that ensure programmatic decisions related primarily to technical, commercial, and capability factors on the anticipated mission-related economic benefits are derived from acquisition and procurement and continue right through in-service sustainment and modernisation to disposal (SecNav 2011).

![Figure 2 Fundamental Components of Asset Management](image)

3.1 Fundamental Aspects of Asset Management

An asset is an item, thing or entity that has potential or actual value to an organization where value can be tangible or intangible, financial or non-financial, and includes consideration of risks and liabilities. The recognised international standard defines asset management as the 'coordinated activity of an organisation...
to realize value from assets’ where the realisation of value normally involves ‘a balancing of costs, risks, opportunities and performance benefits’ of an identified asset (SA 2014). It must be overtly stated that each ship and submarine is the asset to be managed; the systems, equipment and components inside each warship contribute to the overall asset but those individual components, in the context of fleet life cycle management, are not the assets to be managed. Ships or submarines, not individual components, are the material assets that allow operational commanders the ability to execute maritime doctrine. It is not the collection of pumps, valves, cables and steel that protects Australia on and under but a complete warship. The warship must be identified as the asset; the fleet must be seen as the asset portfolio.

Internationally, asset management has been acknowledged as a proven method for realising greater value through recognised practices, principles and methods (IAM 2015). Asset management links physical assets, business systems, humans and processes to the overall goals of the organisation with the practical challenge of being inherently interdisciplinary (El-Akruti, Dwight and Zhang 2013). Problems within asset management ‘are hard to distinguish from operations management or general management’ (Dwight and El-Akruti 2009) and often lead to asset management being mistakenly identified as being accomplished or practiced when only some elements of asset management are disparately demonstrated in random pockets of the organisation. Asset management, if implemented correctly, prohibits development of disjointed or incoherent costs by holistically directing program execution. Without critical analyses that account for business aspects, asset management will not deliver the intended results. Technical debt results in delayed technical work or rework that is incurred when shortcuts are taken and can increase as shortcuts are employed to reduce schedule pressures (Lane et al 2013). Technical debt and trade-offs influenced by project budgets and schedules must be captured in cost benefit analyses to highlight objective evidence to quantify technical risk and commercial gain when identifying a feasible solution that meets stakeholders’ needs. The common practice of making maintenance/sustainment and production/project management decisions separately can be rather costly with significant benefits realised from making these decisions in an integrated fashion. Effective asset management consolidates objectives of a wide range of disciplines within an organisation, balances those objectives against internal and external requirements, and concentrates on an asset’s total life cycle. Tywoniak et al correctly surmise that asset management can be applied to different industries and the interpretation can vary depending on the contextual application (2008). For this reason, it is imperative that asset management be very clearly defined as to how it applies to life cycle management of RAN ships.
3.2 Central Components of Life Cycle Management

Optimising the three basic asset management elements – availability, capability and affordability – will help achieve seaworthiness. Ship and submarine capability and availability should not be delivered without regard to cost; affordability incorporates a business-related perspective so decisions can be considered in a commercially astute manner balancing the overall approach to life cycle management. Asset management mandates commercial and business acumen interests play an equally important role in decisions affecting short- and long-term seaworthiness objectives.

Availability can be applied is several ways depending on whether one evaluates a system in an ideal or actual environment. Regardless of the instance, “availability” must be precisely defined and how it should be applied. Availability is the frequency with which something is available for use. ‘In a technical sense the availability of a system is the probability that the system will be found in a satisfactory condition (e.g. functioning, operational, “up” etc) at a moment in time when a demand for its services occur’ (Wagner and Mylander 1999). Inherent availability \( A_i \) results from system design and indicates how effective the system(s) can be regardless of operational environment in which the equipment is to function. (Blanchard and Fabrycky 2006).

\[
A_i = \frac{MTBF}{MTBF + Mct} \quad \text{Equation 1}
\]

\( A_i \) is best applied to equipment or systems because it is defined operability through mean time between failure (MTBF) and mean time for corrective maintenance (Mct). (Mean time to repair (MTTR) can be substituted for Mct.) \( A_i \) is a primary concern of systems engineers focussed on the design and upkeep of discrete systems or equipment. While it is appropriate to apply \( A_i \) to a ship’s systems’ designs, it is more appropriate to consider operational availability \( A_o \) for the complete asset. The mean time between maintenance (MTBM) signifies the uninterrupted operational running period (ORP) or the vessel’s ability to conduct operations. The mean down time (MDT) quantifies the average amount of time the submarine would be unavailable for operations. \( A_o \) is of greatest concern to owners and operators who utilise a capable platform to deliver tangible outcomes and results. Simply put, vessel availability is the probability a given ship or submarine will operate satisfactorily when needed.

\[
A_o = \frac{MTBM}{MTBM + MDT} \quad \text{Equation 2}
\]

When operational environments and “real world” operations are the primary consideration factor, distinguishing the amount of time the ship or submarine is available for operations versus the time it is in actual maintenance should be the prime factor regardless of whether the designated repair time is scheduled or
emergent (i.e. unplanned). A more practical way to define $A_o$, especially in the context of holistic life cycle management, is through seaworthiness. In terms of maritime readiness, $A_o$ can simply be defined as the proportion of time a warship meets seaworthiness requirements in a given time period. Fleet availability requirement outlines the $A_o$ on which operational planners depend and operational commanders rely for protecting the nation. It must be acknowledged that even though a vessel may be deployed, if it suffers a casualty that prevents mission execution, it should not be considered available for tasking. In the context of warship life cycle management as discussed in this paper, availability means a ship or submarine will be maintained to the requisite state of material readiness necessary for uniformed RAN personnel to conduct required operations. This encapsulates the essence of seaworthiness.

Capability Development Group (CDG) defines defence capability as ‘the capacity or ability to achieve an operational effect (where) an operational effect may be defined or described in terms of the nature of the effect and of how, when, where and for how long it is produced’ (2014). Capability provides deterrence against potential adversaries and, if necessary, conduct ‘offensive operations, generating a strategic effect by the capacity to strike the key capabilities of an adversary’ and destroy those capabilities through lethality (Barrett 2015). Capabilities must evolve to meet emerging threats. In essence, naval capability is the ability to deter an enemy and, if deterrence fails, to impart lethality that will guarantee success and victory in the maritime battlespace. Modernisation must regularly occur through scheduled enhancements and upgrades to ensure Australian warships retain dominance on and under the sea. But, capability cannot be achieved without regard to cost. Financial constraints necessitate costs be considered. Capability upgrades and subsequent sustainment efforts required to maintain the specified level of capability must all be deemed affordable.

Affordability simply means having financial means to support a given system or the actions, procedures, practices and operations needed to realise outcomes. In many cases, financial constraints provide the limiting factor for an organisation. These limitations are a key component in determining value for money which reside at the centre of government procurement methodology (Finance 2014). Affordability is regulated by the finances available to actually fund a project, development effort or actions needed within a system. Since this term can be used in several different ways with regard to acquisition and sustainment programs, it is useful to clearly articulate the definition applicable to asset management and seaworthiness. Affordability in fleet life cycle management indicates the possibility of maintaining and modernising a warship as planned with the financial resources that will likely be available. For the RAN, the term is most appropriately applied across each vessel and the entire fleet. In other words, affordability means a program is affordable if it is contained within an affordable portfolio (Porter et al
In this sense, asset management must be applied to individual vessels, across each class and collectively throughout the whole fleet asset portfolio.

### 3.3 Improved Seaworthiness through Asset Management

Material Seaworthiness across the life cycle equates to optimising the concurrent achievement of each component for any seagoing asset or asset portfolio. Table 1 shows the equivalency between the three components identified earlier as fundamental to asset management with three components of warship life cycle management. Applying these objectives yields a more precise convention related directly to objectives identified by senior Defence officials and substantiated by Coles and Rizzo. Attributes associated with each of these life cycle management components can be broken down further into tangible contributions to overall seaworthiness. The following sections will further illustrate lower level components within each of the life cycle management objectives and show how they contribute to improving seaworthiness.

**Table 1 Asset Management and Life Cycle Management objectives.**

<table>
<thead>
<tr>
<th>Asset Management objectives</th>
<th>Life Cycle Management objectives</th>
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<tbody>
<tr>
<td>Increase Availability</td>
<td>Reduce operational time lost to defects</td>
</tr>
<tr>
<td>Increase Capability</td>
<td>Maintain regional superiority</td>
</tr>
<tr>
<td>Increase Affordability</td>
<td>Decrease total sustainment costs</td>
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### 4 Reduce Operational Time Lost to Defects

A ship or submarine is intentionally removed from operational service during scheduled intermediate (I) or depot (D) level maintenance periods. I- or D-level maintenance periods are scheduled within a vessel’s Usage and Upkeep Cycle (UUC) to provide dedicated time for maintenance. An ORP is the time between successive scheduled maintenance periods and represents the time each vessel should be available to the operational commander. During ORPs, the vessel’s material condition should suffice for conducting scheduled operations. Casualties, degradations or unplanned losses of equipment and systems during ORPs hinder seaworthiness. The unplanned loss of a ship or submarine not only reduces Availability but can significantly affect the nation’s maritime capability. As witnessed earlier this year, debilitating propulsion casualties prevented both LHDs from rendering humanitarian assistance after Cyclone Debbie struck Queensland (Davies 2017). Factors affecting Availability encompass a vessel’s entire UUC but is most affected by disruptions that disproportionately affect RAN operations when a fleet unit is not inside a scheduled maintenance period. Availability can be increased with a sustainment regime that minimises or eliminates unplanned failures through predictive maintenance and restores equipment or systems to operational status when unplanned failures do occur.
4.1 Quantify Material Readiness

Seaworthy warships must have shipboard systems and equipment in a material condition that supports operational readiness and the ability to accomplish assigned missions. Periodic assessment and verification of a vessel’s material condition against established standards indicates operational readiness and functional performance that may show early warning of failures predicted to occur outside a scheduled maintenance period. Knowing the material condition underpins reliability centred maintenance (RCM) which, in turn, supports maintenance efficiency of critical components and optimisation of maintenance periodicities. System performance analysis and material condition assessments utilise maintenance data, surveys and condition monitoring data to provide the foundation for extension or reduction of component refurbishment periodicity. Moreover, it provides the foundation for modifications, modernisation and upgrades of equipment and systems and supports the revision or elimination of component maintenance requirements with confidence that component reliability will not be diminished.

A key component to understanding the material condition is to have appropriate levels of confidence in the MTBF, a fundamental factor for determining $A_i$. Knowing the material condition of any vessel will provide objective and quantifiable information that can characterise seaworthiness using:

- inherent system availability ($A_i$),
- early identification of fleet materiel issues,
- probabilities of expected losses of equipment and systems through trend analysis,
- objective data to support material certification extension,
- revising preventive maintenance schedules,
- confidence levels of material readiness to support future missions,
- validated MTBF(s) and
- leading indicators (with correlation factors) for predictive corrective maintenance prior to system intrusion

Through understanding the entire platform’s material condition, its systems and the state of all the equipment, better predictions can be made when compiling maintenance packages for a scheduled maintenance period to ensure the most useful type and level of maintenance is planned and accomplished. More importantly, it enhances predictive capability for pre-deployment system grooming and maintenance to maximise the probability of mission accomplishment through minimising the probability of debilitating system failure during at-sea operations, thus enhancing overall seaworthiness.
4.2 Prevent Failures

Systems performance monitoring and analysis, materiel readiness assessments and classical RCM all provide valuable information regarding the state of shipboard equipment (Allen and Stevens 2011). Knowing the material condition of the ship or submarine does not prevent failures from occurring. The information must be transformed into maintenance actions to conduct the appropriate level of system grooming, repair or equipment replacement to lower the probability of failure during identified operational periods. Routine maintenance must be conducted outside of scheduled maintenance periods to actively prevent failures from occurring. Maintenance conducted between scheduled maintenance periods cannot be relegated to only urgent defects (URDEFs) that hinder a vessel’s ability to conduct operations. Seaworthiness demands scheduling and accomplishment of work outside of scheduled maintenance periods to allow a ship or submarine to be consistently maintained at acceptable readiness levels.

Ship staff, sustainment providers and operational commanders should recognise every scheduled in-port period as an opportunity to accomplish continuous maintenance during the operational running period. Time allotted for continuous maintenance is precious and may be restricted by Notice for Sea (NFS) requirements so careful consideration must be taken to not jeopardise any vessel’s seaworthiness during alongside maintenance opportunities. Refurbishing equipment just prior to failure will increase Ao and avoid disruptions to ship staff evolutions and will prevent potentially excessive damage caused by run-to-failure operations.

4.3 Expedite Post-failure System Restoration

Operational naval assets must be seaworthy to conduct sustained operations at sea. They must be available and capable when needed by operational commanders. Unplanned failures can cripple a vessel rendering it useless to the operational commander. Quickly rectifying equipment failures or system outages will improve Ao and thus improve seaworthiness. System restoration can be achieved through expeditiously replacing failed equipment from Ready for Issue (RFI) items segregated in a dedicated rotatable pool. Repair organisations can use standardised and pre-approved work packs to rapidly replace faulty shipboard equipment with RFI units using minimum personnel to restore seaworthiness in the shortest possible time. Moreover, this “replace” vice “remove-repair-reinstall” method can shift the burden of equipment refurbishment from time-sensitive operational periods to other less critical periods. This type of planned equipment replacement program can significantly reduce the time required to rectify disabled or degraded equipment. The USN’s Trident Planned Equipment Replacement (TRIPER) program was developed specifically to increase Ao, and seaworthiness for its nuclear ballistic submarine (SSBN) fleet.
The TRIPER program was developed because operational commanders’ requirements demanded a 20% increase in Ao over previous submarine classes (CNO 2012). The TRIPER program ensures a high state of material readiness during ORPs and frees up scope in the total Maintenance Availability Work Package (MAWP) for the next scheduled I- or D-level maintenance period. Components are replaced on either a time-phased schedule or when triggered by specific condition-based monitoring thresholds. TRIPER equipment requiring I- or D-Level maintenance and which likely cannot be accomplished during scheduled maintenance periods without unacceptable impact on other sustainment requirements are included in the program. The methodology used in the TRIPER program can be tailored specifically for RAN warships to boost Ao and increase seaworthiness of Australia’s strategic maritime defence assets.

5 Increase Lethality and Deterrence

The RAN’s most senior naval officer identifies strategic maritime capability through five unique factors: deterrence, lethality, availability, sustainability, and affordability (Barrett SIA 2015). Regional superiority requires deterrence and lethality. Deterrence is the maintenance of military power for the purpose of discouraging attack against Australia or its forces or coalition partners; lethality (or deadliness) is a measure of the warship’s ability to cause death or destruction to opposing forces. To maintain its regional superiority, the RAN must develop and field new capabilities to counter adversaries’ Orders of Battle. Australian warships must be constantly upgraded with new equipment and better systems to maintain regional superiority. RAN capability upgrades may result in quieter submarines or AWDs that can detect and destroy intercontinental ballistic missiles or frigates that can remotely engage airborne threats using Cooperative Engagement Capability (CEC). Seaworthiness will be improved by ensuring RAN vessels can deliver greater lethality and deterrence by meeting required operating capabilities with equipment and systems that meet technical specifications.

5.1 Improve Capability

A vessel’s material capability can be increased by either modernising components to improve reliability and mitigate obsolescence issues or by installing new equipment that will provide new military functionality for countering current or future threats. Increasing system reliability enhances Ao in the specific system. Improvements that decrease the time required to conduct preventive or corrective maintenance will drive down the quantity of time necessary to restore equipment to its operating condition. Moreover, design changes that increase the time required between maintenance actions will drive MTBF higher. Upgrading existing system components that result in achieving one or both of these outcomes will in-
crease $A_i$ and thus deliver a system capable of providing required performance levels with more consistency and reliability.

Modifications designed to provide new capabilities or improve the military performance criteria of specific systems are considered capability enhancements and result in a warship that provides greater deterrence and lethality effects. These modernisations are intended to counter new or emerging threats from known enemies or potential adversaries. They may also be developed to support closer cooperation and synchronisation with friendly navies, allies and coalition partners. RAN ships and submarines must continue to be outfitted with technologically superior systems to ensure deterrence and lethality remain at the forefront of its naval power defences and, if necessary, offensive projection of power. Irrespective of the type of modernisation – system reliability or military capability – installed in the vessel, both are crucial elements within life cycle planning; they undoubtedly will affect financial programming and budgeting efforts regardless of the expected service life.

5.2 Plan for Service Life Extensions

Australia’s shipbuilding industry is delicate and has been subjected to inconsistencies stemming from a highly partisan and unstable federal government that has produced six prime ministers over the last decade (Birkler et al 2015). While there is a plan for rolling acquisition and construction, there is no guarantee that in 20 years Australia’s shipbuilding industry will be sufficiently robust to ensure maritime capability experiences no gaps (Defence 2017). In the RAN, each ship represents a significant percentage of the fleet. Removing a ship from service without a replacement will cause enormous disruption. A debilitating casualty caused by fire or collision in a Major Fleet Unit (MFU) could accelerate a vessel’s decommissioning, reducing RAN maritime power immediately through a major capability shortfall that may last for several years. Late introduction and delivery of newly constructed ships will require older ships and submarines to remain in service longer if seaworthiness and operational commitments will be maintained. The success of future ship construction programs must be higher than previously experienced in order to guarantee no lapse in capability.

Delays to ship construction programs should be expected. Contingencies for extending active vessels’ service lives must be part of each vessel’s life cycle management plan. A holistic life cycle approach for the current fleet must incorporate and plan for the ability to extend the expected service life of every current platform as a mitigation to future ships and submarines achieving Initial Operating Capability (IOC) later than originally expected. Unplanned extensions to ships generate significant cost through the logistics and supply chain. However, it is less expensive across the life cycle to plan early and often for service life exten-
Increasing geopolitical tensions in the Indo-Pacific region will not abate in the coming decades. Australia cannot accept lapses in maritime capability especially when service life extension contingencies can be planned and integrated well ahead of planned withdrawal dates. Service life extensions, regardless of whether they will happen or not, must be considered a critical element in every RAN vessel’s life cycle planning effort.

5.3 Meet Capability

RAN warships’ required capabilities are derived from operating environments, Orders of Battle of known or potential enemy forces, established military alliances and national defence strategy. Shipboard systems and equipment are designed and chosen for inherent ability to provide the necessary capabilities when incorporated into the overall ship design. A warship’s lethality and deterrence depends on the crew’s ability to tactically employ properly functioning materiel (e.g. shipboard equipment and systems) using prescribed procedures. The inherent design of a ship or submarine, when operated according RAN protocol, will deliver an operational effect in a nominated environment within a specified time and sustain that effect for a designated period. A Capability Baseline (BLCAP) meets requirements operational commanders must have to execute maritime doctrine.

Each warship’s BLCAP evolves throughout its life cycle if the vessel is expected to counter future threats and remain regionally superior. A vessel’s design must identify and include materiel that, when operated correctly by ship staff, delivers the required operational capabilities. The physical configuration is the actual assembly of equipment and systems in each ship or submarine. A vessel’s actual physical configuration cannot deviate from the design configuration or capability gaps may arise. Life cycle management works to ensure the physical configuration matches the design configuration so the ship or submarine delivers the BLCAP. This synchronisation across physical make-up, design configuration and required operating capabilities is fundamental to managing warships’ life cycles. Life cycle management achieves this synchronisation by establishing and maintaining a whole of life forecast for each ship or submarine and then planning, executing and managing each MAWP across the life cycle. Scheduled depot-level maintenance periods should deliver a warship whose actual (physical) configuration matches the approved configuration baseline thereby providing a vessel that meets required operational capabilities.

The whole of life forecast distributes and allocates all identified shipyard services and expected maintenance and modernisation efforts across the vessel’s life cycle by assigning work in discrete time periods that coincide with scheduled
maintenance periods. It provides the foundation for assembling MAWPs that will ensure each ship and submarine can meet its \( \text{BL}_{\text{CAP}} \) upon the completion of scheduled maintenance periods. An MAWP contains all the maintenance and modernisation approved for accomplishment during a scheduled maintenance period. Ideally, a properly planned and executed MAWP will deliver a vessel whose material condition meets the design configuration and thus achieving synchronisation between the vessel’s physical state, design and capability requirements. The work contained in a MAWP should restore or preserve the vessel’s inherent design reliability and performance characteristics (NAVSEA 2007) for the requisite period within the life cycle. At the end of a scheduled depot-level maintenance period, deviations from the approved configuration or concessions against established requirements should be minimised if not eliminated.

Life cycle management incorporates future \( \text{BL}_{\text{CAP}} \) planning to ensure concurrent achievement of availability, capability and affordability remain at the centre of decision making processes that cover short-, medium- and long-term plans. A holistic and proactive approach to forecasting will facilitate planning, programming and budgeting that informs future financial requirements and defence budgets that will deliver required maritime capabilities in the coming decades. Appropriately planning for the most economical fleet includes forecasting costs associated with installing and maintaining capability upgrades across the entire life cycle that will meet future capabilities needed so tomorrow’s fleet can maintain regional superiority within predicted financial allocations.

6 Reduce Total Sustainment Costs

Total cost of ownership (TCO) is the amount of money spent on operations, personnel (and support), victuals, fuel, maintenance, equipment (parts, tools etc), upgrades and disposal throughout the life cycle. While the total cost of owning, operating, crewing, outfitting and sustaining the fleet rests with CN, defence sector industry participants play a major role in sustainment costs. Total sustainment cost (TSC) is a critical element to managing the life cycle of any vessel. TSC must be quantified and validated to provide a solid and objective basis for TCO. Seaworthiness cannot be achieved at any cost. The RAN must operate within its allocated budget. Life cycle management requires decisions based on balancing affordability with capability and availability. These decisions mandate cost analyses and consideration across the life cycle as part of the holistic and inclusive asset management activities to achieve organisational objectives (El-Akruti et al 2015).

As maritime platforms age, sustainment costs increase due to the effects of age, wear and parts supportability (e.g. obsolescence). In order to best utilise the budgeted sustainment funding, each scheduled maintenance period must be optimised to ensure the planned work scope will deliver a capable ship or submarine
that can meet required Ao during the operational running period. Using this methodology throughout the UUC (until planned withdrawal from service) means all work can be either identified or quantified across the life cycle. Optimising sustainment efforts means each vessel will receive the most appropriate maintenance and modernisation during the most advantageous time for the right amount of money. This concept of doing the right work at the right time for the right cost requires a holistic approach that considers the entire life of the vessel and the ramifications of decisions on the short-, medium- and long-term. Using this approach, TSC can be estimated and validated through credible and verifiable data based on all forecasted work across the life cycle which includes any service life extension plans. Time-phased cost profiles will show each vessel’s whole of life forecast allowing evaluation of total life cycle cost impacts when determining scope, budget and schedule of life cycle sustainment activities.

6.1 Understanding Life Cycle Costs

Life cycle costs must be based on the planned (and estimated) scope of sustainment efforts across the life cycle. This must take into account direct labour, indirect support (required to support the direct labour efforts) and overhead functions necessary to manage the platform across its life cycle. Of these, direct labour costs are probably the easiest to estimate whereas indirect support and overhead costs can vary depending on the type and quantity of work and the contracting methods used to accomplish the sustainment work. A naval vessel’s life spanning three or four decades will undoubtedly be subject to a plethora of sustainment providers, contracts and contract types. Irrespective of this there must be a total life cycle management plan established for each vessel upon which life cycle costs can be based with a high degree of consistency and clarity. Australia’s domestic shipbuilding capability cannot construct and deliver similar vessels within a class simultaneously. Throughout its life, each ship or submarine, exists at a different stage of its life cycle when compared to others within the class.

To appropriately manage RAN vessels as individual assets, each ship and submarine must have its own individual life cycle management plan that consolidates all maintenance, maintenance support requirements and assessments, approved modernisation and required industrial support services to deliver seaworthiness through life. A life cycle management plan, similar in concept and development to the asset management plan discussed in ISO 55001, can provide the vessel’s total sustainment effort if the appropriate data is included and amalgamated to support life cycle decisions. It identifies all the constituent components and provides the task requirements and information needed to plan, schedule, and control all levels of maintenance and modernisation effectively across the life cycle. As much as possible it must allocate expected effort based on preventative maintenance, corrective maintenance (planned and unplanned), improvements to increase reliability of existing systems, upgrades to deliver future capabilities and
the industrial support services necessary to provide operational (e.g. waterborne) support and docked depot-level maintenance services. Applying accepted labour rates to the sustainment effort yields the TSC for a given vessel providing indicative life cycle costs that can be further refined as the vessel ages and sustainment progresses. Periodic updates will help refine the overall life cycle estimate and either validate or dismiss previous assumptions. For more accurate management within current budgetary constraints, short-range business plans covering near term planning and execution provide higher fidelity for the immediate future.

### 6.2 Right Work, Right Time, Right Cost

While a life cycle management plan covers the long-term plan across the ship’s planned service, an annual business plan contains the rolling account of the current execution year, the next financial year and a third “out year” in order to provide the total indicative cost, scope and schedule required to maintain the asset for the foreseeable future. This business plan is not developed separately to the life cycle management plan but is rather a more granular and refined look at vessel in-service sustainment over the next three years. The life cycle management plan begets the more granular annual business plan so data between the two are shared thus providing a single source of truth but with differing degrees of fidelity. The validated and costed business plan identifies all the work that can be executed within the allocated financial year and sets the requirements for the next two financial years. This consistently establishes sustainment planning and execution requirements for scheduled maintenance periods so decisions affecting availability, capability and affordability can be made using decision support tools and scenario planning methods that optimise overall seaworthiness across multiple financial years.

A ship or submarine annual business plan contains all the identified and itemised maintenance and modernisation and the available budget to support the vessel during the execution year and advance planning and funding needs for sustainment in future years. Sustainment efforts must be scheduled and executed when it makes most sense. While operational vessels should automatically reside at the top of an overall priority list, it does not mean that any material deficiency should trump all others. Proactive maintenance is key to maintaining operational platforms in a seaworthy state but this must be balanced against reactive maintenance for non-critical systems that do not affect seaworthiness. ‘For non-severe failures, where there are no additional costs attributed to failure beyond material and labor to repair the component, a fix-when-fail strategy may still be more cost effective’ (Allen 2009). These short-term business plans are the method by which affordability is objectively determined. They include all known direct, indirect and overhead work a vessel requires and capture all expected costs to ensure there is validity to the plan. In addition to identifying funds for the next financial year, it also estimates and predicts the funding requirements for future years. Out-year esti-
mates provide the basis for successive years’ funding estimates and adjustments will be made to refine those estimates as time progresses through successive business planning cycles.

6.3 Optimise Time Available for Maintenance

A fundamental tenet to sustainment optimisation relies on maintenance and modernisation work inside a scheduled maintenance period being accomplished and certified to approved technical standards with first time quality. This facilitates a successful set-to-work program that recertifies all systems for unlimited operational use. Each scheduled maintenance period must complete on schedule – this is a given. $A_o$ cannot be decreased due to maintenance overruns at the end of a scheduled maintenance period. Scheduling, planning and accomplishing the right work at the right time for the right cost resides at the core of a valid in-service sustainment program. Designated maintenance periods are scheduled within a UUC to allocate dedicated time within the life cycle for maintenance and modernisation. They are derived from systems and equipment design criteria and expected usage. In dynamic operational environments in which warships routinely operate, mission requirements or real-world contingencies can severely disrupt a well-planned UUC. In such instances, seaworthiness can suffer irreparably to the point where military capability or $A_o$, or both will be significantly degraded.

To counteract this potential situation from arising, routine preventive and corrective maintenance should not be limited to only scheduled maintenance periods. Whenever a ship or submarine is “alongside” (i.e. moored to a pier) it should be considered an opportunity for conducting maintenance on a not-to-interfere basis and to minimise disruption to ship staff training and certification evolutions. Any such unscheduled maintenance opportunity (UMO) should be exploited to maintain the highest levels of material readiness possible. This “continuous maintenance” philosophy is a proven method for naval platforms and significantly contributes to increasing $A_o$. It is most advantageous, and usually least expensive, to conduct continuous maintenance in the vessel’s home port. Moreover, it instils a proactive maintenance regime that can contribute to lower probabilities of an URDEF5 occurring during underway periods.

Any time a ship is “alongside” in its home port, it is should be available for maintenance. In some cases, an RAN ship or submarine may be alongside outside its home port undergoing emergent repairs to rectify a high priority URDEF. Priority 1 URDEFS and some Priority 2 URDEFS may prevent the vessel from com-

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5 The Urgent Defect (URDEF) system is RAN tool to highlight and resolve a capability deficiency, which may or may not be technical in nature. The Maritime Commander needs to be appraised of the impact of a deficiency in terms of both operational requirements and the potential effects that options to resolve the deficiency may have on other components of capability management.
Completing its mission to rectification becomes absolutely crucial to seaworthiness. Normally, these types of repairs are the single cause for the ship or submarine remaining alongside. In some cases, these repairs can take weeks to rectify. Lengthy URDEF rectifications should considered UMOs where other corrective maintenance can be accomplished during this “window of opportunity”. When URDEF repairs are known in advance, operational commanders can schedule working ports where “expeditionary maintenance” can be accomplished within the allotted alongside period. The challenge with expeditionary maintenance is operational commanders are loathe to schedule working ports for deployed ships because there is often the expectation that ship staff will be required to assist in repairs. Working ports, where short UMOs can be conducted, should be factored into deployment schedules. Working ports, if poorly managed or scheduled too frequently can negatively affect crew morale and could eventually be viewed negatively by operational commanders. However, if they are managed well, A0 could be positively influenced and seaworthiness improved. Occasionally there are periods when the ship is undergoing ship-wide certification, testing or evaluation and it may not be available but these are infrequent and the duration is relatively short.

7 Key Recommendation

Dedicated asset managers, assigned to individual naval vessels, provide a considerable potency in the development and implementation of life cycle management for ships and submarines. While the term “asset manager” can be considered a singular plural with the function residing with an entire organisation, for naval vessels this role must be reserved for a responsible and accountable person within that organisation. A dedicated person, acting as the vessel’s life cycle manager, works on a daily basis to optimise availability, capability and affordability across the life cycle. Defence assigns responsibility for organising, directing, coordinating and controlling the ship (or submarine) to accomplish assigned missions to individual commanding officers (ADF 2009) who only retain command for a few years before passing authority to a successor. Military personnel are quick to recognise the inherent responsibility bestowed upon a vessel’s commanding officer but this is quickly dismissed when viewed within the context of the entire life cycle. It is unlikely and impractical for seagoing commanding officers to make decisions in a holistic manner that may not affect the vessel for years or decades in the future.

In general, an asset manager ‘is responsible for a range of activities carried out over an asset’s life-cycle, including: planning, designing, developing, operating, maintaining, rehabilitating, retiring and disposing’ of the asset in a technically, economically, and socially responsible and sustainable way (Brown et al 2014). Other challenges facing an asset manager include: understanding business cost and performance drivers, including regulatory drivers; determining investments to optimise performance and operational costs; managing the delivery of performance;
managing the delivery of investment programmes; monitoring asset condition; and
devising appropriate maintenance policies (Cornish and Morton 2001). Assigning
ship (or submarine) asset managers to each RAN vessel will undoubtedly receive
mixed reaction and much scepticism. The USN’s Port Engineer Program encoun-
tered a similar reaction when it was introduced for surface ships in the 1980s. As
the principal advocate for the assigned ship, a port engineer is the link between the
assigned ship and shore maintenance establishment. Each port engineer is trained
to understand the structure, workings and policies of the various organizations
critical to in-service sustainment and interfaces across multiple organisations to
ensure satisfactory material condition the assigned ship (USN 2014). Port engi-
neers in the USN are essentially the ship’s asset manager acting on behalf of the
TYCOM. Many initially viewed port engineers as threats who were given too
much authority but this was eventually overcome and the port engineers are now
viewed as essential to life cycle sustainment of conventionally powered ships
USN ships (Staples 2009).

Within Australia’s maritime sector, asset management functions are split be-
tween government and industry with the majority of those activities being out-
sourced through CoA contracts to industry. While these functions remain the
responsibility of the asset owner, the CoA does not maintain the persons or the
expertise to cover this whole range. Australia’s acquisition and sustainment
framework simply does not support it. As a result, the CoA must outsource the
life cycle management effort to defence suppliers. Commercial life cycle mana-
gers, acting as the asset owners’ trusted agents, must negotiate this process to nego-
tiate short-, medium- and long-term success while balancing the asset owner's de-
mands with those of reducing daily operational costs. There may be a risk that
when the asset management responsibility is outsourced to industry, the level of
experience required by Defence may degrade to the point resulting in a lack the
qualified and experienced personnel that can act as the intelligent customer to en-
sure value for money and optimum seaworthiness is delivered through perform-
ance based contracts. Regardless of whether these ship/submarine life cycle
managers are Australian Public Service employees, uniformed Defence Force per-
sonnel or contractors performing “above the line” functions on behalf of the CoA,
a dedicated asset manager for each ship and submarine can improve readiness and
enhance overall seaworthiness across the fleet.

8 Conclusion

The Australian government is embarking on the biggest reconstitution of the
RAN and naval vessels since WWII. The RAN readily admits that asset manag-
ment is the desired method for managing maritime platforms and that it must be a
coordinated effort by both government and private industry. Within Defence, The
RAN’s maritime assets are owned, operated and maintained by an expanded set of
decision-makers. The Submarine Enterprise and WAMA are merely two (of sev-
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eral) of the hybrid models, alliances and relational contracts that are being used to manage unique risks and opportunities associated with asset management. CASG has initiated long-term binding contracts with Australian defence firms to bolster Defence’s commitment to establishing and maintaining sovereign asset management. But, applying the principles and practices of asset management to naval vessels through life cycle management will enhance seaworthiness across the fleet.

The RAN requires seaworthy platforms to provide Australia’s maritime security. Overcoming challenges enveloped by budgetary constraints, potential adversaries’ naval power and prescribed operating conditions of readiness present challenges to seaworthiness. No perfect solution currently exists that stands out above all others to deliver seaworthiness, but as asset management practices and principles provide the best foundation for Australia. As the RAN and CASG continues on the journey, both organisations cannot ignore the importance of warship life cycle management as a major influence to future sustainment efforts. While asset management is a valid method, the implementation remains the most challenging aspect incorporation into the wider defence maritime domain. Life cycle management activities applied to naval vessels will improve seaworthiness across the fleet. These activities cover whole of life planning for each vessel, sustainment of each collective class and individual ship/submarine husbandry. Management across the life cycle constitutes what has been termed elsewhere as “responsible custodianship of assets” (New and Steven 2011) and can help deliver enhanced material seaworthiness to the RAN’s fleet through asset management decision-making processes.

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