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AVAILABILITY-ORIENTED CONTRACT MANAGEMENT APPROACH: A SIMPLIFIED VIEW TO A COMPLEX NAVAL ISSUE

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ABSTRACT

Navies around the world aspire to improve their fleet operational availability. Many navies struggle to achieve their targeted high operational availability even though they are certain that they have continuously implemented improved maintenance concepts and philosophies, allocated the necessary budget and implemented advanced human capital development plans. Nevertheless, the efforts may be futile when they could not be allocated precisely in tackling the issues concerning "human and equipment" related Downtime Influence Factors (DIFs) impacting ship operational availability. The extended exploratory research encapsulated all the efforts in discovering a simplified methodology in tackling this complex naval issue. The 13 objectives achieved in this paper covers the initial work in identifying the DIFs until the development of a Contract Management Control and Monitoring System (ConCaMS) that is able to assist policymakers and all stakeholders including Contract Managers in managing the ship maintenance contract efficiently and effectively. The ConCaMS is able to guide so that actions could be taken earlier enough for recovery to be possible, as opposed to traditional methods. Additionally, the ConCaMS could also be used by policymakers and Top Management of the private sectors as well as the governments as a proven method in comparing contract performance between various contracts, by using availability as the performance benchmark.

Keywords: *Naval ship availability; downtime influence factors (DIFs); availability-oriented framework; contract management control and monitoring system (ConCaMS); recovery availability (Ao) for in-service support*.

1. BACKGROUND ON MAINTENANCE

For many decades, maintenance was regarded as an unavoidable part of the production function and difficult to manage. Hence, maintenance was initially considered as 'necessary rework' and was only given minimal focus. In most organisations, maintenance remains to be considered a burden, and sometimes even considered as a needless cost, that was given the least priority in time, resources and budget. This phenomenon is rampant worldwide, across various industries and through the cultural divide. This negative connotation only changed gradually where maintenance became a separate, fully recognized and essential business function (Xia-Feng *et. al,* 2008). It was only after World War Two that more attention was attributed to it in aviation and in addition in other industrial sectors like defence, nuclear, chemical and petrochemical. Ship maintenance was not well structured or organized in comparison to the other industrial entities which observed that huge savings may be made when carrying out proper maintenance tasks (Lazakis *et al.*, 2010).

Similar to other industries, ship maintenance was considered part of operational tasks needed to be performed on a daily basis, a mere necessity to move the ship to perform its mission from one place to another. For the merchant marine, the shipping industry has made great progress based on studies and recommendations by academicians as well as consultation by international maritime organisations, governing bodies and classification societies. The improvements also include the areas of safety and environmental protection, with the objective in general of increasing the quality, reliability and availability of the ships. This has consequently increased the positive image of the ship operators, ship owners and supporting organisations from the private sector.

Naval vessels or navy ships on the other hand, are a completely different breed altogether. They have various designs to complete their different missions, with a vastly different range of equipment and systems onboard especially those related to battle and combat management such as Anti Surface Warfare (ASuW), Anti-Submarine Warfare (ASW), Anti-Air Warfare (AAW), Electronic Warfare (EW), Search and Rescue (SAR), humanitarian and many other navy related functions. Examples of complex cross-functional capability frameworks as depicted by (Olivier *et al.*, 2014) in Figure 1.

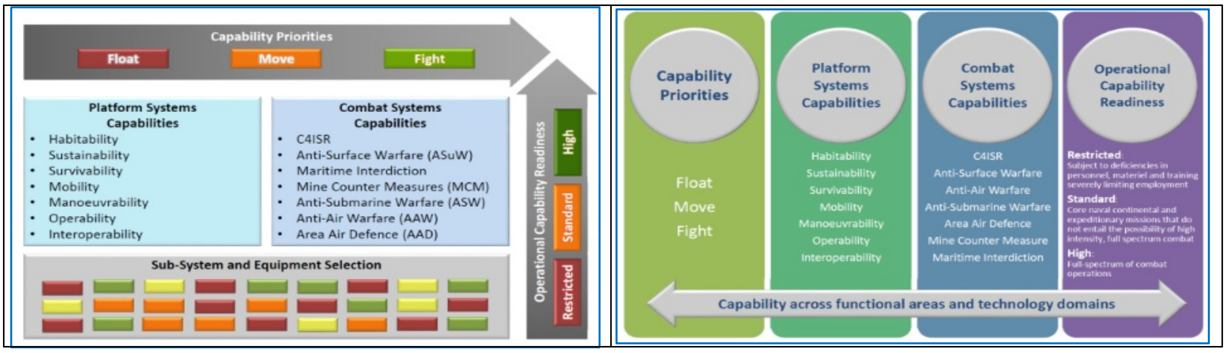


Figure 1: Examples of cross-functional capability frameworks (Olivier *et al.*, 2014).

An example of naval vessels is reflected in Figure 2 illustrating Royal Malaysian Navy (RMN) Patrol Vessels (PV) and Figure 3 depicting the PV undergoing maintenance.

Figure 2: Example of naval vessels (RMN Patrol Vessels KD KEDAH and KD PAHANG).

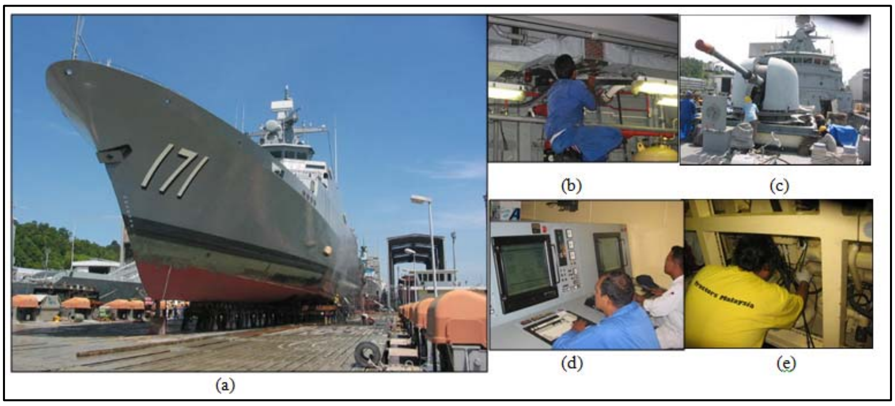


Figure 3: (a) Upslip of RMN PV KD KEDAH (b) HVAC maintenance (c) Gun maintenance (d) Ship control and monitoring system (SCAMS) maintenance (e) Main engine maintenance

Compared to merchant vessels, the naval vessels differ in their concept of operations, their range of equipment and their concept of equipment redundancies, and vary in their policy and priority of maintenance. In general, naval vessels are not expected to comply with merchant ship's requirements of meeting the environmental standards, and most importantly are not strictly bounded to achieve a targeted profit as compared to commercial establishments.

Nevertheless, these warships have been facing similar issues encountered by their sisters in the merchant marine sector, due to the fact that the shipbuilding contract appears to have no direct bearing on the maintenance contract. Even though it is quite normal for naval ships to have their life-cycle cost (LCC) calculated prior to delivery, the most visible part is the acquisition cost which is normally more evident. The 'not-so-evident' part which includes the operational cost, maintenance cost, spare parts supply costs, engineering documentation, most of which are part of the Integrated Logistics Support (ILS) costs, are not attended to as strictly as the acquisition cost. Frequently the cost of sustaining equipment is 2 to 20 times the acquisition cost (Barringer, 1997). This continues to happen even though the 'not-so-evident' costs over the lifetime of the vessel are significantly higher than the acquisition cost, most likely due to the length of time involved from 'cradle to grave' averaging between 25-30 years and also due to the unfamiliarity of organisations towards this area. This has resulted in limited technical and financial data being collected especially in developing countries including Malaysia based on authors' experience in the RMN and supporting industries, to study and compare projected versus actual maintenance activities and its associated costs.

1.1 Complexity of Naval Ships

A modern naval vessel or warship/submarine would consist of in excess of 100 integrated systems that are linked structurally, mechanically, electrically, hydraulically, pneumatically and electronically (SIA, 2018). The systems need power and cooling, and required to communicate with each other to achieve full operational capability (Henry & Bill, 2015). Consequently, the naval ship operational availability turns into a complex problem (Dell'Isola & Vendittelli, 2015). The ship design of major surface combatants capable of effectively responding to all possible missions within the spectrum of modern conflicts and military operations other than war (MOOTW) is increasingly difficult due to the complex nature of the rapidly evolving and unpredictable global threat environment. Naval ship design can also be understood to be a networked System-of-Systems (SoS) multidisciplinary process whereby a decision on one aspect of the design may have simultaneous, multiple effects on other aspects of the design (Ford *et al.*, 2013; Olivier *et al*., 2014).

Traditional ship design methodologies have evolved from the sequential nature of the design to more advanced computational methods enabling the simultaneous manipulation of several degrees of freedom to better understand the interdependencies between factors (Olivier *et al*., 2012), consequently this design complexity has been identified by Pascual *et al*. (2006) as causes of greater risk for asset downtime. The naval vessel is also designed to effectively respond to all possible missions and all kind of complex military operations according to its roles. The evolution of the Roles of the Navy (Canadian Navy, 2012) has developed into "Trinity of Roles" and the evolution from Booth Model to Leadmark Model can be described through Figure 4.

Navies worldwide face similar challenges in achieving high asset availability, where the situation is aggravated due to the complex nature of warships including the variety of military roles (Directorate of Maritime Strategy Canada, 2001). To improve any assets operational availability undoubtedly further complicates the problem due to a long list of interconnected contributing factors (GAO,1982), whereby interdependencies and uncertainties involving human and equipment related factors appear with unclear significance and unknown weightage.

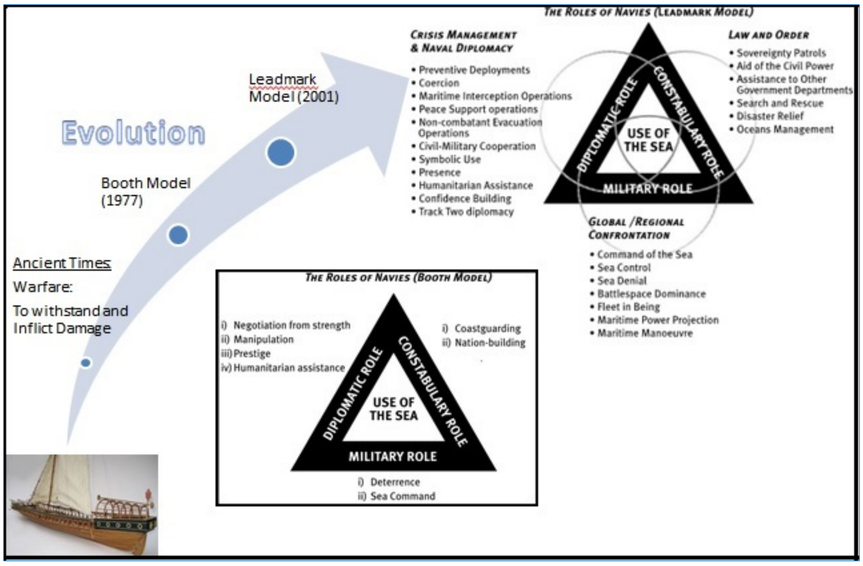


Figure 4: Evolution of the roles of the Navy - "Trinity of Roles".

1.2 Contract Management Concepts

Following delivery of each vessel on completion of construction and trials activities, and especially after the end of the warranty period, the vessel shall be completely under the responsibility of the Navy for the operations and maintenance activities. Unless a special maintenance contract is awarded by the Navy to the shipbuilder or any authorized party, the coordination of maintenance activities would then become less efficient and troublesome due to the limited number of Navy support team personnel allocated to maintain the ship as well as the inexistence of a significantly large budget allocation for the maintenance of the vessel. Many navies consider this as the In-Service phase and sign an In-Service Support (ISS) contract for the maintenance of the vessels. Several navies including United Kingdom (Datta & Roy, 2010; Tomkins, 2012) and Australia (Henry & Bil, 2015) on the other hand implement the most recently popular but costly "Performance or Availability Based Contract" whilst others remain with the traditional "execution upon receipt of order only" philosophy or commonly known as per-order basis. There exist other types of contracts with other sorts of forms and contents but mostly are modifications from the two major types above.

The United States Navy (USN) generally continues to apply a traditional service procurement practice, as opposed to the shift in concept in the UK, since 2000 to apply Availability Contracting, an approach that began replacing the traditional procurement service practice (Datta & Roy, 2009). Therefore it is an accepted fact that the complexity of the naval vessel itself as an asset, with complex roles and missions is further aggravated by the intricacies of the various types of maintenance contracts they belong to.

1.3 Achieving High Operational Availability of Naval Ships – a complex problem

All navies in the world aspire to improve the operational availability of their fleet. Most navies such as the USN (Marais *et al.*, 2013), Korean Navy (Paik, 2014) and RMN (RMN, 2011) have specific operational availability targets, but still remains a problem to be achieved. Astoundingly despite the sophistication and considerably higher maintenance budgets by modern navies such as USN, it remains a question as to why availability is still less than expected.

Naval vessel or warship in itself as an asset is inherently complex, and the operational availability of warship is also a complex problem (Dell'Isola & Vendittelli, 2015). Therefore, improving Ship Availability or Operational Availability of naval vessel further magnifies the complexity of the problem making it "complexly complicated". Ship Availability is defined by Inozu (1996) and Blanchard & Fabrycky (1998) as the probability that the ship is available and capable of performing the intended function at any random point of time. Hou Na *et al.* (2012) described availability as "uptime" which can be formulates as one minus downtime or known as unavailability, with the resulting mathematical implication that the more unavailability or "downtime", the lesser the availability achieved. This can be easily described as stated in Equation 1 and Figure 5:

$$\text{Availability (Uptime)} = 1 - \text{Unavailability (Downtime)} \quad (1)$$

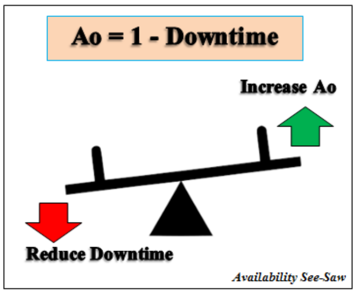


Figure 5: Availability see-saw.

Ship operational availability is also described as the number of days the warships are available for operational tasking in a year (GAO, 2015). Therefore, the objective in achieving high operational availability can only be achieved by reducing the impact of all factors that create downtime or unavailability. Nevertheless, as we know, this remain a challenging task for all navies in the world, similarly faced by any other assets from any engineering fields globally.

1.4 Simplifying a Complex Problem

The complex naval vessel systems and machineries, dynamic and ever-changing roles and mission, location of naval bases, sailing alone or part of a battlegroup, meeting various operational tempo, when compounded with the various types of complicated maintenance contracts they belong to with specific targeted operational availability, makes the situation multiple times more complex than meets the eye. It is further aggravated due to a long list of contributing factors to Ship Availability that are intertwined, with so many ambiguities and uncertainties on the relationship between each factor involving human and equipment, the unclear significance and weightage of each factor, the unknown direct and indirect impact of each factor onto each other, and onto the resulting Ship Availability.

The question now comes to whether it would be possible for the 'complexly complicated' situation to be simplified for the benefit of better understanding of the various levels of stakeholders. Would it be possible to holistically study the human and equipment related Downtime Influence Factors (DIFs) affecting Ship Availability? Would this better understanding of stakeholders benefit various organisations in their ultimate effort for improving the Ship Availability? Would the research findings assist Project Managers and Contract Managers in managing their contracts better, even with some commonly known constraints? Would this research benefit other industries in similar manner?

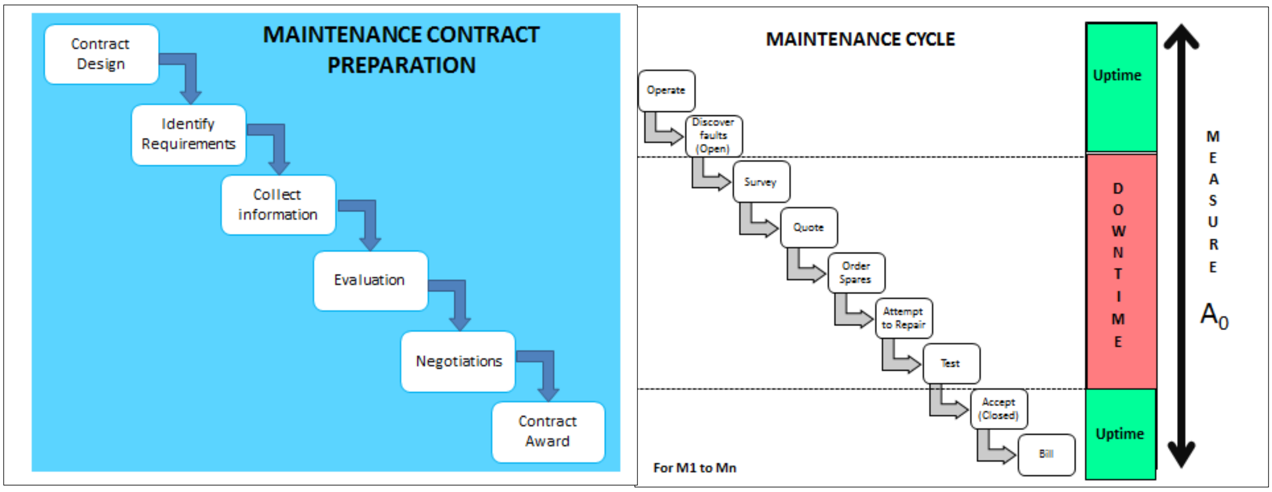
A few researchers have attempted to consolidate some factors to find interdependencies and also try to implement best practices in Project Management (PM), but none have been able to holistically consolidate as many factors as necessary for a thorough study. The race to maximize operational availability or uptime is hampered by the simple fact that there exists a long list of possible contributing factors affecting downtime. There was no literature published previously that attempted to consolidate human and equipment related factors on naval ships, in fact for any engineering field in general until studied recently by Al-Shafiq *et.al* (2017a). The most current and closest research to the naval ship availability is for the Italian Navy which concluded that Ship Operational Availability of warships require a more innovative and comprehensive approach for the design and support by Dell'Isola & Vendittelli (2015). Donkelaar (2017) studies the operational availability for the Royal Netherlands Navy pointing out that the availability requirements are not met and insufficient at present.

The snowballing effect as a result of ineffective Contract Formulation impacts the Contract Manager three-fold, a weak contract to be implemented resulting in the brewing and subsequent surfacing of a magnitude of issues that could have been avoided, inability for the assets to be managed with high availability, and the non-existence of a model or mechanism to assist the Contract Manager in managing the contract efficiently. This negative effect is magnified due to the limited data being populated and analysed to date with these objectives in mind, as a result of poor awareness and understanding on most stakeholders towards the importance of this issue at hand. The complexity of naval ship maintenance activities coupled with the limited literatures available to date on factors having negative influence on ship availability has created a seemingly impossible task to improve the current situation faced by the contract managers in the implementation of the ISS contract.

The step by step approach in this research would provide all stakeholders with a clearer view to recover from the situation beginning with the identification of the range of DIFs that influence naval ship availability, concentration on the severe or critical DIFs using a Risk Analysis, identification of the severe DIFs' impact to cost, budget, schedule and scope of the contract and finally the development of a mathematical algorithm that provides the opportunity to produce a ship availability-oriented Contract Management System for naval vessels that would provide a solution to systematically tackle the issues mentioned above.

2. AVAILABILITY-ORIENTED CONTRACT MANAGEMENT APPROACH: KEY OBJECTIVES

In accordance to Ford *et al.* (2013) the In-Service phase is considered 70% of the ships through life cost. During In-Service phase, the number of involved stakeholders will vary as the vessel cycles through tasking, upkeep and regeneration. Prior to the ISS phase, a maintenance contract for the vessel would then be prepared, drafted and negotiated. The overall process of the preparation of the maintenance contract is described in Figure 6.



(a) **(b)**

Figure 6: Maintenance contract preparation and implementation: (a) Maintenance contract preparation (b) Maintenance cycle.

There would be numerous maintenance cycles happening onboard the ship on a daily basis as illustrated in Figure 6, and some may even happen concurrently. There are many factors related to human and equipment (system and machinery) that affects the maintenance of the vessels over the contract period, but there exists insufficient reference or historical records to be analysed.

As with most of other navies especially from the developing world, the RMN PV ISS contract managers (RMN, 2011), only monitor and record equipment and spares related information against cost versus schedule, since the contractual requirements common to most navies are to monitor the start and end of rectification process through defect reports as well as the delivery of spares. Nevertheless, these contract managers as well as the maintainers realize that there exist other factors impacting the availability of the vessels, but they were uncertain on the significance and scale of each issue because it has been considered an unchartered territory in research. Therefore, unless a comprehensive study on these factors is conducted to identify and rank these human and equipment related factors, they will continually never be monitored and recorded. Only when historical records are established, analysis could be conducted to decipher the contents. Ultimately, a Contract Management Control and Monitoring System (ConCaMS) could be developed to assist contract managers and maintainers to maintain the vessels effectively and efficiently. This ConCaMS system which is not available in the market to date, may also be utilized as a Diagnostic Tool in guiding the stakeholders in making critical decisions towards meeting the targeted Ship Operational Availability.

In order to pave the way towards this uncharted area of knowledge, the authors have established a list of Key Objectives to be achieved on this research, as indicated in Table 1.

Table 1: Availability-oriented contract management approach key objectives.

Key Objectives	Description
Objective 1	Development of a Conceptual Model on how the human and equipment related factors affect the maintenance and availability of the vessel over a contract period.
Objective 2	Identification of the best methodology to approach the study.
Objective 3	Development of a Conceptual Model depicting the relationship between Operational Availability (Ao), Maintenance activities and Maintenance Cycles.
Objective 4	Identification of human and equipment related factors (Downtime Influence Factors) affecting Ship Operational Availability.
Objective 5	Ranking of the Downtime Influence Factors (DIFs) from most severe to least severe.
Objective 6	Identifying the Impact of DIFs from Contract and Project Management perspectives, especially on Cost, Time, Quality and Scope.
Objective 7	Development of a Contract Management Control and Monitoring System Spiral.
Objective 8	Development of an Availability-oriented Contract Management Framework.
Objective 9	Development of an Availability-oriented Contract Management Cycle.
Objective 10	Development of an Availability-oriented Contract Management Model.
Objective 11	Improving Availability through Change in Contract Clauses – A suggested Mechanism.
Objective 12	Development of an Availability-oriented Contract Management Control and Monitoring System (ConCaMS).
Objective 13	Development of an Availability-oriented Contract Management Dashboard

2.1 Objective 1: Development of a Conceptual Model on the How the Human and Equipment Related Factors Affect the Maintenance and availability of the Vessel Over a Contract Period

Brainstorming sessions and Focus Group Discussions (FGD) managed to derive some conceptual models on how the human and equipment related factors affect the maintenance and availability of the vessel over the contract period. The model is described in Figure 7 as follows:

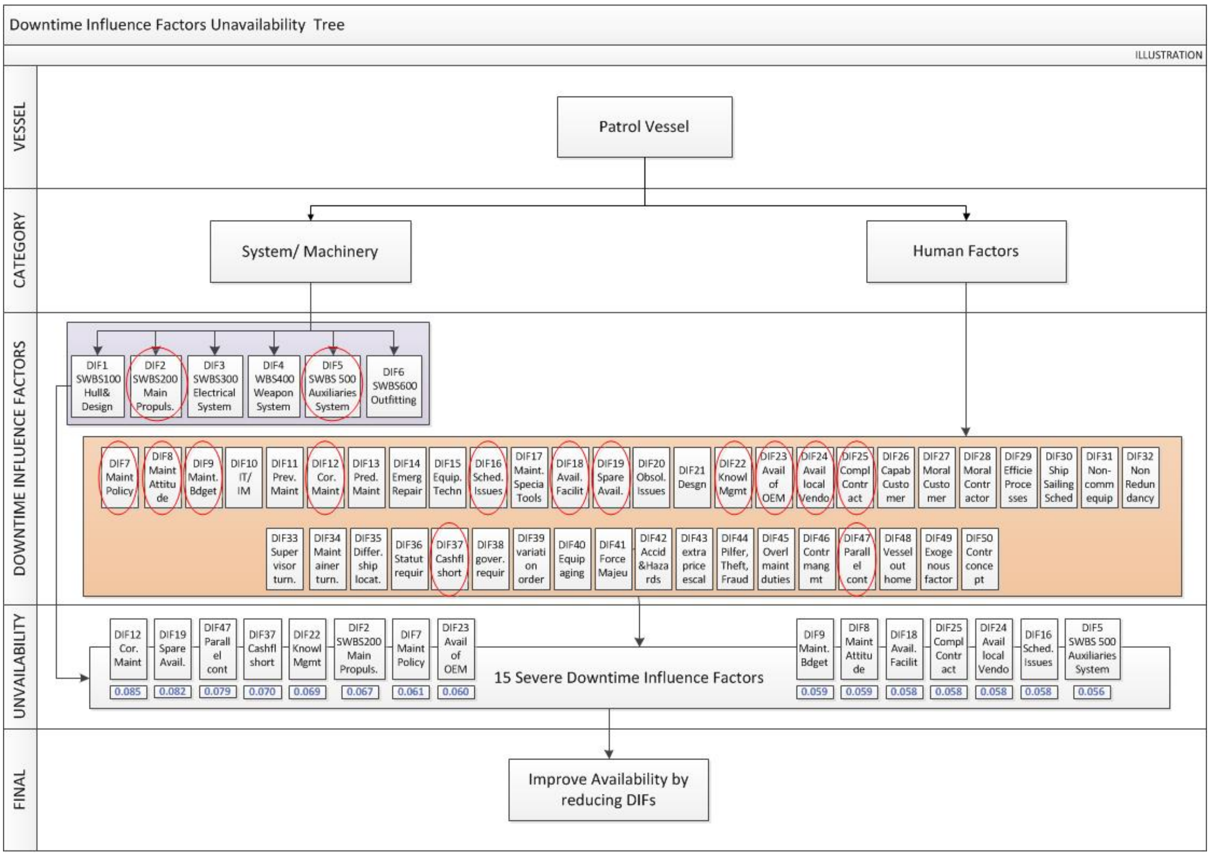


Figure 7: Relationship between human and equipment factors to availability.

2.2 Objective 2: Identification of the Best Methodology to Approach the Study

Since the 1980's efforts have been initiated in studying availability improvement concepts to military assets (GAO, 1982). Various maintenance concepts had been applied by diverse industries worldwide ever since with varying degrees of success. The authors have explored the usage of many methodologies for this research, however Delphi was chosen as the most suitable methodology in line with Skulmoski *et.al* (2007) to explore new concepts within and outside the existing body of knowledge in the field and in accordance to Franklin & Hart (2007) since the complexity of naval ship availability phenomenon is without previous history, a quickly changing event that outdates the literature, and a very complex phenomenon that truly requires experts for understanding it.

2.3 Objective 3: Development of a Conceptual Model depicting the relationship between Operational availability (Ao), Maintenance Activities and Maintenance Cycles

The relationship between Operational Availability (Ao), Maintenance activities and Maintenance Cycles for the RMN PV ISS Contract (RMN, 2011) can be described in Figure 8. This situation is also generically applicable to most of other navy fleets.

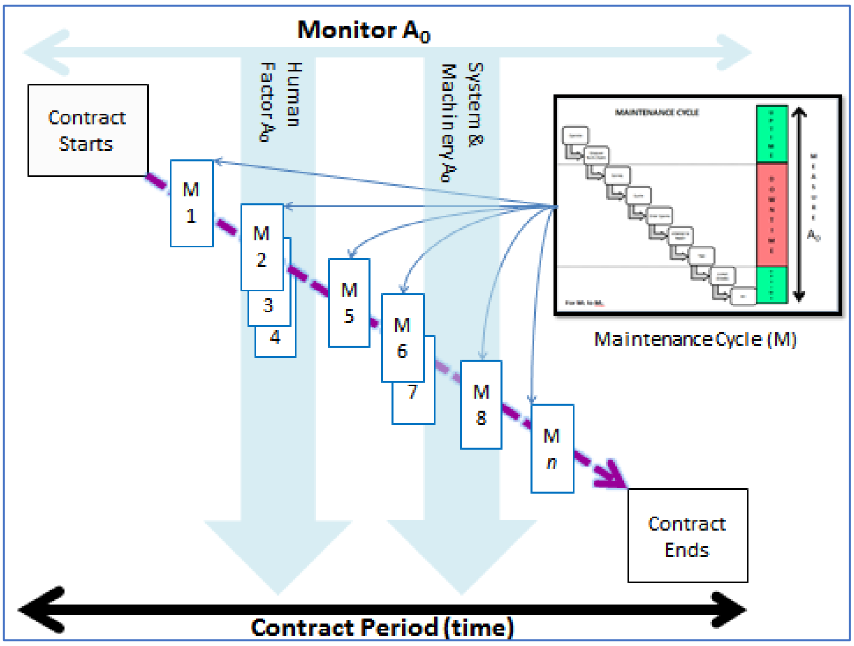
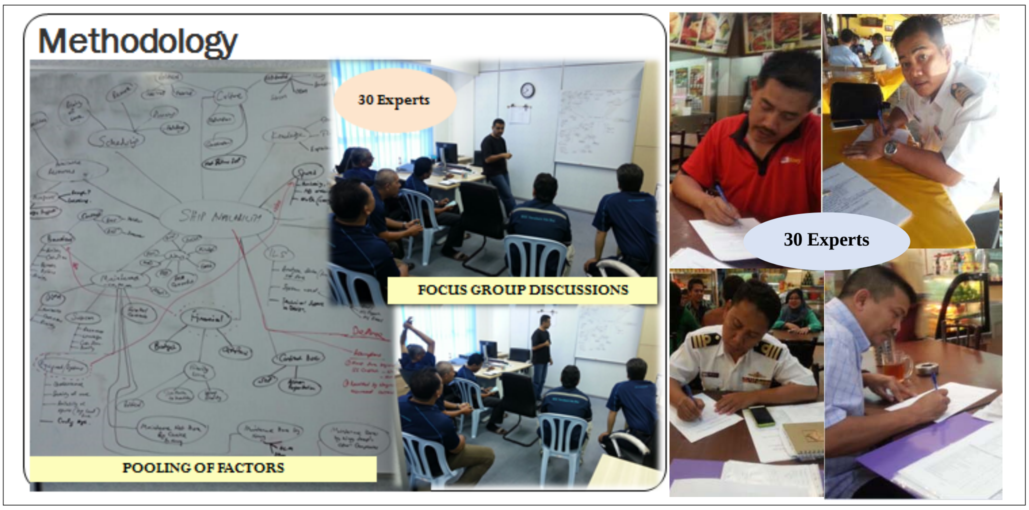


Figure 8: Relationship between Operational Availability (Ao), Maintenance activities and cycles.

2.4 Objective 4: Identification of the Human and Equipment Related Factors (Downtime Influence Factors) Affecting Ship Operational Availability

Prior to this research there was no specific holistic study of all the factors that affect naval maintenance downtime or naval ship availability. Therefore, for this exploratory study, extensive Literature Research across more than 500 literatures were conducted by the authors across various engineering disciplines, and the screening process resulted in close to 200 literatures found applicable to generate the list of factors. The result was used during the subsequent brainstorming session and Focus Group Discussions with 30 experts in Figure 9 from the PV ISS Maintenance organisations and the RMN to reconfirm and pool the variables into relevant groups. The population of interest has been described in this study as experienced, knowledgeable Malaysian Naval ISS experts that have direct involvement in the PV ISS Contract. The total number of experts complying with these criteria was 46. Subsequently, the researcher applied judgmental sampling based on the accessibility of these experts to determine the selected 30 experts. Baker & Edwards (2012) recommended guidance on sampling size for qualitative interviews and stated that saturation is central to qualitative sampling depending on the methodological and epistemological perspective. Meanwhile Adler & Adler (2011) advised sample pool sizes with a mean of 30, though later confirmed that the best answer is to gather data until empirical saturation has been reached since some qualitative researchers have argued that as little as 1 opinion can add value to the area of research. Moreover, good results can be obtained with a homogenous group of experts, with a panel as small as 10 to15 individuals (Adler & Ziglio, 1996).

The result was presented by Al-Shafiq *et al.* (2017a, b) as the identified Downtime Influence Factors (DIFs) that affect naval ship availability for the PVs in Malaysia. The method in identifying the variables is reflected in Figure 10. Subsequently, the authors proceeded with multiple rounds of Mixed Method Sequential Delphi with Snowballing Technique as reflected in Figure 11, moving from 30 Experts to five Top Management Experts as part of the self-validating iterations in the Delphi process.



(a) (b)

Figure 9: Experts participating in Brainstorming and FGD during Delphi Rounds: (a) The PV ISS Maintenance organisation (b) The RMN officers.

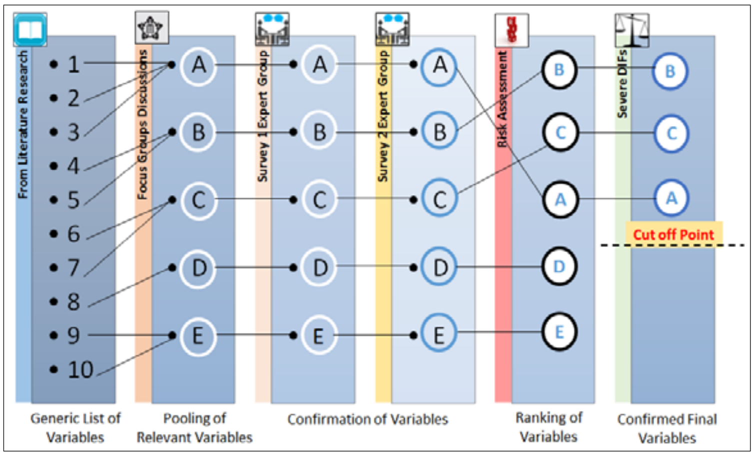


Figure 10: Method of identifying key variables.

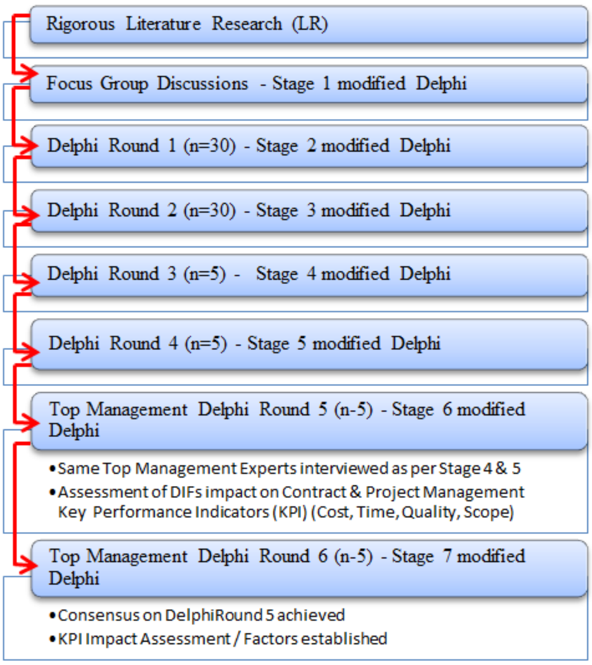


Figure 11: The Delphi rounds.

2.5 Objective 5: Ranking of the Downtime Influence Factors (DIFs) from Most Severe to Least Severe

Al-Shafiq *et al.* (2017a, b) identified via a mixed method sequential modified Delphi approach the Downtime Influence Factors (DIFs) that impact the Naval Availability of the Royal Malaysian Navy (RMN) In-Service Support Contract. In total 35 expert opinions were elicited. The list of 50 DIFs was then prioritised based on a risk management model and 15 Severe DIFs were identified as per Figure 12.

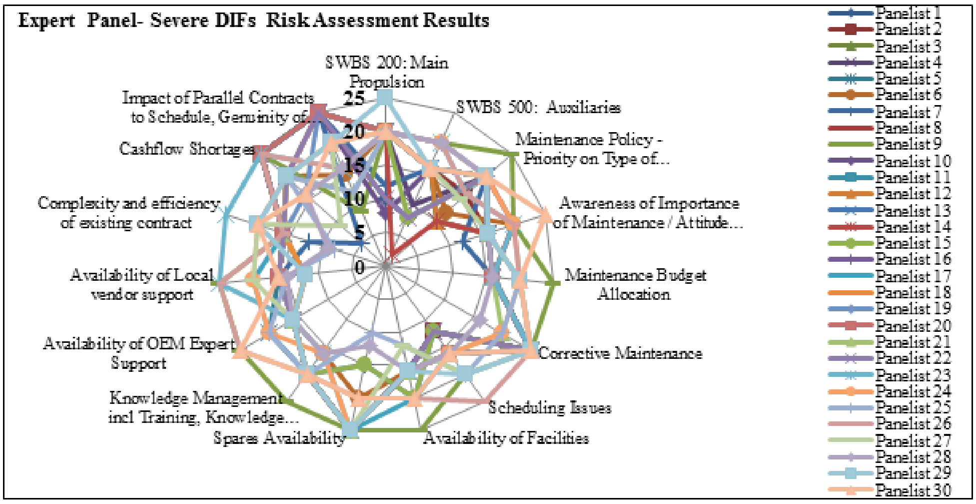


Figure 12: Expert panel – Severe DIFs risk assessment results.

2.6 Objective 6: Identifying the Impact of DIFs from Contract and Project Management Perspectives, Especially on Cost, Time, Quality and Scope.

There is a clear relationship between Project Management (PM) and Contract Management (CM), as well as the relationship of both towards maintenance activities. On the other hand, there is an existing relationship between maintenance activities and availability. Darnall & Preston (2010) describes that PM is complicated because project manager must understand several knowledge areas and develop a variety of tools and technique to successfully manage a project. In a nutshell, PM is focused at managing all aspects of a project to ensure that it can be completed and that the project deliverables are achieved within the main project constraints (Scope, Time, Cost & Quality) which are basically in accordance with the contract. CM is focused at ensuring that terms and commitments agreed in the contract are adhered to. Contract Managers responsibility areas overlap at times with those of a Project Manager, since contract managers are tasked with ensuring that projects are delivered on budget or profitably. Both PM and CM activities for Naval ISS contracts are intrinsically linked via the limiting factors or constraints to the Ship Availability through the DIFs as diagrammatically represented in Figure 13.

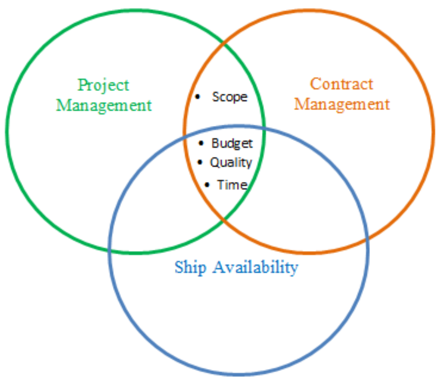


Figure 13: PM, CM and ship availability constraints and impact factors.

A questionnaire was produced and administered to the Top Management Experts in a follow up interview from Stage 5 of Delphi. The objective was to understand the link between the 15 Severe DIFs to the PM Constraints and the CM Objectives. The constraints of "Cost", "Time", "Quality" and Scope" were identified as Key Performance Indicators (KPIs). A three-point rating scales for the effect on each KPI was used as per Table 2. Table 3 contains the consolidated results on PM and CM KPIs.

Table 2: Three-point rating scale to quantify the effect of each KPI.

Cost:	**Time:**	**Quality**	**Scope:**
No Impact (NI)	No Impact (NI)	No Impact (NI)	Fixed
Lower (L)	Shorter Duration (SD)	Better (B)	
Higher (H)	Extended Duration (ED)	Reduced (R)	

Table 3: Severe DIF impact on KPIs.

S/No	Severe DIFs	Top Management Experts					
		KPI	E1	E2	E3	E4	E5
1	SDIF1	Cost	H	H	H	H	H
		Time	S	S	S	S	S
		Quality	B	B	B	B	B
		Scope	F	F	F	F	F
2	SDIF2	Cost	H	H	H	H	H
		Time	S	S	S	S	S
		Quality	B	B	B	B	B
		Scope	F	F	F	F	F
3	SDIF3	Cost	NI	NI	NI	NI	NI
		Time	S	S	S	S	S
		Quality	B	B	B	B	B
		Scope	F	F	F	F	F
4	SDIF4	Cost	NI	NI	NI	NI	NI
		Time	S	S	S	S	S
		Quality	B	B	B	B	B
		Scope	F	F	F	F	F
5	SDIF5	Cost	H	H	H	H	H
		Time	S	S	S	S	S
		Quality	B	B	B	B	B
		Scope	F	F	F	F	F
6	SDIF6	Cost	H	H	H	H	H
		Time	S	S	S	S	S
		Quality	B	B	B	B	B
		Scope	F	F	F	F	F
7	SDIF7	Cost	NI	NI	NI	NI	NI
		Time	S	S	S	S	S
		Quality	B	B	B	B	B
		Scope	F	F	F	F	F
8	SDIF8	Cost	H	H	H	H	H
		Time	S	S	S	S	S
		Quality	B	B	B	B	B
		Scope	F	F	F	F	F

S/No	Severe DIFS	Top Management Experts					
		KPI	E1	E2	E3	E4	E5
9	SDIF9	Cost	H	NI	H	H	H
		Time	S	S	S	S	S
		Quality	B	B	B	B	B
		Scope	F	F	F	F	F
10	SDIF10	Cost	NI	NI	NI	NI	NI
		Time	S	S	S	S	S
		Quality	B	B	B	B	B
		Scope	F	F	F	F	F
11	SDIF11	Cost	H	H	H	H	H
		Time	S	S	S	S	S
		Quality	B	B	B	B	B
		Scope	F	F	F	F	F
12	SDIF12	Cost	H	H	H	H	H
		Time	S	S	S	S	S
		Quality	B	B	B	B	B
		Scope	F	F	F	F	F
13	SDIF13	Cost	NI	NI	NI	NI	NI
		Time	S	S	S	S	S
		Quality	B	B	B	B	B
		Scope	F	F	F	F	F
14	SDIF14	Cost	NI	NI	NI	NI	NI
		Time	S	S	S	S	S
		Quality	B	B	B	B	B
		Scope	F	F	F	F	F
15	SDIF15	Cost	H	H	H	H	H
		Time	S	S	S	S	S
		Quality	B	B	B	B	B
		Scope	F	F	F	F	F

The results of the study were described by the authors in Al-Shafiq *et al*. (2017c) as follows:

a. The improvement of certain Severe DIFs would not have a negative "cost" impact.
b. In addition, the reduction of all 15 severe DIFs will have a positive effect on "time" and "quality". Since "scope" is considered fixed for the ISS contract period there is no impact on scope.
c. The possibility that the negative impact on "costs" to be outweighed by the positive effects on "time" and "quality.
d. The findings confirm that all 15 Severe DIFS have impact on project management and contract management constraints of cost, time, quality and scope. It is also possible to identify whether the impact is positive, negative or neutral.
e. An important finding is that contract managers are now able to pinpoint which DIFs to improve when there are budget or cost limitations.

2.7 Objective 7: Development of a Contract Management Control and Monitoring System (ConCaMS) Spiral

The authors realised the necessity to develop a figure to reflect the steps taken in the study, so a Contract Management Control and Monitoring System Spiral in Figure 14 was produced.

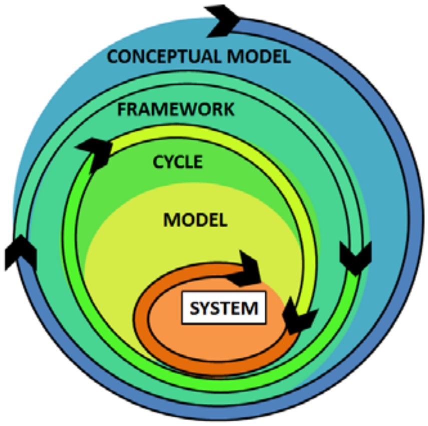


Figure 14: Contract Management Control & Monitoring System (ConCams) development spiral.

2.8 Objective 8: Development of an Availability-oriented Contract Management Framework

An Availability-oriented Contract Management Framework was developed by the authors after taking consideration of all available INPUT from prior research steps, and inserted all requirements for the PROCESS as well as the expected OUTPUT, based on the McGrath (1984) IPO Model. The developed Framework is described in Figure 15.

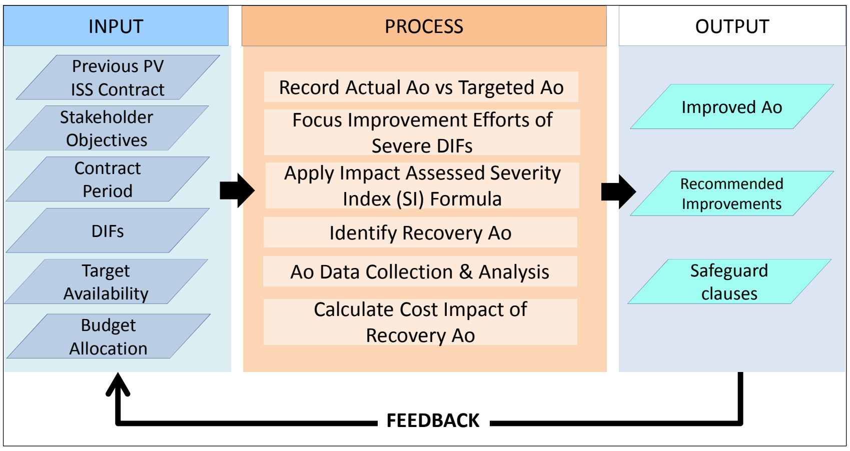


Figure 15: Input-Process-Ouput (IPO) framework for ISS ship availability-based contract.

2.9 Objective 9: Development of an Availability-oriented Contract Management Cycle

During the contract period, there would be uptimes and downtimes for the naval vessels. This downtime includes the maintenance periods (M_1 to Mn) as described in Figure 8. The DIFs would be the factors that influence the downtime, whereby those that have a negative impact over a prolonged period are considered severe DIFs. Ideally, at the end of the 3-year PV ISS contract period, the targeted availability is compared with the actual availability of the vessels, and improvements from "lessons learned" are expected to be implemented in the next contract. An Availability-oriented Contract Management Cycle has been developed by the authors for this purpose following discussions with the Experts as described in Figure 16.

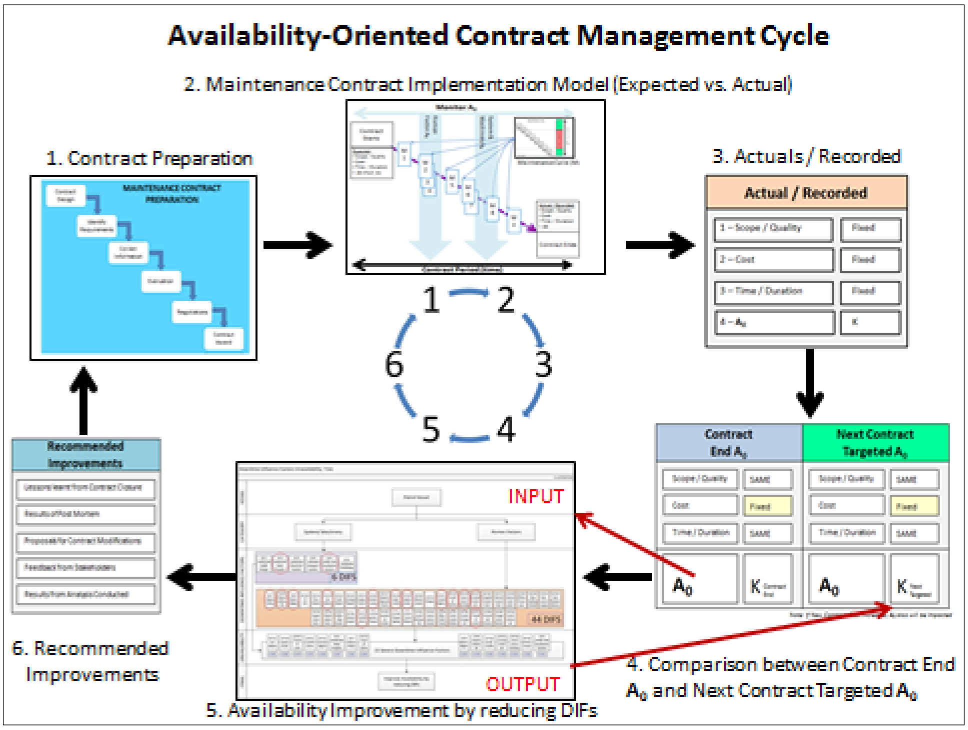


Figure 16: Availability-oriented Contract Management Cycle.

The Key Monitoring Criteria for the Availability-oriented Contract Management Cycle is reflected in Figure 17 and the steps to be followed are described in Steps 1 to 6 in Figure 16:

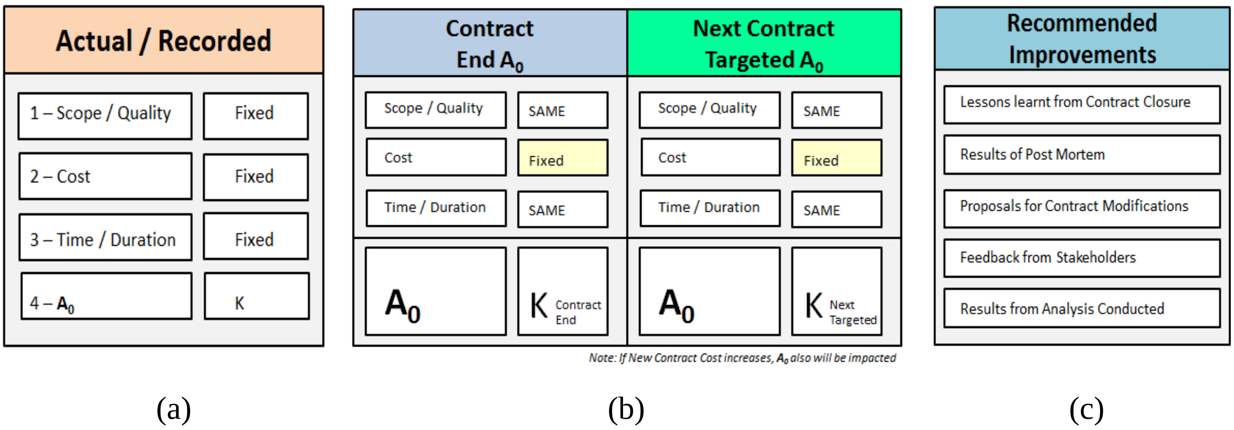


Figure 17: Key Monitoring Criteria: (a) Actual vs Recorded (b) Comparison of contract end Ao vs Targeted Ao (c) Recommended improvements.

The Experts who are stakeholders realized that they concentrate mostly on day-to-day operations and kept busy in "everyday fire-fighting culture' that they have never been able to record and analyse the past to improve in the future. Urgencies supersedes importance, and problems become crises. On the other hand, many of the stakeholders agreed that an in-depth research as triggered by the authors is necessary before a concerted effort could possibly be placed in improving the implementation of the PV ISS contract in the future, as they are currently blind and clueless to the root causes as well as the recommended solutions. It is the authors' aim to develop a systematic approach towards managing these real-life and legacy issues through this research.

Equally important is the new concept of "Recovery Availability" or "Recovery Ao" as termed by the authors which shall assist in guiding the Top Management especially the Contract Managers in taking the necessary steps on a daily basis in achieving the targeted availability as opposed to only be able to discuss during scheduled monthly or quarterly meetings without any substance or evidence. With proper guidance and Top Management buy-in, the Contract Managers shall have the mandate to implement the necessary improvement efforts on resource and time allocations in order to be on the path of recovery towards the Targeted Availability. An example of the calculated availabilities and Recovery Ao based on the developed ConCaMS system is reflected in Figure 18.

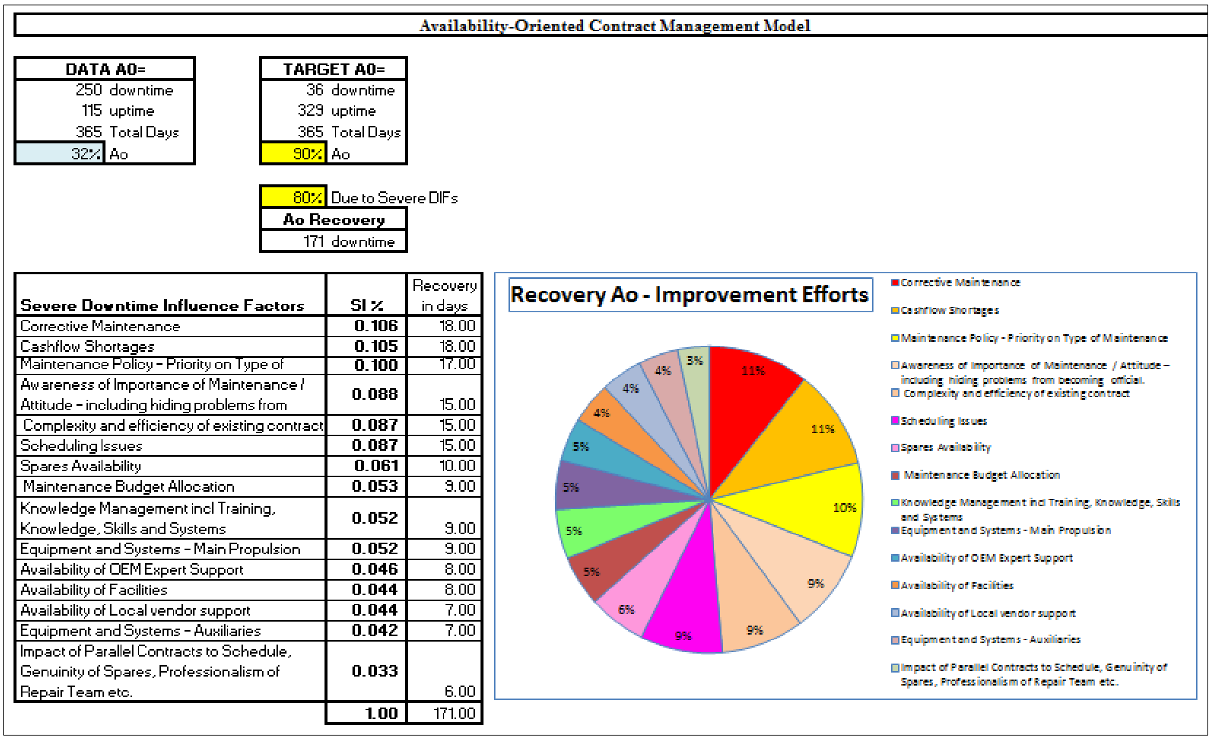


Figure 18: Example of Recovery Ao in the ConCaMS.

2.10 Objective 10: Development of an Availability-oriented Contract Management Model

The 50 DIFs identified in the earlier stages were assessed based via Risk Assessment Method. Qualitatively, risk is proportional to the expected losses that can be induced by a certain accident and to the likelihood of an occurrence. Greater loss and greater likelihood result in an increased overall risk (Ristic, 2013). In engineering, the definition of risk is:

$$\text{Risk} = (\text{Probability of Incident/ Accident}) \times (\text{Losses per Incident / Accident}) \qquad (2)$$

Both panellist groups were requested to identify and rank the DIFs by severity by assigning a value to the probability of the DIF occurring during the contract duration and the Impact the DIF had onto the Availability of Naval Vessel for the ISS Contract by means of a 5-point Likert Scale as per below.

Table 4: 5 Point Likert scale for impact and likelihood.

Impact	
Description	**Rating**
Extreme	5
High	4
Medium	3
Low	2
Negligible	1

Likelihood	
Description	**Rating**
Almost Certain	5
Likely	4
Possible	3
Unlikely	2
Rare	1

After identifying the quantity of key measures of DIFs, the experts scoring was referred to determine the DIF Severity Index. The starting point was to identify the importance of each weighting. The cut off point for a Severe DIF was determined as 16 with an availability impact perceived as "High and above" and a probability of occurrence of "Likely and above". A preliminary series of weighted Severity Measures (SM) was developed based on the mean ratings advocated by all the respondents as presented by Al-Shafiq *et al.* (2017d). The weighting for each of the top DIFs was computed using the following equation:

$$\boldsymbol{W_{SMi} = \frac{M_{SMi}}{\sum_{1}^{15} S_{SMi}}} \tag{3}$$

where:

$\boldsymbol{W_{SMi}}$ represents the importance weighting of particular severe DIFs
MSMi represents the mean rating of particular severe DIFs
$\sum$ ***SSMi*** represents the summation of the mean rating of the severe DIFs

A composite indicator was developed to evaluate severity of the DIF for a particular contract or project. A Severity Index (SI) was designed which can be represented by the following formula:

$$SI = W_{SM\,(DIF1)} + W_{SM\,(DIF2)} + W_{SM\,(DIF3)} + W_{SM\,(DIF4)} + W_{SM\,(DIF5)} + W_{SM\,(DIF6)} + W_{SM\,(DIF7)} + W_{SM\,(DIF8)} + W_{SM\,(DIF9)} + W_{SM\,(DIF10)} + W_{SM\,(DIF11)} + W_{SM\,(DIF12)} + W_{SM\,(DIF13)} + W_{SM\,(DIF14)} + W_{SM\,(DIF15)} \tag{4}$$

Once the SI had been defined, the PM and CM KPI score was quantified for each of the severe DIFs. The initial algorithm was derived based on the assumption that this is a linear and additive model. Nevertheless, it is only valid to derive a linear and additive model if there is no correlation between the weighted Severe DIFs. Pearson correlation matrix was calculated and analysed for the algorithm development in this study using SPSS to ascertain the linear correlation. The Pearson's correlation coefficient obtained in SPSS was referred to determine whether the linear relationship between Weightage of Severity (WOS) was statistically significant. A statistically significant relationship between two or more WOS represented a challenge and requirement to adjust the SI algorithm to consider the multiplier effect between these factors. A linear correlation or multiplier effect is subsequently singled out and adjusted in the SI.

Downtime Influence Factors to Ship Availability	Initial Rank	Adjusted SI Rank	Initial SI	Adjusted SM & SI
Corrective Maintenance.	1	1	0.085	0.142
Spares Availability.	2	2	0.082	0.082
Impact of Parallel Contracts.	3	15	0.079	0.022
Cashflow Shortages.	4	3	0.078	0.078
Knowledge Management.	5	4	0.070	0.070
Equipment and Systems – Propulsion.	6	5	0.069	0.069
Maintenance Policy and Priority.	7	6	0.067	0.067
Availability of OEM Expert Support.	8	7	0.061	0.061
Maintenance Budget Allocation.	9	8	0.060	0.060
Awareness of Importance of Maintenance / Attitude.	10	9	0.059	0.059
Availability of Facilities.	11	10	0.059	0.059
Availability of Local Vendor Support.	12	11	0.058	0.058
Complexity and Efficiency of Existing Maintenance Contract.	13	12	0.058	0.058
Scheduling Issues.	14	13	0.058	0.058
Equipment and Systems – Auxiliaries	15	14	0.056	0.056
TOTAL			1.000	1.000

SI*= 0.142 X Corrective Maintenance*
+ 0.082 X Spares Availability
+ 0.022 X Impact of Parallel Contracts
+ 0.078 X Cashflow Shortages
+ 0.070 X Knowledge Management
+ 0.069 X Equipment and Systems: Main Propulsion
+ 0.067 X Maintenance Policy
+ 0.061 X Availability of OEM Expert Support
+0.075 X Maintenance Budget Allocation
+ 0.059 X Awareness of Importance of Maintenance & Attitude
+ 0.059 X Availability of Facilities
+ 0.058 X Availability of Local Vendors
+ 0.058 X Complexity and efficiency of existing contracts
+ 0.042 X Scheduling issues
+ 0.056 X Equipment and Systems: Auxiliaries

Figure 20: Impact assessment adjusted SI.

A preliminary series of weighted Severity Measures (SM) was developed based on the mean ratings advocated by the 35 respondents. The weighting for each of the top 15 SMs was computed according to Equation 4. Only two instances of linear correlation or multiplier effect were found. These were singled out and adjusted in the SI. The resulting Impact Assessment (IA) SI formula is described as per Figure 20.

2.11 Objective 11: Improving Availability through Change in Contract Clauses – A suggested Mechanism

Based on authors' experience, during the naval ship ISS maintenance contract preparation and negotiation stage, neither the RMN nor the Subcontractor is aware of any mechanism or model to simulate possible outcomes of the ISS Contract to be signed. As a result, the ISS Contracts continue to be awarded based on legacy contract terms and clauses. There has been no improvement due to the lack of studies being carried out on improving the contract clauses as well as the contract clauses' relevancy towards the dictated Ship Availability. In the case of the RMN PV ISS Contract, the contract contains a total of 58 Clauses.

A possible approach in improving the Availability is by identifying which clauses have a direct impact on Availability, i.e. Availability Subset clauses. The proposed mechanism is to cross-tabulate the totality of the PV ISS Contract clauses against the 15 Severe DIFs identified in earlier research stages. Thereon each clause is carefully analysed and dissected in terms of the likelihood that a change in the clause would impact the said DIF. The clauses are rated as either "Not Relevant" (NR), 1 as "Relevant" and editions required to clauses and "0" for Relevant but no editions required.

An example is Clause 1 Definitions of Terms. There are certain terms that if defined explicitly with the corresponding action it can guide and prompt contract stakeholders to improve availability. i.e. Defining Beyond Economical Repair (BER) with the corresponding action that a spare part classified as BER requires an immediate notification to be sent to the GOVERNMENT. Another example is specifying that a minimum stock as per the suggested preventive maintenance plan must be met in order to avoid spare parts unavailability. The researchers have identified a total of 32 clauses out of 58 clauses for which the clause formulation could impact the availability throughout the contract period. For this, Figure 21 shows a subset of the findings.

SEVERE DIFs	
DIF S1	SWBS 200: Main Propulsion
DIF S2	SWBS 500: Auxiliaries
DIF S3	Maintenance Policy - Priority on Type of Maintenance
DIF S4	Awareness of Importance of Maintenance / Attitude – including hiding problems from becoming official.
DIF S5	Maintenance Budget Allocation
DIF S6	Corrective Maintenance
DIF S7	Scheduling Issues
DIF S8	Availability of Facilities
DIF S9	Spares Availability
DIF S10	Knowledge Management incl Training, Knowledge and Skills
DIF S11	Availability of OEM Expert Support
DIF S12	Availability of Local vendor support
DIF S13	Complexity and efficiency of existing contract
DIF S14	Cashflow Shortages
DIF S15	Impact of Parallel Contracts to Schedule, Genuinity of Spares, Professionalism of Repair Team etc

NR=	Not Relevant
YES = 1	Needs to be improved
NO=0	Relevant but no editions

CONTRACT CLAUSES		DOWNTIME INFLUENCE SEVERITY FACTORS															
		1 DIF1	2 DIF S2	3 DIF S3	4 DIF S4	5 DIF S5	6 DIF S6	7 DIF S7	8 DIF S8	9 DIF S9	10 DIF S10	11 DIF S11	12 DIF S12	13 DIF S13	14 DIF S14	15 DIF S15	Ao Subset?
CLAUSE 1	DEFINITION OF TERMS		1	1	1	1	1	1	1	1	1	1	1	1	1	1	YES
CLAUSE 2	INTERPRETATION	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NO
CLAUSE 3	REPRESENTATION AND WARRANTY	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NO
CLAUSE 4	SCOPE OF CONTRACT	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	YES
CLAUSE 5	DESCRIPTION OF THE SPARES, MAINTENANCE, ILS AND	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	NO
CLAUSE 6	TENURE OF CONTRACT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	NO
CLAUSE 7	COSTOF CONTRACT AND STAMP DUTY	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NO
CLAUSE 8	AMENDMENTS TO THE CONTRACT	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NO
CLAUSE 9	GOVERNMENT RIGHTS	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	YES
CLAUSE 10	ORDERING METHOD	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	YES
CLAUSE 11	CONTRACT VALUE	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	YES
CLAUSE 12	PRICES	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	YES
CLAUSE 13	TAXES	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NO
CLAUSE 14	PERFORMANCE BOND	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NO
CLAUSE 15	METHOD OF PAYMENT	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NO
CLAUSE 16	PACKING AND MARKING	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	YES
CLAUSE 17	PACKING AND PRESERVATION	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	YES
CLAUSE 18	BAR CODING	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	YES
CLAUSE 19	TRANSPORTATION	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	YES
CLAUSE 20	INSURANCE	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	YES
CLAUSE 21	DELIVERY PERIOD FOR SPARES	1	1	0	0	0	1	1	0	1	0	0	0	0	0	0	YES
CLAUSE 22	SUPPLY OF SPARE PARTS FOR MAINTENANCE	1	1	0	0	0	1	1	0	1	0	0	0	0	0	0	YES
CLAUSE 23	TURN AROUND TIME FOR MAINTENANCE AND ILS	0	1	1	0	0	1	1	0	0	0	1	1	0	0	1	YES
CLAUSE 24	DELIVERY PERIOD FOR TRAINING	1	1	0	1	0	1	1	1	0	1	1	1	0	0	0	YES

Figure 21: Availability oriented approach – impacted clauses.

The proposed mechanism requires a significant amount of contract stakeholder engagement and feedback to corroborate the proposed changes to the clauses. Contracts are typically signed at the beginning of a 3-year contract period and will not be amended until the next contract period. As such any proposed changes would require to be incorporated into the new contract. Due to the time constraints of the study parameter, the intention of the authors was to "pave the way" for future research to validate the proposed mechanism. An example of the Contract Clause Flow Mechanism to improve the impacted clauses is reflected in Figure 22.

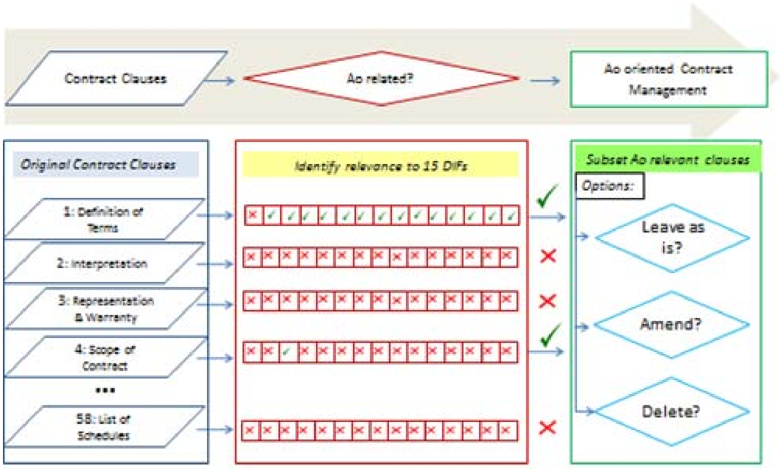


Figure 22: Contract clause flow mechanism.

2.12 Objective 12: Development of an Availability-oriented Contract Management Control and Monitoring System (ConCaMS)

The step by step approach in the ConCaMS Spiral with associated objectives as reflected in Figure 23 would provide all stakeholders with a clearer view of the steps taken from Objective 1 to Objective 13 for the purpose of achieving the target of improving ship operational availability. This includes development of conceptual models, identification of DIFs, ranking of DIFs using Risk Analysis methodology, Identification of the DIFs that impact to cost, budget, schedule and scope of the contract, the development of a mathematical algorithm resulting in the Severity Index (SI), all the way to the development of the Availability-oriented Framework, Model and System.

This would provide all stakeholders including the contract managers the tool to systematically plan, calculate, diagnose, project, and manage the contract implementation during and after the contact period with a firm control of all factors that impact the ship availability. This shall also enable the Top Management of organisations to use this tool to compare contact performance between similar contracts albeit having some differences between them. To date, there has not been any suitable tool that is generally being able to assist in conducting contract performance benchmarking especially on naval ship ISS maintenance contracts. Two contracts with different Budget, Time, Quality and Scope could still be compared by using Ship Availability as the determining criteria using the ConCaMS System.

This Availability-oriented Approach, is a breakthrough that would eliminate the previous real-life issues of contract manager's inability to use any guide or model or mechanism to measure and control risks during the implementation of the contract, which has a snowballing effect in another blind preparation of future contracts. A display of the ConCaMS output is reflected in Figure 24.

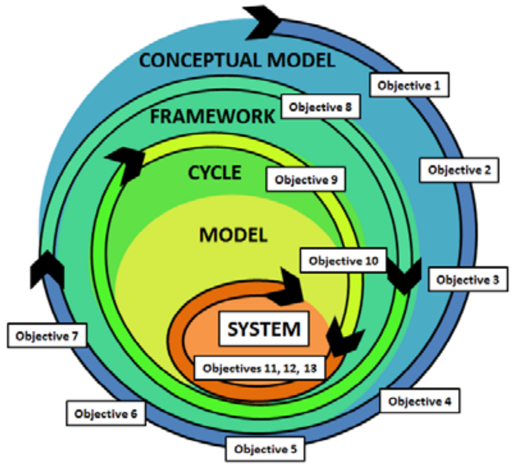


Figure 23: ConCams Development Spiral with associated objectives.

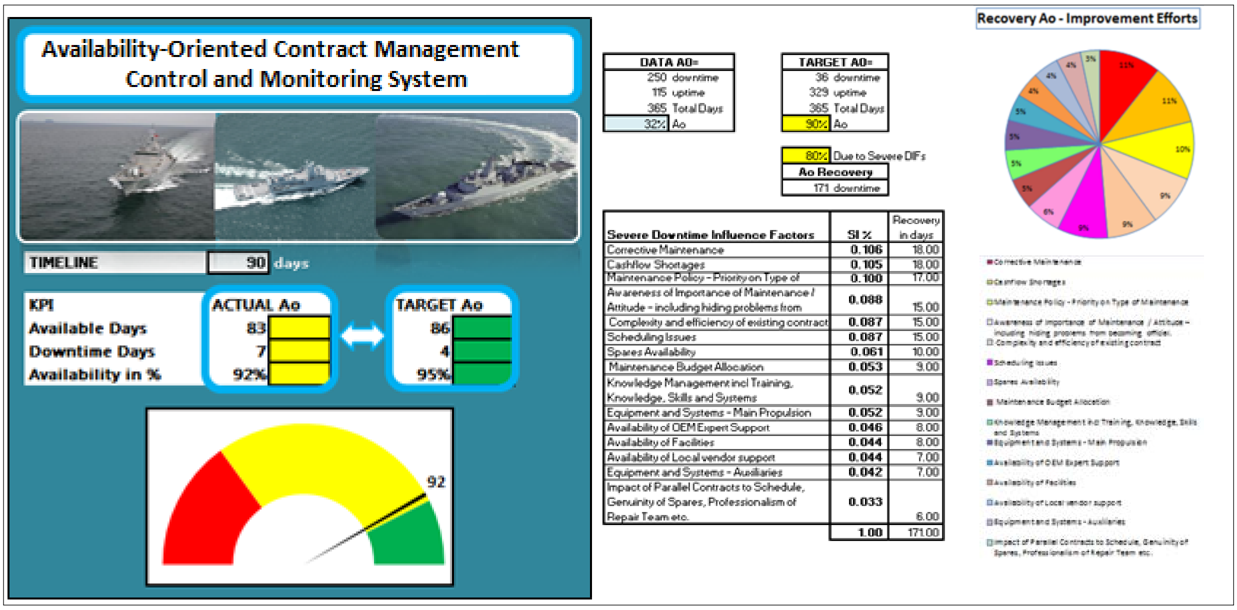


Figure 24: ConCaMS Display output.

2.13 Objective 13: Development of an Availability-oriented Contract Management Dashboard

For the benefits of future research, a template of an Availability-oriented Contract Management Dashboard has been developed by the authors. The dashboard was developed with feedback from the Experts and confirmed by Top Management of the RMN Planning as well as the RMN Strategic Management Department as logical and reasonable method in daily collection of data onboard every vessel in the future. The data collection would enable the ISS Contract Managers from the private sector and the RMN to better analyse the impact of DIFs on the availability of navy vessels, and make any necessary improvements when compared to the published results of the current study by the authors using Expert opinions.

The Dashboard is also Availability-oriented, enabling the Contract Manager to monitor the availability status of each vessel, also the combined availability status of the fleet, with simple indicators highlighting the daily Actual and compounded Actual versus Targeted Availabilities, with a calculated Recovery Availability (Recovery Ao) figure displayed for reference. The dashboard shall also be able to record possible additional DIFs that have not been discovered previously in the current research. An example of the Dashboard Input and Ouput screens are as per Figure 25.

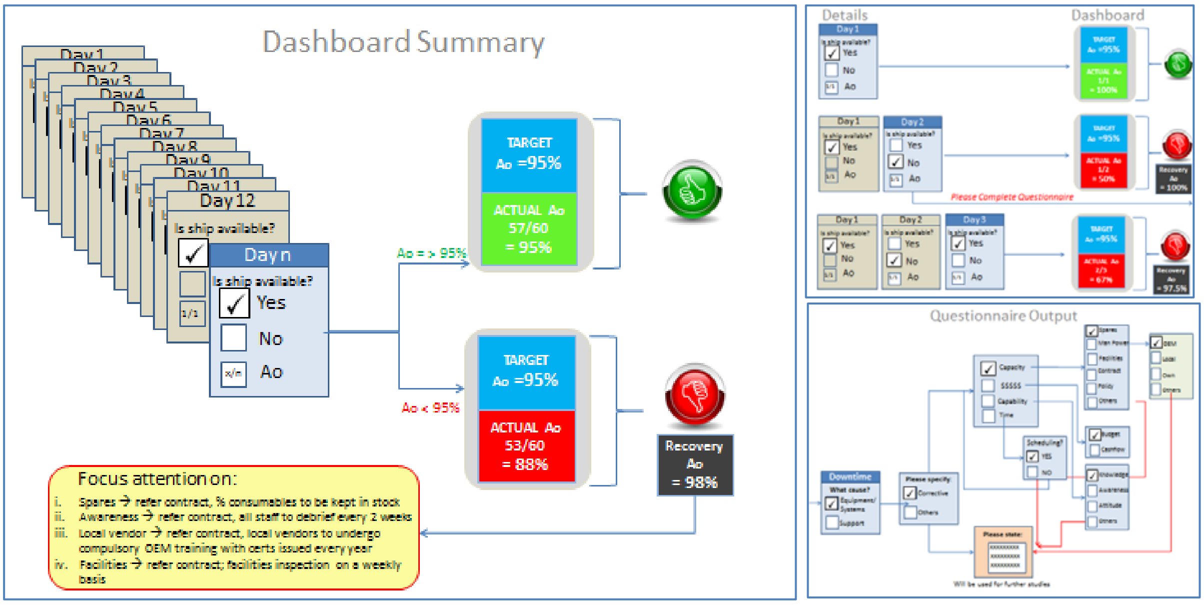


Figure 25: Dashboard input and output screen examples.

3. CONCLUSION & RECOMMENDATION FOR FUTURE STUDY

The ultimate goal of the authors in this study was to explore the possibility of producing a system or mechanism that could assist in improving Naval Ship Operational Availability, even though the authors realize that the situation was very complex in nature. Due to the limited research available previously, improvement efforts could not be placed precisely in tackling issues involving human and equipment related factors impacting ship availability. The challenging journey began when the authors realized that the "huge step" towards demystifying the complex naval issue in improving ship availability begins with "a tiny step" in identifying the factors impacting the ship availability. As elaborated above, the authors continued to broaden the horizon on available knowledge by progressively evolving through the "ConCaMS Development Spiral" achieving various levels of progress on each of the 13 Key Objectives researched in this paper. The ConCaMS Spiral with the labelled location of the various objectives would further assist policymakers and stakeholders of various organisations to develop their respective action-plans.

The authors have exhaustively researched and screened though more than 700 literatures of possible factors affecting maintenance from various engineering disciplines during this study and found that there has not been any discovery of a "one-size fits all solution" towards this complex naval ship availability issue. This research therefore provides a valuable contribution to the body of knowledge towards improving Naval Ship Availability. Nevertheless, due to the time, resources and financial constraint involved in this exploratory but highly specialized research in naval ship maintenance that spanned over 5 years, and in order for the results to remain current for the partial fulfilment of the Doctorate in Mechanical Engineering, the authors have concluded the research by paving the way for more focused future research in all of the areas covered in the 13 Objectives described in this paper.

One of the major obstacles of the research is the necessity to implement an acceptable verification and validation methodology for the "immense" number of variables concerning a complex asset such as the naval ships. This is a tremendous task when only limited data have been collected by various organisations. The same issue on verification and validation applies for the findings by researchers on recommended amendments to contract clauses, as the time-consuming Delphi Methodology would not work as the availability of the Experts could not be guaranteed for an extended amount of time. Future studies could also utilise other methods including Operational Research tools and techniques so that results could be used to supplement or confirm the findings of the current research

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